Communication Frictions, Sentiments, and Nonlinear Business Cycles*

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Abstract:

In the context of a rational expectations macroeconomic model with communication frictions, we show that the level of economic activity is a nonlinear and time-varying function of aggregate economic fundamentals and sentiment shocks. In particular, because of communication frictions, it is possible for small sentiment shocks to cause large changes in aggregate output, and, similarly, for large changes in sentiment shocks to cause small changes in aggregate output. We also find that communication frictions have nonlinear effects on the variance of aggregate output, meaning that improving the communication does not always reduce the variance of aggregate output.

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1 Introduction

Motivated by Angeletos and La'O (2013) and Benhabib *et al.* (2015), we consider a rational expectations macroeconomic model with communication frictions, and show that the level of economic activity is a nonlinear and time-varying function of aggregate economic fundamentals and a certain type of extrinsic shocks that Angeletos and La'O (2013) refer to as 'sentiments.' We show that communication frictions amplify or shrink the effect of exogenous sentiment shocks on aggregate output, meaning that it is possible for small changes in sentiment shocks to cause large changes in aggregate output and for large changes in sentiment shocks to cause small changes in aggregate output. We also show that improving communication does not always reduce the variance of aggregate output.

Theoretical background. One of the most celebrated business cycle models in the past 40 years is the information-based monetary misperceptions model of Lucas (1972), originated from Friedman (1968), and Phelps (1970). In this model, in a rational expectations setting, economic agents have incomplete information about prices in the economy, and monetary shocks (created by the monetary authority) are a principal cause of business cycles. In particular, economic fluctuations are induced because individual producers faced with a change in the price of their product do not know whether it stems from a shift in relative demands or a changed level of aggregate demand. If it was the former, the optimal response would require a change in output whereas if it was the latter the optimal response would require no such change in the level of output. More recently, Barnett (2012) provides another possible explanation of the non-neutrality of money and the sources of business fluctuations, consistent with the price misperceptions model, stressing monetary misperceptions due to low quality monetary data provided by central banks.

In recent years, most economists believe that monetary shocks are not the principal cause of business fluctuations. In fact, following the powerful Lucas (1976) critique, the modern core of macroeconomics consists of the real business cycle approach and the New Keynesian approach. The real business cycle approach (known as freshwater economics), developed by Kydland and Prescott (1982), is a stochastic formalization of the neoclassical growth model and represents the latest development of the classical approach to business cycles. It assumes rational expectations and forward-looking economic agents, relies on market-clearing conditions for households and firms, relies on shocks and mechanisms that amplify the shocks and propagate them through time, and is designed to be a quantitative mathematical formalization of the aggregate economy. According to the original real business cycle model, which has become a centerpiece of business cycle research, under the classical assumption that wages and prices are fully flexible, most aggregate fluctuations are efficient responses to random production function shocks (usually called real shocks) and government stabilization policy is inefficient. More recent real business cycle models also assume some type of nominal rigidities, so that both technology and demand shocks play a role in determining business cycles, and recognize that some form of government stabilization policy is actually useful.

The opposing New Keynesian approach (known as saltwater economics) advocates models with sticky prices (prices that do not adjust instantaneously to clear all the markets), consistent with the assumption of sticky nominal wage rates in Keynes (1936). It points to economic downturns like the Great Depression of the 1930s and the Great Recession that followed the recent global financial crisis, and argues that it is implausible for the efficient level of aggregate output to fluctuate as much as the observed level of output, thereby advocating government stabilization policy. In recent years, however, the New Keynesian approach makes systematic use of the modeling methodology of the real business cycle approach, and so the division between the two approaches has greatly decreased. In fact, the current New Keynesian model is based on the "dynamic-stochastic-general-equilibrium" framework and combines it with Keynesian features, like imperfect competition and sticky prices, to provide a theoretical framework for macroeconomic policy analysis. Both the real business cycle model and the New Keynesian model are largely immune to the Lucas (1976) critique.

In the aftermath of the global financial crisis there has also been a revival of interest in endogenous economic fluctuations, founded on (deterministic) chaos theory. The discovery that perfectly deterministic systems of low dimensions and with simple nonlinearities can have stochastic behavior has received a lot of attention in macroeconomics and has brought about a profound re-consideration of the issue of randomness. Besides its obvious intellectual appeal, chaos is interesting in macroeconomics, because of its ability to generate output that mimics the output of stochastic systems, thereby offering an endogenous explanation of economic fluctuations. If, for example, chaos can be shown to exist in macroeconomic variables, the implication would be that (nonlinearity-based) prediction is possible, at least in the short run and provided that the actual generating mechanism is known exactly. In the long run, however, chaos implies that prediction is all but impossible due to its property of sensitive dependence on initial conditions. Chaos also implies the persistence of the effects of temporary shocks and the impossibility of government stabilization policy in the absence of changes in the values of the structural parameters that govern the behavior of the economic system. For a review of this literature, see (for example) Benhabib and Nishimura (1985), Grandmont (1985), Baumol and Benhabib (1989), Bullard and Butler (1993), and Barnett *et al.* (2015). For more recent work that also deals with deterministic endogenous business cycles (including chaos) caused by financial frictions, see Kunieda and Shibata (2011, 2014).

There are many criticisms of the modern core of macroeconomics — see, for example, Farmer and Geanakoplos (2008) and Kirman (2010). As Serletis (2016, p. 462) puts it, "one is the assumption that economic agents act in isolation and the only interaction between them is through the price system. This is clearly unrealistic as it fails to capture the interdependence, interaction, and economic networks of the real world. Another is the aggregation assumption according to which the behavior of the aggregate (or macro) economy corresponds to that of the representative economic agent, consistent with the reductionist belief that 'the whole is the sum of its parts.'" Another criticism of the current mainstream approach to macroeconomics concerns the definition of rational expectations. As Hendry and Mizon (2010, p. 13) argue, "dynamic stochastic general equilibrium models are intrinsically non-structural, and must fail the Lucas critique since their derivations depend on constant expectations distributions." In this regard, Blanchard (2014, p. 28) also wrote that these techniques made sense "only under a vision in which economic fluctuations were regular enough so that, by looking at the past, people and firms (and the econometricians who apply statistics to economics) could understand their nature and form expectations of the future, and simple enough so that small shocks had small effects and a shock twice as big as another had twice the effect on economic activity."

Finally, another serious criticism of the modern core of macroeconomics pertains to its formalization of the origins of business cycles. Typically, dynamic stochastic general equilibrium models attribute short-run fluctuations to shocks to fundamentals like preferences, technologies, or government policy. This, however, is highly unsatisfactory. As Angeletos and La'O (2013) recently put it in their Conclusion, "if taken literally, these shocks seem empirically implausible. Instead, short-run phenomena appear to have a largely self-fulfilling nature—one that leads many practitioners to attribute these phenomena to more exotic forces such as 'animal spirits,' 'sentiments,' or 'market psychology,' and one that standard macroeconomic models have failed to capture." These phenomena have attracted a great deal of attention in the aftermath of the global financial crisis. In fact, the global financial crisis and the Great Recession and European debt crisis that followed have changed our view about the importance of such phenomena and frictions in the macroeconomy. We have moved from a regime where frictions do not matter (prior to the crisis) to a world where frictions matter a lot.

Contribution. In this paper, in the spirit of Angeletos and La'O (2013) and Benhabib *et al.* (2015), we investigate how communication frictions can lead to economic fluctuations and to a nonlinear relationship between the level of economic activity and aggregate economic fundamentals and sentiment shocks. In doing so, we extend the Angeletos and La'O (2013) rational expectations macroeconomic model by introducing an idiosyncratic preference indicator regarding work aversion and a communication friction. We incorporate two types of economic fundamentals and an exogenous sentiment shock and investigate their effects on economic fluctuations. We show that the level of economic activity is a nonlinear and time-varying function of aggregate economic fundamentals and the sentiment shock. We also show that communication frictions have nonlinear effects on the variance of aggregate output, meaning that improving the communication does not always reduce the variance of aggregate output.

Layout. The paper is organized as follows. In the next section we lay out the rational expectations macroeconomic model and characterize the equilibrium. In sections 3 and 4 we derive equilibrium outcomes under perfect and imperfect communication and show our main result that the level of economic activity is a nonlinear and time-varying function of aggregate economic fundamentals and sentiment shocks. Section 5 also shows how communication frictions have nonlinear effects on the variance of aggregate output. Section 6 concludes.

2 The Model

We reformulate the Angeletos and La'O (2013) model by introducing quantified communication frictions. The model has a continuum of islands, indexed by $i \in [0, 1]$, which are heterogeneous in terms of total factor productivity (TFP). Time is discrete, and indexed by $t \in \mathbb{N}$. In each island, there are a representative household and a representative single good producer, which is the firm. We assume that there are two stages in each period t, with employment and production taking place in stage 1 and trading and consumption occurring in stage 2. Moreover, trading takes place through random pairwise matching. Each island has to decide how much to produce in stage 1, according to an information set about its trading partner. In this paper, we assume that the information set is about total factor productivity, an idiosyncratic work aversion parameter, and communication frictions.

2.1 Households and Preferences

We assume that household i, who lives in island i, maximizes utility

$$\max_{\{c_{it},c^*_{it},n_{it}\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} \beta^t \left[\left(\frac{c_{it}}{1-\phi} \right)^{1-\phi} \left(\frac{c^*_{it}}{\phi} \right)^{\phi} - \delta_i \frac{n_{it}^{\varphi}}{\varphi} \right] \tag{1}$$

where $\phi \in (0,1)$, β is the discount factor, c_{it} is the locally produced good, and c^*_{it} is the imported good from the trading partner. n_{it} is the labor supply, which induces disutility and $\varphi > 1$. We refer to $\delta_i \in \mathbb{R}^+$ as the work aversion parameter in island i, and assume that δ_i is constant over time but varies across islands with a cross-sectional distribution. A high δ_i value implies a high work aversion in island i, and consequently a low level of work and production (output). The probability density function of the work aversion parameter is given by $\mathcal{P}_\delta$.

The household's budget constraint is

$$p_{it}c_{it} + p^*_{it}c^*_{it} \leq w_{it}n_{it} + \pi_{it} \tag{2}$$

where p_{it} and p^*_{it} denote the prices of the local and imported goods, respectively, w_{it} is the wage rate, and π_{it} is the local firm's profit.

2.2 Firms and Technologies

We also assume that the firm in island i has the following production function

$$y_{it} = A_i n_{it}^{\theta} \tag{3}$$

where $\theta \in (0,1)$. A_i denotes total factor productivity. The total factor productivity of each island has a cross-sectional distribution, and the probability density function of total factor productivity is given by $\mathcal{P}_A$.

2.3 Communication Frictions

Finally, we make some assumptions about communication and information. In stage 1, islands do not know the matching results so that no island knows who its trading partner will be. However, the decision of each island's production has to be made in stage 1, depending on the received information about the total factor productivity of its trading partner, communication frictions, and its trading partner's work aversion. Let's assume that island i's trading partner is island j, where j is not an identity of any island. We assume that island i receives the information set

$$\mathcal{I}_{it} = (A_i, A_j, \delta_i, \mathcal{Z}_{it}, \zeta_t) \tag{4}$$

where ζ_t describes the severity of the communication friction and $\mathcal{Z}_{it}$ will be specified below. This information set shows that island i knows its own TFP, A_i, its trading partner's TFP, A_j, and its own work aversion parameter, δ_i. However, island i does not know island j's work aversion parameter, δ_j, because of the communication friction, ζ_t, and the sentiment shock, ξ_t.

We assume that each island knows how severe the communications friction is, and, in fact, that the communication friction is observable in period t. One might think that this is an odd assumption, however, it is reasonable with the model setup. Let's consider the outcome of period $t-1$ first. Since each pair of islands meet and share information in the second stage of period $t-1$, the communication friction ζ_{t-1} is revealed. ζ_{t-1} characterizes how the exchanged information and communication are biased in period $t-1$. Suppose that there is a 'communication system,' which is constructed by, for example, (including but not limited to) social networks, the media, market research, and market surveys. This system determines the quality of information and communication. If there is nothing done for the communication system after period $t-1$, the friction in this system should be constant in the succeeding period. However, improving communication is always a desirable objective so that there should be some efforts in the economy to achieve a higher ζ_t in period t. In addition to those efforts, we also assume that in this communication system there are reasonable exogenous variations which intensify the communication friction. For instance, the market surveys may be of a bad quality, say because of a low participation rate, irrational participants, or badly designed questions. Another example is that there might be corruption in the social networks or the media. Therefore, ζ_t may or may not be bigger than ζ_{t-1}. Since the economy could have a good assessment about the communication system and its friction, by knowing ζ_{t-1}, the observable efforts, and the exogenous variations, we assume that ζ_t is observable.

2.4 Sentiment Shocks

In equation (4), $\mathcal{Z}_{it}$ is the information that island i has about its trading partner's (which is island j) work aversion parameter, δ_j. We assume that $\mathcal{Z}_{it}$ is an affine combination of the true work aversion parameter, δ_j, and the sentiment shock, ξ_t, as follows

$$\mathcal{Z}_{it} = \zeta_t \log \delta_j + (1 - \zeta_t)\xi_t \tag{5}$$

where $\zeta_t \in (0, 1)$. The sentiment shock, ξ_t, is an aggregate shock and characterizes an optimistic or pessimistic attitude towards work. The sentiment shock does not change each island's preferences towards work, but only influences each island's beliefs about its trading partner's work aversion. For example, island i forms its beliefs about its trading partner's work aversion depending on $\mathcal{Z}_{it}$, and then makes a production decision. Thus, the sentiment shock distorts the true information in the economy. The level of distortion is determined by the communication friction, ζ_t. In particular, the information received by island i regarding work aversion in island j is of high quality when ζ_t is close to 1 (less communication friction). A smaller ζ_t (more communication friction) means less accurate information about island j's work aversion. We also assume that $\log \delta_j$ and ξ_t are normally distributed, $\log \delta_i \sim \mathcal{N}(\mu_\delta, \sigma_\delta^2)$ and $\xi_t \sim \mathcal{N}(0, \sigma_\xi^2)$, and that ζ_t varies over time with a non-specified distribution. Moreover, all of these shocks and variables are not correlated so that the covariance between any two of them is always zero.

It is to be noted that our results do not rely on our setup regarding the sentiment shock. Alternatively, we could assume an idiosyncratic communication noise with a time varying distribution, and our results and conclusions will still hold in that case.

2.5 Equilibrium Characterization

Household i maximizes (1) subject to (2) with respect to c_{it}, c_{it}^*, and n_{it}. The Lagrangian for this problem is

$$\mathcal{L} = E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \left[\left(\frac{c_{it}}{1-\phi} \right)^{1-\phi} \left(\frac{c_{it}^*}{\phi} \right)^{\phi} - \delta_i \frac{n_{it}^{\varphi}}{\varphi} \right] + \lambda_{it} \left[w_{it} n_{it} + \pi_{it} - p_{it} c_{it} - p_{it}^* c_{it}^* \right] \right\}$$

where λ_{it} is the Lagrange multiplier. The first-order conditions with respect to c_{it}, c_{it}^*, and n_{it} are (respectively)

$$\left(\frac{c_{it}}{1-\phi} \right)^{-\phi} \left(\frac{c_{it}^*}{\phi} \right)^{\phi} - \lambda_{it} p_{it} = 0 \tag{6}$$

$$\left(\frac{c_{it}}{1-\phi} \right)^{1-\phi} \left(\frac{c_{it}^*}{\phi} \right)^{\phi-1} - \lambda_{it} p_{it}^* = 0 \tag{7}$$

$$-\delta_i n_{it}^{\varphi-1} + \lambda_{it} w_{it} = 0. \tag{8}$$

We normalize the local good's price so that $\lambda_{it} = 1$. Under this normalization, equations (6) and (7) imply

$$\frac{\phi}{1-\phi} \frac{c_{it}}{c_{it}^*} = \frac{p_{it}^*}{p_{it}}. \tag{9}$$

According to the trading pattern, the total value of c_{it}^* must be equivalent to the value of the ith island's exported goods. That is,

$$p_{it}(y_{it} - c_{it}) = p_{it}^* c_{it}^*. \tag{10}$$

Equations (9) and (10) yield

$$c_{it} = (1-\phi) y_{it}. \tag{11}$$

We also have

$$c_{it}^* = \phi y_{jt}. \tag{12}$$

Equation (6), (11), and (12) yield the equilibrium condition

$$p_{it} = y_{it}^{-\phi} y_{jt}^{\phi} \tag{13}$$

according to which the trading price of good i is determined by the relative outputs of goods i and j. A larger produced amount of good i decreases its price.

Firm i has to make a production decision in stage 1 based on the information set $\mathcal{I}_{it}$. Following Angeletos and La'O (2013), we assume that firm i formulates a rational expectation about the price of its good, conditional on the information set $\mathcal{I}_{it}$, and chooses the demand for labor. Thus, the firm's maximization problem is

$$\max_{n_{it}} \pi_{it} = E_{it}(p_{it}) A_i n_{it}^{\theta} - w_{it} n_{it}$$

where $E_{it}(p_{it}) = E(p_{it} | \mathcal{I}_{it})$. The first-order condition with respect to n_{it} is

$$\theta E_{it}(p_{it}) A_i n_{it}^{\theta-1} = w_{it}$$

or, equivalently,

$$\theta E_{it}(p_{it})\frac{y_{it}}{n_{it}} = w_{it}. \tag{14}$$

Equations (8) and (14) imply

$$n_{it} = \left[\frac{1}{\delta_i}\theta E_{it}(p_{it})y_{it}\right]^{\frac{1}{\varphi}}. \tag{15}$$

Substituting equation (15) into the production function (3) yields

$$y_{it} = \left[A_i\delta_i^{-\tau}\theta^{\tau}\right]^{1/(1-\tau)}[E_{it}(p_{it})]^{\tau/(1-\tau)} \tag{16}$$

where $\tau = \theta/\varphi$ and $\tau \in (0,1)$. The equilibrium between islands i and j is pinned down by equations (13) and (16). We could write these two equilibrium conditions as

$$\begin{aligned} p_{it} &= y_{it}^{-\phi}y_{jt}^{\phi} \\ y_{it} &= \left(A_i\delta_i^{-\tau}\theta^{\tau}\right)^{1/(1-\tau)}[E_{it}(p_{it})]^{\tau/(1-\tau)}. \end{aligned}$$

Furthermore, we could rewrite these equilibrium conditions as

$$p_t(\mathcal{I}_{it},\mathcal{I}_{jt}) = y_t(\mathcal{I}_{it})^{-\phi}y_t(\mathcal{I}_{jt})^{\phi} \tag{17}$$

$$y_t(\mathcal{I}_{it}) = \left[A(\mathcal{I}_{it})\delta(\mathcal{I}_{it})^{-\tau}\theta^{\tau}\right]^{1/(1-\tau)}\left[E_t(p_t(\mathcal{I}_{it},\mathcal{I}_{jt})|\mathcal{I}_{it})\right]^{\tau/(1-\tau)}. \tag{18}$$

It means that the equilibrium between two islands is pinned down by the information sets $\mathcal{I}_{it}$ and $\mathcal{I}_{jt}$. We can generalize these two conditions for each pair of islands. Let $\mathcal{I}$ denote the information set received by a local island and $\mathcal{I}'$ the information set obtained by its trading partner, for any pair of islands. The island which receives $\mathcal{I}$ is called island of type $\mathcal{I}$, and its trading partner is called island of type $\mathcal{I}'$. The two conditions (17) and (18) can be consequently written as

$$p_t(\mathcal{I},\mathcal{I}') = y_t(\mathcal{I})^{-\phi}y_t(\mathcal{I}')^{\phi} \tag{19}$$

$$y_t(\mathcal{I}) = \left[A(\mathcal{I})\delta(\mathcal{I})^{-\tau}\theta^{\tau}\right]^{1/(1-\tau)}\left[\int_{\mathcal{S}} p_t(\mathcal{I},\mathcal{I}')\mathcal{P}_t(\mathcal{I}'|\mathcal{I})d\mathcal{I}'\right]^{\tau/(1-\tau)} \tag{20}$$

where $\delta(\mathcal{I})$ is the work aversion of an island of type $\mathcal{I}$ and $\mathcal{P}_t(\mathcal{I}'|\mathcal{I})$ is the conditional probability that type $\mathcal{I}$ island has a trading partner of type $\mathcal{I}'$. $\mathcal{S}$ is the superset of all information set. Equations (19) and (20) imply

$$\begin{aligned} \log y_t(\mathcal{I}) = (1-\vartheta)&\left[\log\theta^{\tau/(1-\tau)} + \log A(\mathcal{I})^{1/(1-\tau)}\right] \\ &+ \vartheta\frac{\log\int_{\mathcal{S}} y_t(\mathcal{I}')^{\phi}\mathcal{P}_t(\mathcal{I}'|\mathcal{I})d\mathcal{I}'}{\phi} - \vartheta\frac{\log\delta_t(\mathcal{I})}{\phi} \end{aligned} \tag{21}$$

where $\vartheta = \phi\tau/(1-\tau+\phi\tau) \in (0,1)$. Since

$$\frac{\log\int_{\mathcal{S}} y_t(\mathcal{I}')^{\phi}\mathcal{P}_t(\mathcal{I}'|\mathcal{I})d\mathcal{I}'}{\phi} = \frac{\log\int_{\mathcal{S}} \exp\left[\phi\log y_t(\mathcal{I}')\right]\mathcal{P}_t(\mathcal{I}'|\mathcal{I})d\mathcal{I}'}{\phi}$$

let's define $\psi(x) = \exp(\phi x)$ so that

$$\frac{1}{\phi} \log \int_{\mathcal{S}} y_t(\mathcal{I}')^{\phi} \mathcal{P}_t(\mathcal{I}'|\mathcal{I}) d\mathcal{I}' = \psi^{-1} \left[E_t \psi(\log y_t(\mathcal{I}')|\mathcal{I}) \right].$$

Therefore, the equilibrium condition (21) becomes

$$\begin{aligned} \log y_t(\mathcal{I}) = (1-\vartheta) \left(\log \theta^{\tau/(1-\tau)} + \log A(\mathcal{I})^{1/(1-\tau)} \right) \\ + \vartheta \psi^{-1} \left[E_t \psi(\log y_t(\mathcal{I}')|\mathcal{I}) \right] - \vartheta \frac{\log \delta_t(\mathcal{I})}{\phi}. \end{aligned} \tag{22}$$

It suggests that an island of type $\mathcal{I}$ will have a higher output if it has a higher TFP. The output is also an increasing function of the expectation about its trading partner's output, since ψ^{-1} is an increasing function. We show that work aversion $\delta(\mathcal{I})$ has a negative effect on output. The intuition is straightforward, because a lower $\delta(\mathcal{I})$ reduces the disutility from providing labor. Therefore, the household provides more labor with a lower wage rate.

3 Perfect Communication

Perfect communication means that every island knows its trading partner's work aversion. In the example of islands i and j, it requires that island i and island j both know $\mathcal{I}_{it}$ and $\mathcal{I}_{jt}$. Under this assumption, we can drop the expectation operator in equation (22), because each island knows its output and that of its trading partner. Hence

$$\log y_{it} = (1-\vartheta) \left(\log \theta^{\tau/(1-\tau)} + \log A_i{}^{1/(1-\tau)} \right) + \vartheta \log y_{jt} - \vartheta \frac{\log \delta_i}{\phi}. \tag{23}$$

Similarly, for island j we have

$$\log y_{jt} = (1-\vartheta) \left(\log \theta^{\tau/(1-\tau)} + \log A_j{}^{1/(1-\tau)} \right) + \vartheta \log y_{it} - \vartheta \frac{\log \delta_j}{\phi}. \tag{24}$$

Aggregating equations (23) and (24) yields

$$\begin{aligned} \log y_{it} + \log y_{jt} = \log \theta^{\tau/(1-\tau)} + \log A_i{}^{1/(1-\tau)} + \log \theta^{\tau/(1-\tau)} \\ + \log A_j^{1/(1-\tau)} - \frac{\vartheta}{(1-\vartheta)\phi} \left(\log \delta_i + \log \delta_j \right). \end{aligned} \tag{25}$$

Following Angeletos and La'O (2013), the aggregate output Y_t of this economy can be measured by the logarithmic average of local outputs in the cross-section of islands as follows

$$\log Y_t \equiv \int_0^1 \log y_{it} di.$$

By aggregating equation (25) across each pair of islands, we have

$$\begin{aligned} \log Y_t &= \frac{\tau}{1-\tau} \log \theta + \frac{1}{1-\tau} \int_0^1 \log A_i di - \frac{\vartheta}{(1-\vartheta)\phi} \int_0^1 \log \delta_i di \\ &= \frac{\tau}{1-\tau} \log \theta + \frac{1}{1-\tau} \int_0^1 \log A_i di - \frac{\vartheta}{(1-\vartheta)\phi} \mu_\delta. \end{aligned} \tag{26}$$

Since each island's TFP and work aversion do not change, the aggregate TFP $\int_0^1 \log A_i di$ and the aggregate work aversion parameter μ_δ are constant over time. Therefore, the level of aggregate output, $\log Y_t$, is unique and constant over time when there is perfect communication. In fact, according to equation (26), the level of aggregate output is pinned down by the aggregate TFP and the aggregate work aversion. In particular, aggregate output is an increasing function of the aggregate TFP and a decreasing function of work aversion. Moreover, aggregate output responds linearly to both the aggregate TFP [with an impact of $1/(1-\tau)$] and the aggregate work aversion parameter [with an impact of $-\vartheta/(1-\vartheta)\phi$].

4 Imperfect Communication

We now assume that each island receives the biased information about its trading partner's work aversion. Therefore, each pair of islands has heterogeneous beliefs about work aversion. Island j knows its work aversion parameter δ_j, but island i believes that island j's work aversion parameter is a different one. We will show that imperfect communication leads to output fluctuations without any changes in technology or preferences, consistent with Angeletos and La'O (2013). We will also show that the communication friction leads to nonlinear output responses.

Equation (22) implies that island i with information set $\mathcal{I}_{it}$ has the following output function

$$\log y_{it} = (1-\vartheta)\left(\log \theta^{\tau/(1-\tau)} + \log A_i^{1/(1-\tau)}\right) + \vartheta\psi^{-1}\left(E_{it}\psi(\log y_{jt})\right) - \vartheta\frac{\log \delta_i}{\phi}. \tag{27}$$

We conjecture that under imperfect communication, given the information sets $\mathcal{I}_{it}$ and $\mathcal{I}_{jt}$ in period t, the equilibrium output of island i is given by

$$\log y_{it} = \nu_0 + \nu_1 a_i + \nu_2 \log \delta_i + \nu_3 \mathcal{Z}_{it} + \nu_4 a_j \tag{28}$$

where $a_i = \log A_i$, $a_j = \log A_j$, and ν_0, ν_1, ν_2, ν_3, and ν_4 are all coefficients. Similarly, the equilibrium output of island j is given by

$$\log y_{jt} = \nu_0 + \nu_1 a_j + \nu_2 \log \delta_j + \nu_3 \mathcal{Z}_{jt} + \nu_4 a_i. \tag{29}$$

Because each of $\log \delta_i$, $\log \delta_j$, $\mathcal{Z}_{it}$, and $\mathcal{Z}_{jt}$ is normally distributed, $\log y_{it}$ and $\log y_{jt}$ are also normally distributed. Since $\log y_{jt}$ is normally distributed, we have

$$\psi^{-1}\left(E_{it}\psi(\log y_{jt})\right) = \frac{1}{2}\phi{\sigma_{y_{jt}}}^2 + E_{it}(\log y_{jt}) \tag{30}$$

where $\sigma_{y_{jt}}$ is the standard deviation of $\log y_{jt}$ conditional on $\mathcal{I}_{it}$. Then equations (27) and (30) imply

$$\log y_{it} = c_1 + (1-\vartheta)\log A_i^{1/(1-\tau)} + \vartheta E_{it}(\log y_{jt}) - \vartheta\frac{\log \delta_i}{\phi} \tag{31}$$

where $c_1 = (1-\vartheta)\log \theta^{\tau/(1-\tau)} + \vartheta\phi\sigma_{y_{jt}}^2/2$.

The conjectured solution for $\log y_{jt}$, equation (29), implies

$$E_{it}\log y_{jt} = \nu_0 + \nu_1 a_j + \nu_2 E_{it}(\log \delta_j) + \nu_3\zeta_t \log \delta_i + \nu_3(1-\zeta_t)E_{it}(\xi_t) + \nu_4 a_i. \tag{32}$$

Note that $E_{it}(\zeta_t) = \zeta_t$ and $\text{Var}_{it}(\zeta_t) = 0$. Given $\mathcal{I}_{it}$, we have

$$E_{it}(\log \delta_j) = \mu_\delta + \frac{\zeta_t}{\zeta_t^2 + (1-\zeta_t)^2 \kappa_1^2}(\mathcal{Z}_{it} - \zeta_t \mu_\delta) \tag{33}$$

$$E_{it}(\xi_t) = \frac{(1-\zeta_t){\kappa_1}^2}{\zeta_t^2 + (1-\zeta_t)^2 \kappa_1^2}(\mathcal{Z}_{it} - \zeta_t \mu_\delta) \tag{34}$$

where $\kappa_1 = \sigma_\xi / \sigma_\delta$. Equations (31), (32), (33) and (34) imply

$$\log y_{it} = c_1 + \vartheta \nu_0 + \frac{1-\vartheta}{1-\tau} a_i + \vartheta \nu_1 a_j + c_2(\nu_2 - \zeta_t \nu_3)\mu_\delta + \frac{\vartheta \nu_2 \zeta_t}{\zeta_t^2 + (1-\zeta_t)^2 \kappa_1^2}\mathcal{Z}_{it}$$
$$+ \vartheta \nu_3 \zeta_t \log \delta_i + \frac{\vartheta \nu_3 (1-\zeta_t)^2 \kappa_1^2}{\zeta_t^2 + (1-\zeta_t)^2 \kappa_1^2}\mathcal{Z}_{it} + \vartheta \nu_4 a_i - \frac{\vartheta}{\phi} \log \delta_i, \tag{35}$$

where $c_2 = \frac{\vartheta(1-\zeta_t)^2\kappa_1^2}{\zeta_t^2 + (1-\zeta_t)^2\kappa_1^2}$.

The symmetry between equations (28) and (35) implies the following restrictions

$$\nu_0 = c_1 + \vartheta \nu_0 + c_2(\nu_2 - \zeta_t \nu_3)\mu_\delta$$
$$\nu_1 = \frac{1-\vartheta}{1-\tau} + \vartheta \nu_4$$
$$\nu_2 = \vartheta \nu_3 \zeta_t - \vartheta/\phi$$
$$\nu_3 = \frac{\vartheta \nu_2 \zeta_t}{\zeta_t^2 + (1-\zeta_t)^2 \kappa_1^2} + \frac{\vartheta \nu_3 (1-\zeta_t)^2 \kappa_1^2}{\zeta_t^2 + (1-\zeta_t)^2 \kappa_1^2}$$
$$\nu_4 = \vartheta \nu_1$$

which, when solved for ν_0, ν_1, ν_2, ν_3, and ν_4, yield

$$\nu_0 = \frac{c_1}{1-\vartheta} + \frac{c_2(\nu_2 - \zeta_t \nu_3)}{1-\vartheta}\mu_\delta$$
$$\nu_1 = \frac{1}{(1-\tau)(1+\vartheta)}$$
$$\nu_2 = \frac{\vartheta}{\phi}\frac{\zeta_t^2 + \varrho}{(\vartheta^2 - 1)\zeta_t^2 - \varrho}$$
$$\nu_3 = \frac{\vartheta^2}{\phi}\frac{\zeta_t}{(\vartheta^2 - 1)\zeta_t^2 - \varrho}$$
$$\nu_4 = \frac{\vartheta}{(1-\tau)(1+\vartheta)}$$

where $\varrho = (1-\vartheta)(1-\zeta_t)^2\kappa_1^2$. Since $\vartheta \in (0,1)$, $\tau \in (0,1)$, and $\phi \in (0,1)$, we conclude that $\nu_1 > 0$, $\nu_2 < 0$, $\nu_3 < 0$, and $\nu_4 > 0$. Thus the equilibrium output of island i is given by

$$\log y_{it} = \frac{c_1}{1-\vartheta} + \frac{c_2(\nu_2 - \zeta_t \nu_3)}{1-\vartheta}\mu_\delta + \frac{1}{(1-\tau)(1+\vartheta)}a_i + \frac{\vartheta}{\phi}\frac{\zeta_t^2 + \varrho}{(\vartheta^2 - 1)\zeta_t^2 - \varrho}\log \delta_i$$
$$+ \frac{\vartheta^2}{\phi}\frac{\zeta_t}{(\vartheta^2 - 1)\zeta_t^2 - \varrho}\mathcal{Z}_{it} + \frac{\vartheta}{(1-\tau)(1+\vartheta)}a_j. \tag{36}$$

According to the equilibrium solution (36), the output of island i is increasing in its TFP, $a_i = \log A_i$, as well as in the TFP of its trading partner (island j), $a_j = \log A_j$. The negative ν_2 coefficient on $\log \delta_j$ in (36) is consistent with the benchmark result and suggests that a lower work aversion (a lower disutility from working) will increase output. Finally, the negative ν_3 coefficient on $\mathcal{Z}_{it}$ shows the important role of the communication friction when the communication among the islands is not perfect. It shows that island i will increase its output when it learns that its trading partner has a lower work aversion. The lower work aversion of its trading partner is a signal indicating that its trading partner is likely to have a higher output.

The most striking finding is that an individual island's output decision takes account of the aggregate work aversion parameter, since

$$\mu_\delta = \int_0^1 \log \delta_i di,$$

according to the law of large numbers. The intuition is that every island has to consider the role of aggregate work aversion parameter when it is not able to observe its trading partner's work aversion parameter. The aggregate work aversion parameter is used as a reference in determining the optimal output decision. Moreover, since it can be verified that $c_2(\nu_2 - \zeta_t \nu_3)/(1-\vartheta) < 0$, we find that each island will produce less if the aggregate work aversion parameter is high.

Aggregating the output of each island with revealed ν_0, ν_1, ν_2, ν_3 and ν_4, the aggregate output is

$$\begin{aligned}
\log Y_t &= \frac{c_1}{1-\vartheta} + \frac{1}{1-\tau}\int_0^1 \log A_i di + (\nu_2 + \nu_3\zeta_t)\int_0^1 \log \delta_i di + \frac{c_2(\nu_2 - \zeta_t\nu_3)}{1-\vartheta}\mu_\delta + \nu_3(1-\zeta_t)\xi_t \\
&= \frac{c_1}{1-\vartheta} + \frac{1}{1-\tau}\int_0^1 \log A_i di + \left[\frac{c_2(\nu_2 - \zeta_t\nu_3)}{1-\vartheta} + (\nu_2 + \nu_3\zeta_t)\right]\int_0^1 \log \delta_i di + \nu_3(1-\zeta_t)\xi_t \\
&= \frac{c_1}{1-\vartheta} + \frac{1}{1-\tau}\int_0^1 \log A_i di - \frac{\vartheta}{(1-\vartheta)\phi}\int_0^1 \log \delta_i di + \nu_3(1-\zeta_t)\xi_t \\
&= \frac{c_1}{1-\vartheta} + \frac{1}{1-\tau}\int_0^1 \log A_i di - \frac{\vartheta}{(1-\vartheta)\phi}\mu_\delta + \nu_3(1-\zeta_t)\xi_t. \qquad (37)
\end{aligned}$$

Equation (37) shows that aggregate output, $\log Y_t$, exhibits fluctuations over time. In particular, aggregate output is a time-varying function of the aggregate TFP, $\int_0^1 \log A_i di$, the aggregate work aversion parameter, μ_δ, and the sentiment shock, ξ_t. It is to be noted that there is no communication friction regarding the aggregate TFP, because each island's TFP is always known to each of the other islands. That is, the aggregate TFP is an economic fundamental and plays a consistent role in the determination of aggregate output, with or without the communication friction; a higher (lower) aggregate TFP implies more (less) output.

As can be seen in equation (37), the aggregate work aversion parameter has the same effect on the aggregate output compared to that in the perfect communication equilibrium. In particular, less aggregate work aversion implies less disutility from working, and therefore a higher level of aggregate output. The consistent role of the aggregate work aversion parameter in the perfect communication and the imperfect communication equilibrium suggests that the aggregate output of the economy is always pinned down by the economic fundamental irrespective of whether there is communication friction about this fundamental or not.

The sentiment shock, ξ_t, is a random variable, and introduces randomness to the aggregate output, consistent with Angeletos and La'O (2013). According to equation (37), the aggregate output is a decreasing function of the sentiment shock, since $\nu_3(1-\zeta_t) < 0$. In particular, when economic agents are optimistic, work aversion is low, and the aggregate output is high. This is a kind of self-fulling equilibrium. It means that the attitude (sentiment shock) towards work aversion causes this attitude to be real, and then the aggregate output becomes the corresponding level.

Moreover, the sentiment shock has a nonlinear effect on aggregate output. A small sentiment shock may lead to large fluctuations in aggregate output if the absolute value of $\nu_3(1-\zeta_t)$ is large. Similarly, a large sentiment shock may lead to small fluctuations in aggregate output if the absolute value of $\nu_3(1-\zeta_t)$ is small. That is, the severity of the communication friction determines how aggregate output responds to the exogenous sentiment shock.

5 Nonlinear Business Cycles

5.1 The Effects of Volatility

We can express the relationship between aggregate output under perfect and imperfect communication in terms of the following equation

$$\begin{aligned}\log Y_t^{\text{Imperfect communication}} &= \log Y_t^{\text{Perfect communication}} \\ &\quad + \nu_3(1-\zeta_t)\xi_t + \frac{1}{2}\frac{\vartheta\phi}{1-\vartheta}\int_{j=0}^{1}\sigma_{y_{jt}}^2 dj \end{aligned} \tag{38}$$

according to which communication frictions allow sentiments to be an important part of aggregate output determination, without, however, affecting the way aggregate output depends on the economic fundamentals. Moreover, the conditional variance $\sigma_{y_{jt}}^2$ is given by

$$\sigma_{y_{jt}}^2 = \frac{(\nu_2 - \nu_3\zeta_t)^2(1-\zeta_t)^2\sigma_\delta^2\sigma_\xi^2}{\zeta_t^2\sigma_\delta^2 + (1-\zeta_t)^2\sigma_\xi^2} = \sigma_{yt}^2.$$

Thus, equation (38) can be written as

$$\begin{aligned}\log Y_t^{\text{Imperfect communication}} &= \log Y_t^{\text{Perfect communication}} \\ &\quad + \nu_3(1-\zeta_t)\xi_t + \frac{1}{2}\frac{\vartheta\phi}{1-\vartheta}\sigma_{yt}^2\end{aligned}$$

according to which communication frictions not only allow sentiments to be an important part of the determination of aggregate output, but also allow the exogenous variances, σ_δ^2 and σ_ξ^2, to influence the economy without affecting how the economic fundamentals determine aggregate output. Even though the variances, σ_δ^2 and σ_ξ^2, are fixed, they have time-varying effects on aggregate output, because of the time-varying nature of ζ_t. In particular,

$$\frac{\partial \sigma_{yt}^2}{\partial \zeta_t} < 0$$

suggesting that the volatility effects will be reduced if the communication friction becomes less severe. The intuition is that better communication reduces the effects of these exogenous variances.

5.2 Sentiment Shocks

Equation (37) also implies that the response of aggregate output to a sentiment shock, ξ_t, is $\nu_3(1-\zeta_t) < 0$. The magnitude of this response also depends on ζ_t as follows

$$\frac{\partial \nu_3(1-\zeta_t)}{\partial \zeta_t} = (1-\vartheta)\frac{\zeta_t^2(1+\vartheta) - (1-\zeta_t)^2\kappa_1^2}{\left[(\vartheta^2-1)\zeta_t^2 - \varrho\right]^2}. \tag{39}$$

To determine the sign of the expression on the right side of equation (40), we only need to pay attention to the numerator, which is in a quadratic form

$$\zeta_t^2(1+\vartheta) - (1-\zeta_t)^2\kappa_1^2 = 0.$$

Let $b = \kappa_1^2/(1+\vartheta)$ and rewrite the above equation as

$$(1-b)\zeta_t^2 + 2b\zeta_t - b = 0. \tag{40}$$

The real root of equation (40), $\sqrt{b}/(1+\sqrt{b})$, implies

$$\frac{\partial \nu_3(1-\zeta_t)}{\partial \zeta_t} < 0 \quad \text{if} \quad 0 < \zeta_t < \frac{\sqrt{b}}{1+\sqrt{b}}$$
$$\frac{\partial \nu_3(1-\zeta_t)}{\partial \zeta_t} > 0 \quad \text{if} \quad \frac{\sqrt{b}}{1+\sqrt{b}} < \zeta_t < 1.$$

Thus, the response of aggregate output to a sentiment shock, $|\nu_3(1-\zeta_t)|$, has a parabolic shape. Bad communication (as, for example, when ζ_t is close to zero, meaning that the islands are unable to reach the same expectation about relevant economic conditions) implies a smaller response of aggregate output to sentiment shocks. Higher ζ_t values enhance this response, but increasing ζ_t beyond $\sqrt{b}/(1+\sqrt{b})$ reduces the response. The response of aggregate output to a sentiment shock achieves its maximum when $\zeta_t = \sqrt{b}/(1+\sqrt{b})$. The maximum response of aggregate output to a sentiment shock is given by

$$|\nu_3(1-\zeta_t)| \Big|_{\zeta_t=\sqrt{b}/(1+\sqrt{b})} = \frac{\vartheta^2}{2\phi\sqrt{1+\vartheta}}\frac{1}{(1-\vartheta)\kappa_1}.$$

5.3 Communication Frictions

Finally, the communication friction plays an important role in the determination of the variance of aggregate output

$$\mathrm{Var}(\log Y_t) = [\nu_3(1-\zeta_t)]^2\,\sigma_\xi^2. \tag{41}$$

According to equation (41), the variance of aggregate output is time-varying and depends on the communication friction and the variance of the sentiment shocks. Moreover, according to the non-monotonic relationship in equation (39), the communication friction has nonlinear effects on the variance of aggregate output, suggesting that better communication does not always imply less uncertainty.

Let's take the limit of $\log Y_t$ in equation (37) as $\zeta_t \to 1$. We have

$$\begin{aligned}\lim_{\zeta_t\to 1}\log Y_t &= \frac{c_1}{1-\vartheta} + \frac{1}{1-\tau}\int_0^1 \log A_i di - \frac{\vartheta}{(1-\vartheta)\phi}\int_0^1 \log\delta_i di + \nu_3(1-\zeta_t)\xi_t \\ &= \frac{\tau}{1-\tau}\log\theta + \frac{1}{1-\tau}\int_0^1 \log A_i di - \frac{\vartheta}{(1-\vartheta)\phi}\int_0^1 \log\delta_i di \\ &= \frac{\tau}{1-\tau}\log\theta + \frac{1}{1-\tau}\int_0^1 \log A_i di - \frac{\vartheta}{(1-\vartheta)\phi}\mu_\delta. \end{aligned}\tag{42}$$

which is exactly the equilibrium outcome under perfect communication, equation (26). In this case, the sentiment shock has no effect on the variance of aggregate output. That is, when $\zeta_t \to 1$, there are no heterogeneous beliefs and each island knows its trading partner's output.

On the other hand, the limit of $\log Y_t$ in equation (37) as $\zeta_t \to 0$ is

$$\begin{aligned}\lim_{\zeta_t\to 0}\log Y_t &= \frac{c_1}{1-\vartheta} + \frac{1}{1-\tau}\int_0^1 \log A_i di - \frac{\vartheta}{(1-\vartheta)\phi}\int_0^1 \log\delta_i di + \nu_3(1-\zeta_t)\xi_t \\ &= \frac{\tau}{1-\tau}\log\theta + \frac{1}{1-\tau}\int_0^1 \log A_i di - \frac{\vartheta}{(1-\vartheta)\phi}\int_0^1 \log\delta_i di \\ &= \frac{\tau}{1-\tau}\log\theta + \frac{1}{1-\tau}\int_0^1 \log A_i di - \frac{\vartheta}{(1-\vartheta)\phi}\mu_\delta + \frac{1}{2}\frac{\vartheta^3}{(1-\vartheta)\phi}\sigma_\delta^2. \end{aligned}\tag{43}$$

suggesting that the economy is stable and there is no uncertainty, even with the worst communication in each period. When $\zeta_t \to 0$, each island knows that its trading partner receives the sentiment shock only. Each island also understands that its trading partner will make production decisions by responding to the received information. Since both islands i and j get the same sentiment shock, island i knows island j's belief about island i's work aversion, which is just the sentiment shock. In the same way, island j knows island i's belief about island j's work aversion. Moreover, island i knows what island j expects its production to be and also knows how island j responds to this expectation. Similarly, island j knows what island i expects its production to be and also knows how island i responds to this expectation. This situation is like a game, with each island choosing the production level expected by its trading partner, so that they reach a Nash equilibrium by cooperation.

Based on these results, we conclude that there is a parabolic relationship between the variance of aggregate output and the communication friction, ζ_t. The variance of aggregate output could be completely eliminated at the two extreme values of ζ_t, $\zeta_t = 0$ and $\zeta_t = 1$. The reason for this result is that there are no heterogeneous beliefs at $\zeta_t = 0$ and $\zeta_t = 1$. In particular, the communication friction acts like a filter, creating different beliefs about each island's work aversion. For example, island i knows its own work aversion, but island j (which is island i's trading partner) forms its belief about island i's work aversion based on the received information. Therefore, island i and island j have heterogeneous beliefs about island i's work aversion. Similarly, island i and island j have heterogeneous beliefs about island j's work aversion. It is this heterogeneity in beliefs that causes aggregate output to exhibit time varying variance, but this variance is eliminated at the two extreme values of ζ_t, $\zeta_t = 0$ and $\zeta_t = 1$.

Finally, improving the communication does not always reduce the variance of aggregate output. The reason for this result is because of the heterogeneity in beliefs about work aversion. In particular, as ζ_t increases above zero towards $\sqrt{b}/(1+\sqrt{b})$, the homogenous beliefs between island i and island j disappear and heterogeneous beliefs emerge. Similarly, as ζ_t declines below 1 towards $\sqrt{b}/(1+\sqrt{b})$, heterogeneous beliefs also show up. In fact, the degree of heterogeneity increases as ζ_t declines towards $\sqrt{b}/(1+\sqrt{b})$, and this increases the variance of aggregate output.

6 Conclusion

In the context of a rational expectations macroeconomic model with communication frictions, we show that the level of economic activity is a nonlinear and time-varying function of aggregate economic fundamentals and sentiment shocks. In particular, communication frictions amplify or shrink the effect of exogenous sentiment shocks on aggregate output. That is, because of communication frictions, it is possible for small changes sentiment shocks to cause large changes in aggregate output. Similarly, it is possible for large changes in sentiment shocks to cause small changes in aggregate output. We also find that communication frictions have nonlinear effects on the variance of aggregate output, meaning that improving the communication does not always reduce the variance of aggregate output.

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