1 Introduction

There is little doubt that economic agents are differentially informed about some things that are quite important to them. For example, David Halberstam's classic, *The Best and the Brightest*, describes how the McNamara-led cost cutters at Ford in the 1950s worked to reverse engineer the construction of Chevrolets, which was the market leader produced by General Motors at the time.

> "The night each year when they got hold of their first Chevy, everyone gathered around in a special room and broke it down piece by piece into hundreds of items, each one stapled to a place already laid out for it, and they concentrated on it – no brain surgeon ever concentrated more – every one wondering how Chevy had done this or that for a tenth of a cent less, cursing them slightly – so *that* was how they had done it!"

Information about a trading partner's conditions, a competitor's products and pricing, market demand, and about aggregate economic activity are all plausibly different across agents. The central question for macroeconomics is whether such information heterogeneity just averages out – as in Muth's (1961) setting where individuals suppliers are simply assumed to have expectations that differ from the average in idiosyncratic manner which Muth describes as "distributed around the predictions of the theory" – or whether information heterogeneity influences the nature of fluctuations in the economy.

The interest in informational equilibrium models was lively in the late 1970s and early 1980s, then was dormant until the last five years or so. Having worked on this class of problems in my dissertation, before turning to other topics, I am delighted to have the opportunity to discuss this interesting and valuable paper by George-Marios Angeletos and Jennifer La'O (henceforth, AL) that is both representative of recent developments and breaks interesting new ground.

AL develop a tractable economic environment which features important strategic complementarity between quantity actions across locations of economic activity and significant information heterogeneity across agents. They

use this framework to show how these two structural elements lead to important macroeconomic effects of noise in public signals, which is an interesting substantive hypothesis. In particular, they argue that when agents are differentially informed, it can be the case that noise is far more important for the business cycle than fundamentals.

Relative to the bulk of the earlier literature that simply postulated supply and demand functions, along with particular welfare criteria, the recent literature – as exemplified by AL – is develops "noisy business cycle" results in the context of a fully specified dynamic stochastic general equilibrium models, so that internal consistency is imposed so that it is feasible to conduct welfare analysis. When AL do so, with exogenous public signals, they conclude that business cycle outcomes are information-constrained efficient, even in settings where there is a large effect of noise. To reach this conclusion, they establish that decentralized market outcomes are efficient under perfect competition. Turning to the more general case that is used in much of modern macroeconomics, they further argue that monopolistic competition only has the effect of shifting down the level of economic activity, so that the business cycle fluctuations are identical under imperfect competition and perfect competition, but they cannot further establish the efficiency properties of the overall equilibrium.

In my discussion, I will consider four topics that seem important in future work in the area, which I was stimulated to think about by their work: (i) the analysis of optimal policy in a simple imperfect competition macroeconomic model contained within their setup; (ii) the microeconomic implications of a technology shock version of their noisy business cycle model; (iii) the empirical investigation and associated interpretation of noise in this class of models; and (iv) the efficiency of imperfect information models of economic fluctuations.

Before turning to this discussion, I congratulate the authors on producing a fully articulated framework for the analysis of noisy business cycles. The clarity of their presentation in this and in other related papers, substantially reduces the cost of "reverse engineering" the models in the modern literature while making it feasible to push this research program forward. I have little doubt that many of the young "best and brightest" in macroeconomics will continue to move this program forward along the paths outlined in this paper.

2   Policy design with imperfect competition

A core contribution of the work by Angeletos and La'O is an explicit welfare analysis of real business cycles in a model with heterogeneous information and with imperfect competition, an activity made possible by their careful construction of a model with microeconomic foundations. There is a striking result in their corollary 3: decentralized market outcomes are information-constrained efficient under perfect competition. With the additional restriction that there are no markup shocks, their corollary 4 indicates that "the business cycle is efficient in the sense the gap... between the equilibrium and the efficient level of output is invariant".

In this part of my discussion, working by example, I suggest that there may be an efficiency property for such economies if there are restrictions on government instruments, which in turn may be rationalized more deeply as restrictions on the information held by a social planner. To do so, I exploit the fact that there is a simple well-known example of an imperfect competition macroeconomic model nested within the AL setup. This arises when there is only one island. In their version of this economy, households have preferences of the form

$$u(c,n) = \frac{1}{1-\gamma}c^{1-\gamma} - m\frac{1}{1+\epsilon}n^{1+\epsilon}$$

and consumption is an aggregate of differentiated products,

$$c = \left[\int_J c(j)^{\frac{\eta-1}{\eta}}dj\right]^{\frac{\eta}{\eta-1}}$$

where j is the index of firms (as in AL) and $\eta < 0$ is the elasticity of demand

All firms purchase the sole factor of production labor in a market at wage rate w. Each firm has a production function of the form[1]

$$q(j) = An(j)$$

All firms face the same level of productivity, which may be a random variable as it is in AL. The aggregator above implies that each firm faces a demand

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[1]Note that AL use the more general production function of the form $q(j) = An(j)^\theta$ with $0 < \theta < 1$. I specialize to the case of $\theta = 1$ because diminishing return raises the issue of fixed factors, whose rewards would optimally be taxed away similarly to monopoly profits.

the form

$$c(j) = p(j)^{-\eta}c$$

when its relative price is $p(j)$.

2.1 Policy instruments and policy design

To think about optimal policy, we need to specify the available instruments and enforcement mechanisms that the government has at its disposal. Suppose that the government has three potential instruments: a subsidy to firm production at rate s, a labor income tax at rate τ_w and a lump sum profits tax τ_π. Hence, firm profits are

$$\pi = (1+s)p(j()c(j) - \frac{w}{A}c(j) - \tau_\pi$$

and households have a budget constraint of the form

$$c = (1-\tau_w)wn + \pi$$

where $\pi = \int_J \pi(j)dj$ is the profit flow from all firms.

2.2 Imperfect competition equilibria

Firms are monopolistic competitors, so that they set a price which is a markup over marginal cost.

$$p = \mu\frac{w}{(1+s)A}$$

with $\mu = \frac{\eta-1}{\eta} > 1$ being the "gross markup".

In a symmetric equilibrium, $p = 1$, so that the real wage rate is determined according to

$$w = \frac{1+s}{\mu}A.$$

That is, the equilibrium pre-tax wage rate depends positively on the subsidy and productivity, but negatively on the markup.

Firms earn a flow of profits proportional to their output $(q(j) = c(j) = c$ in symmetric equilibrium), which is given by

$$
\begin{aligned}
\pi &= (1+s)c - \frac{w}{A}c - \pi_\pi \\
&= (1+s)(1 - \frac{1}{\mu})c - \pi_\pi
\end{aligned}
$$

Households equate the marginal rate of substitution between work and consumption to the after-tax real wage rate.

$$
-\frac{u_n}{u_c} = w(1 - \tau_w)
$$

Any equilibrium has consumption and labor equal to

$$
\begin{aligned}
n &= n^*[\frac{w(1-\tau_w)}{A}]^{\frac{1}{\gamma+\varepsilon}} \\
c &= c^*[\frac{w(1-\tau_w)}{A}]^{\frac{1}{\gamma+\varepsilon}}
\end{aligned}
$$

with n^* and c^* being the first-best values.[2] In terms of welfare, equilibria have $u < u^*$ if $\frac{w(1-\tau_w)}{A} < 1$.

2.3 Optimal policy with all instruments

The first best outcome can be supported in a decentralized imperfectly competitive equilibrium if $1 + s = \mu$ and $\tau_w = 0$. Intuitively, this involves the social planner and private agents each seeing the same reward to work, A. In such an equilibrium, before-tax monopoly profits are

$$
\pi = (1+s)(1 - \frac{1}{\mu})c = sc
$$

The required subsidy payments are just sc, so that the necessary subsidy plan would be self-financing if all monopoly profits are taxed away.

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[2]These may be obtained by maximizing $u(c, n)$ subject to $c = An$ which requires the condition

$$
-\frac{u_n}{u_c} = A
$$

and are given by $n^* = [\frac{1}{m}]^{\frac{1}{\gamma+\varepsilon}}[A]^{\frac{1-\gamma}{\gamma+\varepsilon}}$ and $c^* = An^*$.

2.4 Optimal policy without lump-sum taxes

Alternatively, one might consider a situation in which there are no effectively lump sum taxes on firms or households ($\tau_\pi = 0$), so that subsidies must be financed with labor income taxes. In this setting, the household views the net reward to labor in equilibrium as

$$(1 - \tau_w)w = (1 - \tau_w)\frac{1+s}{\mu}A$$

and the government budget constraint is

$$sc = \tau_w wn.$$

The latter implies that

$$(1 - \tau_w)(1 + s) = 1 + s(1 - \mu)$$

when combined with $w = \frac{1+s}{\mu}A$ and $c = An$.[3] Hence, any increase in the subsidy will have the effect of reducing the incentive to supply labor $(1 - \tau_w)(1 + s)$ relative to the nonintervention situation of $s = \tau_w = 0$.

2.5 Implication and a conjecture

The example economy displays the property that AL stress in their welfare analysis: the real business cycle fluctuations (induced by shifts in A) are identical to those under optimal policy, even though the level of consumption and work is lower due to monopoly distortions.

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[3]Derivation footnote for RK

$$
\begin{aligned}
&(1 - \tau_w)(1 + s) \\
&= \quad (1 - \frac{sc}{wn})(1 + s) \\
&= \quad (1 - \frac{sAn}{wn})(1 + s) \\
&= \quad (1 - \frac{s\mu}{1+s})(1 + s) \\
&= \quad 1 + s(1 - \mu)
\end{aligned}
$$

However, under the restriction that there are no profits taxes, these fluctuations around a lower level of activity are *efficient* from the standpoint of a social planner. There thus could be an alternative formulation of the constraints on the planner in the more general AL model which would lead to the conclusion that most equilibria are information-constrained efficient, for a government with a limited set of policy instruments (a planner with an alternative set of implementation constraints).

3   Microeconomic implications

A hallmark of modern business cycle models is that there are implications for microeconomic activity, as well as macroeconomic activity. This places an important discipline on aggregate model building. It is also the case that the parameters of macroeconomic models are identified from aggregate time series data.

3.1   Introducing strategic complementarity

Angeletos and La'O have a very slick way of incorporating strategic complementarity with respect to beliefs which this channel to be separated from monopoly power that is a more standard source of complementarity in macroeconomics. That is, they view goods from various "islands" as bundled together in an aggregator

$$c = \left[\int_{islands} c_i^{\frac{\rho-1}{\rho}} \, di \right]^{\frac{\rho}{\rho-1}}$$

so that the parameter ρ governs the strength of complementarity across islands, which are informationally heterogeneous. They additionally allow for standard differentiated product across firms within an island via the aggregator

$$c_i = \left[\int_{firms} c_{ji}^{\frac{\eta-1}{\eta}} \, dj \right]^{\frac{\eta}{\eta-1}}$$

so that the monopolistic competition mechanism is present as well.

3.2 Reduced form

Focusing on a special case with constant returns to scale production and limiting attention to productivity shocks of a Gaussian form, the AL model provides an exact loglinear specification in which island-specific output depends on island-specific productivity and on the island's belief about aggregate economic activity,

$$\log q_{it} = (1 - \alpha)\kappa \log A_{it} + \alpha E_{it}[\log Q_t]$$

where q_{it} is local output, A_{it} is the local productivity shock and Q_t is aggregate economic activity, governed by $\log Q_t = \int_i \log q_{it}$. Note that, for simplicity, I am ignoring the constant term in this equation.

The parameter κ governs the typical RBC mechanisms,

$$\kappa = \frac{1 + \varepsilon}{\varepsilon + \gamma}$$

where ε is the elasticity of the marginal utility of consumption and γ is the elasticity of the marginal disutility of effort.

The parameter α governs the strength of the strategic complementarity across islands,

$$\alpha = \frac{\frac{1}{\rho} - \gamma}{\frac{1}{\rho} + \varepsilon}$$

so that variation in the "macro elasticity" ρ can be used to vary α, while holding fixed the RBC forces (γ, ε). The product differentiation parameter η plays no role in either of these compound parameters, figuring only in the omitted constant term.

3.3 Full information: macro implication

A convenient feature of the AL model is that the parameter α plays no role in the determination of aggregate economic activity under perfect information, since

$$\log Q_t = \kappa \log A_t$$

with $\log A_t = \int_i \log A_{it}$.

Accordingly, when exploring the effects of α on the properties of "noisy business cycles", AL can hold the properties of full information business cycles constant. This makes for conceptually clean experiment: the macro effects of the strategic complementarity parameter ρ operate entirely via incomplete information channels.

3.4 Local market activity

However, it is not the case that all properties of the stochastic equilibrium are invariant to the degree of strategic complementarity as controlled by ρ. Consider the deviation of local output from aggregate output in a particular market k.

$$
\begin{aligned}
\log q_{kt} - \log Q_t &= (1-\alpha)\kappa[\log A_{kt} - \log A_t] \\
&\quad + \alpha[E_{kt} \log Q_t - \int_i E_{it} \log Q_t]
\end{aligned}
$$

Under common information (including complete information), the last line of this expression is zero, so that it is useful to initially specialize to this case.

An increase in strategic complementarity α *reduces* the responsiveness of local activity to the local productivity shock $[\log A_{kt} - \log A_t]$. Hence, there is a tension between using strategic complementarity to generate macro volatility, while maintaining a given degree of micro volatility of shocks (variability of $[\log A_{kt} - \log A_t]$) and a given strength of the RBC mechanisms (κ).

This tension is a pervasive one in macroeconomics, so that it is perhaps reassuring that it appears here. But it means that a full information version of the AL model that was taken to both macro and micro data would place restrictions on the degree of strategic complementarity.

More generally, the volatility of $\log q_{kt} - \log Q_t$ depends on the volatility of $[E_{kt} \log Q_t - \int_i E_{it} \log Q_t]$ as well as its covariance with $[\log A_{kt} - \log A_t]$.

To generate high amplitude response to a local shock, with a high level of the complementarity parameter ρ, there would need to be a particular comovement of local beliefs and local shocks, in ways that would depend on the details of the informational equilibrium. In a sense, there would need to be micro noise effects as well as macro noise effects.

4 What's noise?

In the AL model, noise in public signals is an important, potentially dominant source of business cycle fluctuations. Continuing to work within the special case discussed in the previous section, aggregate output is

$$\log Q_t = (1 - \alpha)\kappa \log A_t + \alpha \int_i E_{it} \log Q_t.$$

That is, if the typical market thinks aggregate economic activity will be higher, in the sense of $\int_i E_{it} \log Q_t$ increasing, then aggregate economic activity will be increased, with a strength of this effect depending on α. With α close to one, the volatility of aggregate output is due principally to the volatility of "average opinion" and noise in public signals is a rational expectations mechanism for shifting expectations without shifting fundamentals.

But what is noise? Future research in this area will have to take a stand on the details of the information structure and the nature of noise, measuring its properties.

4.1 Monetary misperceptions

In the literature on monetary nonneutrality due to imperfect information (stemming from Lucas (1972)), one strand of the literature examined the implications of observable monetary information for real activity. As an example, consider the following basic model that links output (y) to misperceived money

$$y_t = \theta(M_t - \int_z E_{zt} \log M_t)$$

where $\int_z E_{zt} \log M_t$ is average opinion across a set of local markets and θ is a positive coefficient.

Monetary statistics, $\widetilde{M_t}$, can be viewed as the true money stock M_t plus a measurement error, ς_t. As discussed in King (1981), such a Lucas-style model implies that output should be uncorrellated with monetary statistics, even

if these the are measured with error relative to behaviorally relevant money stock (M_t). This is a direct implication of the general point that expectation errors should not be correlated with available information. But the model also has implications for the impact of noise in such public signals if a measure of noise can be constructed. For example, suppose that expectation formation takes the form,

$$\int_z E_{zt} \log M_t = \lambda \widetilde{M}_t + ...$$

with $0 < \lambda < 1$. That is, an increase in the observed monetary statistic will raise average opinion given other determinants of expectations. In this setting, an increase in actual money will raise output, since

$$
\begin{aligned}
y_t &= \theta[M_t - \lambda \widetilde{M}_t + ...] \\
&= \theta[(1 - \lambda)M_t - \lambda\varsigma_t] + ...
\end{aligned}
$$

But monetary noise should lower output, since it raises $\int_z E_{zt} \log M_t$., holding fixed behaviorally relevant money M_t. Studies of revisions in money stock statistics by Barro and Hercovitz (1980) and Boschen and Grossman (1983) did not find the noise effects predicted by the theory.

More recent work by Collard and Dellas (2007) suggests that there are important quantitative effects of mismeasured money during the "monetarist experiment" of the late 1970s and early 1980s. They also find that noise effects can be important for the dynamic implications of model which combine imperfect information and sticky prices.

However the ultimate empirical results on "monetary misperceptions" ultimately turn out, the work in this area illustrates one way to measure noise and to determine its effects on macroeconomic activity.

4.2   Noise as belief shifts

AL take an alternative view of noise, which can is both richer and more agnostic: noise is simply a "convenient modeling device for introducing correlated errors in beliefs of aggregate fundamentals".

With such a perspective, there seem to be two main implications in terms of taking models of this class to data. First, while errors across agents could well be correlated at a point in time, they should be uncorrellated

with information held by agents. Second, the identification of these noise events will likely come about via the cross-equation restrictions of a particular model: an identified belief will be one that produces a particular pattern of comovement at a point in time and a particular evolution of the economy's path.

From this perspective, the illustrative analyses undertaken by AL indicate the potential empirical content of the theory. Taking as given the real structure of the economy, the information structure of the economy will contribute some additional free parameters that will have implications for how the real economy responds to standard shocks as well as how measures of beliefs evolve through time. The noise events themselves are an additional source of shocks. Explorations of identification in these models appears to be a first order matter.

5　Information and Policy

There are a number of settings in which there is a divergent private and social value of information, which can rationalize particular policy interventions. One that is well understood by Angeletos and La'O, but bears stressing, is that agents plausibly learn from prices and other endogenous signals.

In Grossman and Stiglitz (1980), individuals whether to acquire information about underlying fundamentals. In equilibrium, there is generally too little production of information because agents do not take into account the benefits that accrue to others when deciding on whether to become informed. A similar logic presumably applies when individuals are deciding on the precision of signals to acquire.

In models of monetary policy, when agents learn from commonly observed prices (as in Weiss (1980) and King (1982)), policy can affect the information content of such prices. That is: policy can affect the weight that agents place on the endogenous and exogenous signals, as well as exerting more standard income and substitution effects. The earlier generation of models also suggested the possibility that there can be more than one incomplete information equilibrium (more than one configuration of "signal extraction parameters" in noisy rational expectations models), as, for example, in the local product and global bond market analysis of King (1983). Policy parameters in such models can alter the information content of prices in ways that reduce the set of noisy rational expectations equilibria.

Turning to the broader linkage between information and policy, we know from the work of Prescott and Townsend (1984) that there is a rich set of environments in which competitive equilibria are Pareto efficient when individuals have private information. It would be useful to work to extend the welfare analysis of AL to environments that combined individual private information with incomplete information about aggregate conditions. We know also from the work of Kahn and Mukherjee (1988) that competitive equilibria can lose their efficiency properties when incentive constraints contain macro quantities or prices. This suggests that the suggested extension is an important, but subtle one.

6   Concluding comments

I think that the mechanisms stressed by Angeletos and La'O are potentially important for business fluctuations, but that there is much work to be done to measure this importance. We need quantitative models in which the effects of noise are specified and the empirical models in influence of noise is evaluated.

While I am intellectually sympathetic (perhaps nostalgically so), I am far from sure that the mechanisms is the most important types of information for macroeconomics. Recent events put the question starkly. I interpret the class of models advocated by AL as suggesting that economic activity has been low and volatile because the path of aggregate demand is hard for an individual agent to determine, given that it is influenced by the beliefs of others. A much discussed alternative vision stresses asymmetric information in bilateral or multilateral relationships as a source of amplification mechanisms, such as in lending relationships. A final vision suggests that private sector beliefs about government policy responses have played a central role in the recent boom and bust.

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