Chapter 36

AGENT-BASED MACRO

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Abstract

Acceptance of computer modeling and experimentation has spread slowly at best in economics in large part because agent-based models often seem foreign to the neoclassical core of economics, as that core is understood today. But in its beginnings neoclassical economics was not built from choice theory, did not represent decisions as solutions to constrained optimization problems, made no strong assumptions about the rationality of agents, and did not view the world as always in equilibrium. Agent-based economics can tap into this older neoclassical economics of adaptive behavior and ongoing market processes while circumventing the technical obstacles which forced the forerunners to adopt the "static" method.

Agent-based process analysis will finally make it possible to tackle the central problem of macroeconomics, namely, the self-regulating capabilities of a capitalistic economy. Keynes challenged the presumption that flexibility of all prices guaranteed the stability of general equilibrium, arguing that effective demand failures meant that Say's Law did not hold. When supply did not create its own demand, stabilization policy in the form of aggregate demand management was required to restore full employment. In modern general equilibrium based macroeconomics, in contrast, Say's Law always holds, only "frictions" stand in the way of full employment, and stabilization policy lacks any tenable rationalization.

Agent-based computational methods provide the only way in which the self-regulatory capabilities of complex dynamic models can be explored so as to advance our understanding of the adaptive dynamics of actual economies.

Keywords

adaptive behavior, market processes, effective demand failure, stability of equilibrium, Say's Law, natural rate of unemployment, Marshall, Keynes

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The first responsibility of a macroeconomist, surely, is to work towards an understanding of major economic disasters, of how to avoid them and of what to do when, unavoidably, they occur. Macroeconomics originally emerged as a distinct subdiscipline because the Great Depression was not well explained as a manifestation of efficient allocation theory. Disasters keep happening. The last fifteen years have seen the great break in the astonishing growth of Japan, the crises that forced Britain and Sweden to devalue, the Mexican 'tequila' crisis and its repercussions elsewhere, the East Asian and Russian crisis, and the Argentinian default crisis, for example. In the same period, macroeconomics has been reabsorbed into the theory of efficient resource allocation. Many people in the field see this development as having healed an unhealthy rift in the fabric of general economic theory. But this modern macroeconomics fails to throw light on disasters.

An economy is an evolving, complex, adaptive dynamic system. Much progress has been made in the study of such systems in a wide variety of fields, such as medicine and brain research, ecology and biology, in recent years. To people from one of these fields who come to take an interest in ours, economists must seem in the grips of an entirely alien and certainly unpromising methodology. In these other fields, computer modeling and experimentation is accepted without much question as valuable tools. It was possible, already 15 years ago, to hope that economists would find them valuable as well [Leijonhufvud (1993)]. But the intervening years have not witnessed a stampede into agent-based economics.

In fact, macroeconomists are more apt than most to be suspicious, if not outright hostile, to the agent-based approach. The apparent threat of cognitive loss is perhaps steeper in macro than in other areas. Each generation of scholars inherits a knowledge base of theory, of empirically confirmed "facts" and of investigative techniques. Inherent in this base are directions for future work—which problems are interesting and which ones not, what facts are puzzling and which ones can be taken for granted, what methods of investigation are approved and not approved, and so forth. The macroeconomics of the last quarter century, from Lucas through Prescott to Woodford, has been very strongly wedded to stochastic intertemporal general equilibrium theory. It is the well-developed knowledge base with which the last couple of generations of macroresearchers have been equipped. Acquiring it required a large investment. But then recruits to this research program are confident that their technical equipment is the best in the business.

Agent-based economics, in contrast, is in its technical infancy. The tendency, moreover, is to use it to tackle analytically intractable problems, thus making limited use of the treasured skills of modern macroeconomists. ACE models can claim to handle multitudes of heterogenous agents, which intertemporal general equilibrium models do not, but these simple agents, heterogenous though they be, have one thing in common, namely, "bounded rationality"—which runs afoul of how the neoclassical tradition is most often understood. It is also difficult to impose some analytical discipline or empirical constraint on complex dynamic behavior that systems of such agents tend to exhibit—and thus difficult to prevent such models from deteriorating into some species

of computer games. There is also some guilt by association: complex simulation models have a bad track record in economics (Rosser, 1999, pp. 171–175).

The allegiance to modern macroeconomics is also very much fortified by a strong sense of tradition, of carrying on an economics that was 'always' built on 'rational choice', on 'optimizing behavior', on equilibrium, a tradition that you stray from at your peril. But this sense of tradition is in large measure based on a misreading (or, more likely perhaps, a lack of reading) of the history of our subject. What is today commonly thought of as neoclassical economics is really the hypertrophy of optimizing choice theory—the branch of neoclassicism which at one stage in the development of economics happened to be the most easily formalized. There is an earlier tradition of neoclassical economics, in some respects a more interesting one, which could not be adequately formalized and therefore gradually fell into neglect. This tradition could be revived with agent-based methods. It would be worth doing.

1. Two traditions

The British Classical writers, including Marx, sought to deduce how society would develop and the income distribution among classes change with time. The theory was inherently dynamic, driven by basic behavior propositions that were really verbal differential equations of the type "population will grow as long as real wages are above subsistence" or "capitalists will accumulate as long as profits are positive." But no one could handle systems of differential equations, of course. The best that could be done "rigorously" was to deduce the properties of the long-run equilibrium where these *laws of motion* ceased to operate, i.e., the stationary state of the Dismal Science.

The early neoclassicals shared this general outlook. Micro-behavior was thought of as adaptive. People sought to maximize utility or profit, but these were propositions about motivation, not performance. Certain agents in certain roles in certain social settings would be more calculating and better at calculating than others but in general no ambitious claims were made about the 'rationality' of people. Agents were capable of learning and most would be fairly efficient in situations with which they had a lot of experience. Since they were not super-rational, individuals would rely on a framework of institutions constraining the behavior of others so as to make the utility-relevant outcome of effort reasonably predictable. What people would learn from interacting with others would also depend on the institutions governing their transactions. Some countries (Western countries, of course) would do better than others.

The modern theory focuses on the principles of efficient resource allocation. Its core is choice theory, formalized in terms of constrained optimization. When used to explain observed behavior, constrained optimization models attribute *substantive rationality* to agents. Thus, in this theory utility or profit maximization is a statement about actual performance not just motivation. For this to be the case, decision-makers must be assumed to know their *true* opportunity sets in all their dimensions. Applying this behavior description to all agents implies that all choices made must be consistent. The theory does

not leave room for failures to realize the relevant optima. Consistency of plans is the definition of equilibrium in this younger tradition. Set in a temporal context, substantive optimization requires that agents know all future prices (among other things) in drawing up their plans. Thus all choices have to be reconciled *before* anyone's choice can be made. Intertemporal general equilibrium theory may be 'rigorous' but it pays little attention to the sequencing of decisions in time.

In this theory, the 'rationality' of agents knows no bounds. Consequently, they have no very obvious need of institutions. Why they should use money or organize production in firms become riddles, not easily answerable within competitive general equilibrium theory.

2. The ambivalence of neoclassical economics

How the earlier neoclassicism which dominated until the 1930's or 1940's metamorphosed into the modern version is a long and complex story not to be attempted here [cf. Leijonhufvud (2004a)]. What needs to be noted is that neoclassical economics is not one coherent tradition. There is a strong conceptual tension between the older and the modern versions. The older neoclassical economics has a strong affinity to complex systems theory that general equilibrium theory entirely lacks.

Central concepts of complex systems theory, which have caused some excitement in other fields, are old themes in economics. *Emergent order* we have known about since Adam. The troubles with *top-down* control we have known about since Lu and Fritz. *Parallel processing* is what methodological individualism should have committed us to long ago.

Complex systems are generally hierarchical, often with multiple layers. Each system consists of interrelated components or modules that are systems in themselves. The components are simpler than the system of which they are parts. In general, they also have to work on a different time-scale (faster) than the higher-level system [Leijonhufvud (1995)].

All these statements fit naturally into the analytical mode of the older neoclassical tradition. They do not fit into the intertemporal general equilibrium framework of modern macroeconomics. (And the practitioners of modern macro tend to view references to these matters as irritating, wooly-headed talk.) The representative agent that has been made to do such heavy duty in Real Business Cycle theory is a case in point. This mythical figure is not a component, simpler than the system of which he is part. Although the poor man may suffer from multiplicity of equilibria, his 'rationality' is fully adequate to the complexity of the entire system. It is trite to note that the representative agent model leaves no room for supply and demand or "market forces." But the reason why this is thought to be adequate is of some interest, namely, that interactions at modular interfaces are considered inessential in this theory.

Agent-based economics should be used to revive the older tradition. So far the agent-based models that have gotten the most favorable—or at least most tolerant—reception

by the profession at large have tended to tackle problems neglected by the mainstream, such as the work by Kollman et al. (1997) on Tiebout's 'voting with your feet', and the work by Axtell (2001) on the size-distribution of firms. These serve the cause by showing that agent-based economics can solve problems for which economists previously have not had the requisite tools. But it is not with new problems but with the *oldest* that agent-based methods can help us the most. We need to work on the traditional *core* of economics—supply and demand interactions in markets—for, to put it bluntly, economists don't know much about how markets work.[1]

3. Tapping into the older tradition

If the older neoclassical economics made more sense than today's, why did it decline and why did the "modern" take over? The answer, in brief, is that the older tradition in its time came to face insuperable technical obstacles while optimal choice theory did point a way forward to the solution of many problems and ambiguities in received theory. The story is a perfect illustration of both the negative and the positive side of Robert Lucas's (Lucas, 1987, p. 272) thesis that "purely technical developments that enlarge our ability to construct analogue economies" are one of the main forces driving the evolution of economics.

Alfred Marshall is the right representative of the older neoclassicism for the purposes of agent-based economics. Over the last half-century or more, Marshall's influence has steadily declined while that of Walras has been in the ascendance. Marshall's reputation has suffered at the hands of people who read him as a sloppy Slutsky or a Walras unable to attain anything more than a partial equilibrium. But this is judging him by a standard that is conceptually quite alien to his theory. Marshall did not build from choice theory, did not represent decisions as solutions to constrained optimization problems, and made no strong assumptions about the 'rationality' of decision-makers.

Recall that Marshall drew his supply-and-demand diagrams with quantity on the horizontal and price on the vertical axis. He was a conventional man and convention dictated that the independent variable go on the horizontal and the dependent on the vertical axis. (Convention dictates so still, but respect for conventions is not what it used to be.) Marshall started from supply prices and demand prices as functions of quantities. His $p^s(q)$ and $p^d(q)$ schedules are *not* loci of optimal points but indicate minimum and maximum prices, respectively, at which the decision-maker would be disposed to transact.

The "quantity-into-price" constructions [Hicks (1956)] do not state correspondences between price and most preferred quantity. They provide, rather, routines of adaptation in a constantly changing market environment. We may refer to them as "Marshall's *laws of motion*":

For the consumer:

[1] In all fairness, experimentalists and market designers have made important contributions to the understanding of market processes. But macroeconomics is still mired in unclear notions of "flexibility" or the lack of it.

If demand price exceeds the market price, buy more; in the opposite case, buy less.

For the producer:

If market price is above supply price, increase production; in the opposite case, cut back.

To which we should add the requisite rules for the middleman/market maker:

If demand exceeds supply, raise prices to both consumers and producers; in the opposite case, lower prices.

And a second rule for the producer:

If quasi-rents are positive, add to capacity; in the opposite case, let it depreciate.

These behavior rules fall short of the 'substantive rationality' attributed to agents in general equilibrium models. But gradient rules of this sort qualify at least for a measure of 'procedural rationality' [Simon (1976)] in settings where continuity and convexity can be taken for granted.

The combination of these 'laws of motion' makes an almost prototypical agent-based model. As with most such models, the combination of several differential or difference equations makes a non-linear dynamical system that may not be at all well behaved. Certainly, it was well beyond what could be handled with analytical methods in Marshall's time. He improvised his "static method" to tame the potentially unruly dynamics—but he did not trust it very far, although he seems to have thought that what he called the 'continuity principle' (*Natura non facit saltum*) gave some considerable assurance that it would work.

The static method was to take each of the 'laws of motion' separately, rank them in rough order from the speediest to the slowest, and then for each of them find the conditions under which the 'law' would cease to operate, assuming that all processes slower than the one under investigation could be treated as (approximately) constant. This amounts, of course, to assuming that each process will always converge to a well-defined point-attractor, an assumption for which there can be no general warrant, since when all these 'laws of motion' are operating on more or less the same time-scale, the system might well go, for example, to a complex attractor.

4. Taking supply and demand seriously

A simple market model of this general type will help point out a number of items for the agenda of agent-based theory. The first lesson is that the 'laws of motion' are not enough. One must also specify some minimal institutional structure within which they can be shown to operate. A fish market was the favored vehicle for generations of Marshallian pedagogues. It may serve here as well.

We assume a fishing fleet operating out of a port city. Each night, T, the boats go out and return in the morning. The entire catch of the fleet, q_T, is brought to the local fish auction house and sold at auction.

Let lower case t denote clocktime and let capital T denote dates. The adjustment speed of price is assumed qualitatively faster than that of output. Price finds the market clearing level within each market day; output finds its equilibrium over a sequence of days. Assume a stationary demand function:

$$q^d = D(p). \tag{1}$$

The catch landed on day T, q_T, is auctioned off:

$$\begin{aligned} &p_{t+1} = f[D(p_t) - q_T] + p_t; \\ &p_{t+2} = f[D(p_{t+1}) - q_T] + p_{t+1}; \\ &\text{etc.} \end{aligned} \tag{2}$$

By assumption, the algorithm (2) will converge on:

$$p_T^* = p^*(q_T), \quad \text{the market clearing price for day } T. \tag{3}$$

The expected size of the catch for any one boat depends simply on the amount of labor input during the night. The j-th boatowner's supply price is given by his marginal cost schedule:

$$p_j^s = s_j(q_j). \tag{4}$$

He compares his supply price for the catch most recently landed to the market price received and adjusts his rate of production accordingly:

$$q_{T+1,j} = h_j\left[s_j(q_{T,j}) - p_T^*\right] + q_{T,j}, \ldots \text{ etc.} \tag{5}$$

Industry output (the catch of the fleet) evolves according to:

$$q_T = \Sigma q_{T,j} \tag{6}$$

and the condition for short-run equilibrium is (temporary) stationarity of output:

$$\Delta q_T = 0. \tag{7}$$

Equation (7) presumes, without explicit rationale, that the dynamic system will go to a simple point attractor. This attractor defines one point on Marshall's industry supply schedule. To get the rest of it, one has repeatedly to shift the demand function (1) and let the feedback loops (2) and (5) run to find the successive short-period equilibria.

The model has the virtue of portraying a market process with distinct laws of motion for both price and for output. It shows a rivalrous competitive process free of the infinitely elastic demand nonsense of 'perfect competition'. In several other ways, however, it is contrived to simplify matters that are seldom so simple. Here the market is a market *place* where well-defined sets of buyers and sellers meet for a limited time at defined

intervals. The price must clear the market at each meeting and the meaning of market clearance is reasonably well-defined since inventory carry-over is ruled out (no frozen fish in Marshall's time!). However, the *tâtonnement* process in (2) is neither Marshallian nor realistic. Marshall would have assumed a double auction and argued that the final price would normally end up the same as in (3) above.[2]

In a normal, ongoing market, transactors are not all brought together in a single location and at the same time. Without centralization and synchronization, the supply-equal-demand condition "cannot be used to determine price, in Walras's or Marshall's manner" (Hicks, 1989, p. 11). But this also means that Marshall's "static method" will not work after his manner. Instead, ongoing markets require market makers who announce their prices and maintain inventories to handle customers arriving at irregular intervals. Virtually all manufactured goods are produced under increasing returns, not the diminishing returns of Marshall's fishermen and corn farmers. In markets where the producer operates under increasing returns, he often becomes the market maker and has to set a price based on speculation on what volume of sales he may achieve. The gradient climbing of Marshall's law of motion is then obviously inapplicable and a different algorithm has to be found to represent the producer's strategy.[3]

Combining the laws of motion for price and output makes a non-linear market process. Marshall tamed it by his ranking of adjustment speeds and corresponding hierarchy of equilibria. Agent-based modeling has no need for these conceptual crutches. When they are abandoned, however, one has to explain why markets normally do not fluctuate as much as the old laws of motion would suggest. The basic reason is simple. Consider again the fish market. The demand side is made up of middlemen—wholesalers and perhaps some retailers. They would have learned that the housewives, who are the ultimate buyers, will readily change their menus in response to rather small variations in the price of fish. Intertemporal substitution would keep short-period price fluctuations quite constrained. Similarly, fishermen will learn not to respond immediately to every little tick in the market price. Thus, the short-period demand price and supply functions will be much less elastic than the steady-state ones deduced from static utility and production functions. Agent-based methods should enable us to show the coevolution of the strategies of consumers, middlemen and producers that normally keep the tendencies of such systems to oscillate under pretty tight control. The theory should show the tendencies to be present although suppressed, rather than assume them away, for in certain situations the control will break down and make them boil to the surface. Under conditions of high inflation, for example, they show up in the extreme volatility of relative prices (Heymann and Leijonhufvud, 1995, pp. 169–182).

Marshall's adaptive theory avoids the perfect coordination trap which prevents modern optimization/equilibrium theory from helping us understand macroeconomic disasters. However, his 'static method', with its hierarchy of market day, short period and

[2] Much experimental evidence would nowadays support him on this point. But then the double-auction experiments are most often set up so as to conform to the assumptions of the fish-market discussed in the text.

[3] When sales occur in discrete quantities at discrete intervals, the monitoring of demand conditions becomes a non-trivial problem. How long a run of observations is needed to determine whether demand has changed?

long period equilibria, was a set of logical crutches that allowed him to hobble onward a piece with the theory of a complex dynamic economy. We can abandon Marshall's crutches. When that is done, a large, interesting and do-able agenda, of which the items above are only a sample, opens up for agent-based economics.

All this, however, deals with the microfoundations of an agent-based macro. It remains to consider an agenda for macroeconomics proper. The main item concerns the stability properties of the macrosystem—a topic that general equilibrium theorists gave up on some decades ago.

5. Keynes and all that

Prior to Keynes's *General Theory*, economists were quite generally convinced that, if only all agents in an economy obeyed Marshall's "laws of motion", that economy must most surely home in on a full employment equilibrium. Most particularly, of course, this would have to include the willingness of workers to let wages "flex" in the face of unemployment. It was generally accepted that the adjustment process would involve "frictions" of various sorts, but the overall stability of general equilibrium was not in doubt. This view of the matter is the one that we have returned to in the last thirty years or so.

The Great Depression persuaded Keynes that these beliefs must be wrong and that received theory, therefore, stood in need of a fundamental reappraisal. Keynes was a Marshallian and his reappraisal came to involve two departures from that tradition. The first was an argument directed against Marshall's "continuity principle". *Natura non facit saltum* did not hold for investment expectations. These were not solidly founded and could, therefore, shift both abruptly and drastically.

The second departure was more far-reaching. Keynes rejected the proposition that "Supply creates its own Demand" which apparently went under the label of "Say's Law" in Cambridge oral tradition [Clower (2004)]. Say's Law was taken to mean that any excess supply somewhere in the system would be balanced by an excess demand elsewhere. It was conjectured that Say's Law guaranteed the stability of full employment equilibrium as long as all prices (including wages) responded appropriately to excess demands and supplies in the respective markets. Keynes had come to realize that this conjecture was not generally true. (He thought, in fact, that it was always false, but in that he himself was mistaken.)

The problem was that excess supplies might not be balanced by *effective* excess demands, that is, by excess demands that would trigger the 'laws of motion' and cause market participants to change prices and activity levels. The *General Theory* stressed two such *effective demand failures*. The first concerns the coordination of consumption and production over time. An increase in savings creates an immediate excess supply of present goods but does not by itself signal an excess demand for consumption goods in the future. Thus, argued Keynes, "investment causes saving" (by changing income)

"but saving does not cause investment"—two propositions that make no sense within simultaneous equation models but that could be rendered meaningful within the modular architecture of a process model written in an object-oriented program.

The second effective demand failure can occur because the offer of labor services is not in itself an effective demand for consumer goods. In a monetary economy, "goods buy money and money buys goods, but goods do not buy goods" [Clower (1967)]. When labor is thrown out of work, consumption declines and the recessionary impulse is amplified.

The two effective demand failures interact. When a negative shock to long-term expectations reduces investment, the intention of savers is to accumulate more 'bonds' than the business sector intends to issue. If then the Central Bank's policy or ruling opinion on the stock market prevents the interest rate from falling sufficiently, output and real income will fall until saving no longer exceeds investment. There is then no growing market pressure for a correction of the interest rate. At that point, however, we have unemployment at wage rates which would be consistent with full employment had only saving and investment been brought into equality by a decline in the rate of interest rather than by falling output.

The resulting state of the economy, therefore, is one where one price (the interest rate) is inconsistent with general equilibrium, but excess demand in that market is zero so there is no automatic tendency for that price to change. At the same time, a second price (the money wage) *is* consistent with general equilibrium, but there is excess supply (unemployment) in that market that tends to drive it away from that level. Declining money wages would not cure the situation in Keynes's view. If wages and prices were very flexible downwards, a Wicksellian deflation would wreck the financial system and make matters far worse.

Keynes called this state of the economy an "equilibrium" with "involuntary unemployment." Semantic confusion has been unending ever since. His unemployment state will qualify as a Marshallian (short-period) equilibrium in the sense that the time-derivatives of output and employment are zero, but it obviously cannot be a Walrasian equilibrium. Similarly, the notion of "involuntariness" makes no sense within a choice-theoretical framework. What Keynes meant by it was essentially that this unemployment had emerged without any *intentional* interference with the laws of motion in labor markets. Economists have long been used to the *invisible hand* bringing about a coordinated state that was not part of anyone's intention. Keynes's involuntary unemployment should be understood in the same way as a different and less favorable *emergent property* of money-using market systems.

6. Decline and fall

When Say's Law fails to hold, so that Supply does *not* create its own Demand, a readily understandable case can be made for stabilization policy, in the sense made familiar in the Keynesian era, namely, aggregate demand management. Keynes certainly thought

that effective demand failures were ever present and Keynesian economics has probably been overly addicted to aggregate demand management.

The *natural rate of unemployment* (NAIRU) postulate of Phelps and Friedman served in effect to reinstate Say's Law in macroeconomics. It was predicated on the old notion that departures of observed from equilibrium unemployment must be due to lags in the adjustment of wages. This was accepted also by confessed Keynesians since they had long ago left behind Keynes's worries about troubles in financial markets coming in the way of saving-investment coordination. With full employment saving equalling investment, all that is needed for full employment is wage flexibility. As macromodels incorporating the postulate conquered the field, it gradually became clear that they could not provide any rationale for aggregate demand policies. When Supply creates its own Demand, macropolicy—if any—has to be supply-side policy.

Marshall was well aware that his static method falsified the dynamics of the processes on which his theory focused and frequently expressed his doubts about how far the method could be trusted even when dealing just with the isolated market. Keynes, for lack of any feasible alternative, tried to use Marshall's method to tame the adaptive dynamics of the multidimensional macrosystem. In so doing, he was in effect trying to "talk" his way through the analytically completely intractable dynamics of a system of multiple markets with 'laws of motion' operating at different speeds, with some agents hampered by liquidity constraints, with volatile investment expectations and sluggish interest rate expectations, and so on. This was operating far, far beyond the limits of what could reasonably be expected of Marshall's method. Keynes was a very clever man and he managed to make it work after a fashion. But it is hardly surprising that the effort left a legacy of never-ending controversy over "what Keynes meant" and whether what he meant made sense. Nor is it surprising, in retrospect, that his theory could not survive when forced into the even tighter straitjacket of Walrasian general equilibrium.

7. Conclusion

The issues could not be of more importance. If NAIRU-based macrotheories are correct, aggregate demand has had nothing to do with the differences in performance between, say, the United States, the European Union countries and Japan in the 1990's. It has all been a matter of flexibility in the labor market, lower taxes, and government staying out of the way of business. If Keynes was at least partly right—and he certainly was not completely right—it is not so surprising that a country that manages to invest a lot and save hardly at all outperforms those where the opposite is more nearly the case. And the two views of the world differ on a host of other issues as well [Leijonhufvud (2004b)].

Keynes's theory of how a monetary market economy can fail to coordinate activities "automatically" was flawed. But what we have on the other side is little more than blind belief in the stability of general equilibrium.[4] The matter cannot in all intellectual

[4] Cf. Clower and Howitt (1996) and their discussion of the status of the "Classical Stability Postulate."

decency be left there. Agent-based methods provide the *only* way in which we can explore the self-regulatory capabilities of complex dynamic models and thus advance our understanding of the adaptive dynamics of actual economies.

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