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Macroeconomic Policy, Evolution, and Self-Confirming Equilibrium.

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Abstract

This paper uses policy disputes about centuries of experience with commodity money systems and US monetary policy in the 1970s and 1980s to illustrate macroeconomists' enduring struggles with Hume's induction problem and their connection to self-confirming equilibria.

Keywords
Induction, misspecification, self-confirming equilibrium, adaptation, inflation, Pareto problem.

Macroeconomic policy, evolution, and self-confirming equilibrium*

Thomas J. Sargent[†]

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1 Evolution and intelligent design (in macroeconomics)

In the United States, where religion and politics are intertwined, maybe *because* the separation of church and state is taken so seriously, there has been loud public discussion about whether local school boards should require science teachers to teach a theory of 'intelligent design' alongside Darwin's theory of evolution. Less noticed but scientifically more respectable, a theory of intelligent design of public policies has competed for attention with theories of adaptation within macroeconomics. This lecture discusses some of the issues, gathering inspiration from David Hume's thoughts about intelligent design of a polity and about the problem of induction and David Ricardo's thoughts about ways to improve a monetary system.

2 Intelligent design

What I call the intelligent design approach realizes much of the promise of rational expectations macroeconomics. By solving a Pareto

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problem in which a planner and all agents optimize in the presence of information and incentive constraints and a common probability model, it is a coherent response to the Lucas (1976) indictment of pre-rational expectations macroeconomic policy design procedures. Lucas pointed out that those procedures imputed different beliefs to the government and the private citizens exchanging goods and services in markets. In particular, those procedures attributed systematically superior beliefs to the government in the sense that the government's forecasts are statistically better than private citizens'. That assumption underlay a feature that Lucas especially deplored, namely, that the policy-making procedures took private agents' decision rules as invariant with respect to hypothetical government interventions that altered the laws of motion for government policy instruments that impinge on private agents' constraint sets. Via the cross-equation restrictions implied by attributing common beliefs to a government and its citizens, rational expectations models automatically make private agents' decision rules be functions of a government policy. At its most ambitious, the intelligent design approach in macroeconomics uses the rational expectations common belief assumption both to process historical data and to design a new and better equilibrium. Thus, a complete implementation of intelligent design involves these steps:

1. Apply rational expectations econometrics to historical data to estimate parameters that describe private agents' preferences, technology, endowments, and information sets.[1]

2. Posit a timing protocol and an objective function for a government, typically a Pareto criterion.

[1] There are differences of opinion about how to model the government in the historical data set.

3. Find a new rational expectations equilibrium that maximizes the government's objective.
4. Proclaim as advice the government policy that implements that rational expectations equilibrium.

The intelligent design tradition dates back at least to David Hume:

> Political writers have established it as a maxim, that, in contriving any system of government, and fixing the several checks and controuls of the constitution, every man ought to be supposed a knave, and to have no other end, in all his actions, than private interest. By this interest we must govern him, and by means of it, make him, notwithstanding his insatiable avarice and ambition, co-operate to public good. (Hume 1985, p. 43)

The intelligent design approach in macroeconomics supplements Hume's knave assumption with an assumption that everybody in the model shares common beliefs about probability distributions.

But what are the sources of those common beliefs about macroeconomics? This brings me to econometrics and Hume's problem of induction.

3 Induction

Induction is about drawing generalizations from limited observations. Macroeconometrics is induction – using time series data to calibrate macroeconomic models to construct quantitative statements about historically unprecedented government policies. Hume warned us that induction has less secure logical foundations than does *deduction*.

> It may, therefore, be a subject worthy of curiosity, to enquire what is the nature of that evidence which assures us of any real existence and matter of fact, beyond the present testimony of our senses, or the records of our memory. This part of philosophy, it is observable, has been little cultivated, either by the ancients or moderns; and therefore our doubts and errors, in the prosecution of so important an enquiry, may be the more excusable; while we march through such difficult paths without any guide or direction. They may even prove useful, by exciting curiosity, and destroying that implicit faith and security, which is the bane of all reasoning and free enquiry. Hume (1748, Sec. 4, Part I)

Bayesian statistical analysis does not belie Hume's warning about the shaky logical foundations of induction. But Marimon (1996) pointed out that a Bayesian knows the truth from the start and that Bayesian 'learning' merely means conditioning on more information while using a *known* joint density. Thus, the Bayesian formalism sidesteps the logical problem of induction by assuming that the problem of constructing a joint density (i.e., a *model*) has been solved.

4 Modeling and controlling money and the price level

I will use longstanding issues about monetary policy to illustrate macroeconomic problems of induction and policy design. I will focus my discussion on some ideas of David Ricardo.

> The introduction of the precious metals for the purposes of money may with truth be considered as one of the most important steps towards the improvement of commerce, and the arts of civilised life; but it is no less true that, with the

> advancement of knowledge and science, we discover that it would be another improvement to banish them again from the employment to which, during a less enlightened period, they had been so advantageously applied. David Ricardo, 1816.

I will speak about some ideas and experiences that shaped Ricardo's proposal and others that emerged from the struggles of academic economists and policy makers to implement and refine what they had learned from Ricardo. I focus on two important sources of prevailing ideas in macroeconomics. One is a collection of powerful theoretical results and empirical methods that apply the rational expectations equilibrium concept to estimate models and design optimal macroeconomic policies intelligently. The other is an adaptive evolutionary process involving ideas and events that influenced Ricardo, and that are illustrated in the struggles of the U.S. monetary authorities in the 1970s and 1980s to realize the promise for improvement held out by Ricardo.

The rational expectations equilibrium concept equates all subjective distributions with an objective distribution. It is useful to distinguish the step of equating subjective distributions from the step of equating subjective distributions to the objective distribution that actually governs outcomes. By equating subjective distributions for endogenous variables to an equilibrium distribution implied by a model, the rational expectations hypothesis makes agents' beliefs disappear as extra components of a theory and sets up the powerful theoretical results and intelligent policy design exercises that I will summarize. I will then describe theoretical and practical reasons for equating subjective distributions to an objective one and how that facilitates rational expectations econometrics.

The assumption that agents share common beliefs underpins influential doctrines about whether inflation-unemployment dynamics can be exploited by policy makers, the time inconsistency of benevolent government policy, the capacity of reputation to substitute for commitment, the incentives for one type of policy maker to emulate another, and the wisdom of making information public. The common beliefs assumption is especially stressed in modern theories of optimal macroeconomic policy that focus on how a benevolent government optimally shapes expectations. This intelligent design approach to macroeconomic policy perfects an older econometric policy evaluation method that Lucas (1976) criticized because it imputed different beliefs to the government and other agents.

Intelligent design is normative ('what should be') economics, but when it influences policy makers, it becomes positive ('what is') economics. Some researchers in the intelligent design tradition ignore the distinction between positive and normative economics. Thus, Lucas and Stokey (1983) used a normative theory to understand observed time series properties of government debt and taxes. It is also true that some policy advisors have enough faith that evolution produces good outcomes to recommend copying best practices (for example, consider the advice that Keynes gave when he went to India in 1913 and when he helped create the IMF). If only good things survive the tests of time and practice, evolution produces intelligent design.

Theories of out-of-equilibrium learning tell us not always to expect that. A distressing observational equivalence possibility emerges from rational expectations econometrics. It illustrates Hume's induction problem and sets the stage for possible outcomes from an evolutionary system in which adaptive agents are making decisions while they are also learning by updating statistical models each period. A system of such adaptive agents converges to a *self-confirming equi-*

librium in which all agents have correct forecasting distributions for events that occur often along an equilibrium path. But they have possibly mistaken views about events and government policy actions that are rarely observed.[2] This matters because intelligent design of rational expectations equilibria hinges on knowing and manipulating expectations about events that will not be observed. Self-confirming equilibria allow incorrect models that match historical data to survive. That implies inferior policies. I mention examples from a millennium of monetary history that culminated in the ideas contained in the quote from Ricardo. To tell stories about the emergence of U.S. inflation in the 1970s and its conquest under Volcker and Greenspan, I use adaptive models in which the government solves intelligent design problems using probability models that are misspecified, either permanently or temporarily. While these stories differ in many interesting details, they all say that choices of the monetary authorities were affected by misunderstandings that do not occur within a rational expectations equilibrium. These "misspecification stories" provide a backhanded defense for inflation targeting. Coming back to Ricardo, I shall describe a long process of theorizing and experimenting that transformed a European commodity money system with *many* nominal anchors into our present system that wants an anchor.

5 Rational expectations econometrics

Rational expectations econometrics is about how to estimate the parameter vector ρ from historical data. Recent developments remind us of the omnipresence of Hume's problem of induction.

[2]Thus, there is room for a 'law of unintended consequences' that was fondly cited by Friedman (1991) and that indicates a failure to solve Hume's problem of induction.

5.1 Using a misspecified model to estimate a better one

Lucas (1976) convinced us that non-structural models are bad vehicles for policy analysis. But the first-order conditions for estimating a good fitting non-structural model *can* help to make good inferences about parameters of a structural economic model.

5.2 A troublesome possibility

This ideal case raises the following question: what happens when macroeconomic policy makers incorrectly use what from nature's point of view is actually an auxiliary model? Data give the government no indication that it should abandon its model. Nevertheless, the government can make major policy design mistakes because its misunderstands the consequences of policies that it has not chosen.[3] The possibility that the government uses what, unbeknownst to it, is an auxiliary model, not a structural one, sets the stage for *self-confirming equilibria.*

6 Adaptive learning models and their limiting outcomes

This section describes transient and limiting outcomes in models in which agents make decisions by using statistical models that at least temporarily are misspecified. I summarize findings from a literature that studies systems of agents who use forward-looking decision algorithms based on temporary models that they update using recursive least squares algorithms (see Marcet and Sargent (1989), Evans and Honkapohja (1999, 2001), Woodford (1990), and Fudenberg and Levine (1998)). These adaptive systems can have limiting outcomes

[3]See Lucas (1976), Sargent (1999, ch. 7), and Fudenberg and Levine (2007).

in which objective and subjective distributions are identical over frequently observed events, but not over rarely observed events. That causes problems for intelligent macroeconomic policy design. I shall use such adaptive systems to tell some stories about the conduct of monetary policy under the guidance of misspecified models. I begin by defining population objects that suppose that agents have finished learning.

6.1 Self-confirming equilibrium

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A true data generating process and an approximating model, respectively, are

$$f(y^\infty, v^\infty|\rho) \ \text{ and } \ f(y^\infty, v^\infty|\theta). \tag{1}$$

A decision maker has preferences ordered by

$$\int U(y^\infty, v^\infty) f(y^\infty, v^\infty|\theta) d(y^\infty, v^\infty) \tag{2}$$

and chooses a history-dependent plan

$$v_t = h_t(x^t|\theta), \quad t \geq 0 \tag{3}$$

that maximizes (2). This gives rise to the sequence of decisions $v(h|\theta)^\infty$. The difference between this choice problem and the canonical intelligent design problem in macroeconomics is the presence of the approximating model $f(y^\infty, v^\infty|\theta)$ rather than the true model in (2). I call maximizing (2) a "Phelps problem" in honor of a policy design problem of Phelps (1967).

Definition 6.1. *A self-confirming equilibrium (SCE) is a parameter vector θ_o for the approximating model that satisfies the data-matching conditions*

$$f(y^\infty, v(h|\theta_o)^\infty|\theta_o) = f(y^\infty, v(h|\theta_o)^\infty|\rho). \tag{4}$$

An SCE builds in, first, optimization of (2) given beliefs indexed by θ_o, and, second, a $\theta = \theta_o$ that satisfies the data matching conditions (4). Data matching prevails for events that occur under the equilibrium policy $v(h|\theta_o)^\infty$, but it is possible that

$$f(y^\infty, v^\infty|\theta_o) \neq f(y^\infty, v^\infty|\rho) \tag{5}$$

for $v^\infty \neq v(h|\theta_o)^\infty$. In an SCE, the approximating model is observationally equivalent with the true model for events that occur under the SCE government policy, but not necessarily under alternative government policies. The approximating model fails correctly to solve the induction problem identified by Hume, namely, it fails to draw correct generalizations from a limited set of observations.

6.2 Learning converges to an SCE

An SCE is the only possible limit point of an adaptive learning process. Bray and Kreps (1987) distinguish between learning *about* an equilibrium and learning *within* an equilibrium. By saying *about* and not *within*, Bray and Kreps emphasize that the challenge is to analyze how a system of agents can come to learn an endogenous objective distribution by using adaptive algorithms that do not simply apply Bayes' law to a correct probability model. We cannot appeal to the same econometrics that lets a rational expectations econometrician learn an equilibrium because an econometrician is *outside* the model and his learning is a side-show that does not affect the data generating mechanism. It is different when people learning about an equilibrium are inside the model. Their learning affects decisions and alters the distribution of endogenous variables over time, making them aim at moving targets.

Suppose that an adaptive learner begins with an initial estimate

$\hat{\theta}_0$ at time 0 and uses a recursive least squares learning algorithm

$$\hat{\theta}_{t+1} - \hat{\theta}_t = e_\theta(\hat{\theta}_t, y^t, v^t, t). \tag{6}$$

As in the models of learning in games of Foster and Young (2003) and Young (2004, ch. 8), we assume that decision makers mistakenly regard their time t model indexed by $\hat{\theta}_t$ as permanent and form the sequence of decisions

$$\hat{v}(h)_t = h_t(x^t|\hat{\theta}_t) \tag{7}$$

where $h_t(x^t|\theta)$ is the same function (3) that solves the original Phelps problem (2) under the model $f(y^\infty, v^\infty|\theta)$. The joint density of $(y^\infty, v^\infty, \hat{\theta}^\infty)$ becomes

$$f(y^\infty, \hat{v}(h)^\infty, \hat{\theta}^\infty|\rho). \tag{8}$$

The learning literature states restrictions on the estimator e and the densities $f(\cdot|\theta)$ and $f(\cdot|\rho)$ that imply that

$$\hat{\theta}_t \to \theta_o, \tag{9}$$

where convergence can be either almost surely or in distribution, depending on details of the estimator e in (6).

6.3 SCE-REE gaps and the incomplete solution of Hume's induction problem

When $f(y^\infty, v^\infty|\rho) \neq f(y^\infty, v^\infty|\theta_o)$ for some choices of v, the most that can be hoped for is convergence to an SCE. A gap between a rational expectations equilibrium and a self-confirming equilibrium indicates that false generalizations will be drawn from the limited observations used to estimate a model, so that Hume's induction problem has not been solved. That is important for the design of macroeconomic policy.

Macroeconomists build models with many small agents and some large agents called governments. It doesn't matter to a small agent that his views may be incorrect views off an equilibrium path. But it can matter very much when a large agent like a government has incorrect views off an equilibrium path because in solving a Ramsey problem, a government contemplates the consequences of off-equilibrium path experiments. Wrong views about off-equilibrium path events shape government policy and the equilibrium path.

I illustrate these ideas in two ways. First, I sample some historical events that central bankers have learned from. I summarize hundreds of years of monetary theories and experiments that took us to the threshold of the 20th century experiment with fiat currency. Then I jump ahead to the 1960s and 1970s and discuss some statistical models that describe how the U.S. monetary authorities struggled to understand inflation-unemployment dynamics as they sought to meet their dual mandate of promoting high output growth and low inflation.

7 From commodity to token to fiat money

Monetary authorities are preoccupied with nominal anchors. Monetary authorities used to play it safe and to use redundant monetary anchors. About the time that Ricardo wrote, we had acquired the confidence to eliminate that redundancy. Then we eliminated all anchors. We have struggled to find one.

Redish (1990, 2000) and Sargent and Velde (2002) have described a 700 year process of theorizing and experimenting that transformed a European commodity money system with *many* nominal anchors – mint-melt price pairs (i.e., gold or silver points) for full bodied coins of all denominations – to a *one* nominal anchor system that retained gold points for only one standard full bodied coin and used government-issued convertible token coins and notes for other denominations. After another 100 years, governments abolished the gold points for the standard coin too, leaving the nominal anchor to be the monetary authorities' knowledge of the quantity theory of money and their good intentions. Commodity money concealed the quantity theory of money by making the price level be a low variance exogenous variable and the money supply be a low variance endogenous variable. I see a self-confirming equilibrium working here. Eventually, some atypical policy experiments generated data with sufficient variance in price levels and money supplies to reveal the quantity theory to empiricists like Sir William Petty. The quantity theory led to Ricardo's proposal and ultimately induced monetary experts like Keynes to advocate a well-managed fiat system.

8 A warning

Fisher (1926, p.131) warned that "Irredeemable paper money has almost invariably proved a curse to the country employing it", presumably because two obstacles obstruct the path to managing a fiat currency well: (i) political pressures to use fiat money to finance government expenditures, and (ii) temptations to exploit a Phillips curve. Learning models have been used to interpret monetary authorities' struggles to understand and avoid these obstacles. Marcet and Nicolini (2003) and Sargent et al. (2006) constructed adaptive models that focus on Friedman's obstacle (i) and feature private agents' learning. The models in those papers both select among rational equilibria and modify their outcomes enough to fit data from big inflations in Latin America. In the remainder of this paper, I focus on statistical models that feature monetary authorities' struggles with obstacle (ii).

9 Three stories

Sargent (2008) used adaptive models to tell three stories about how the U.S. monetary authorities learned about inflation-unemployment dynamics after World War II. These stories all assume that a monetary authority can control inflation if it wants. If that is true, then why did the U.S. monetary authority allow inflation to rise in the late 1960s and 1970s, and why did it bring inflation down in the 1980s and 1990s? If we assume that its purposes did not change, and that it always disliked inflation and unemployment, then it is natural to focus on changes over time in the monetary authority's understanding of inflation-unemployment dynamics. I shall describe three stories associated with empirical models that feature learning and either temporary or permanent discrepancies between a government's model and a true data generating mechanism.

To get these stories off the ground, it is necessary to impute motives and models to the monetary authority. It is natural to impute popular contemporary models to the government. The 'revisionist history' of the U.S. Phillips curve by King and Watson (1994) provides a good source for these. King and Watson studied how econometric directions of fit (i.e., should you regress inflation on unemployment or unemployment on inflation?) affect government decisions. Hume's induction problem is at the heart of the King and Watson paper. To make contact with studies from the 1970s, King and Watson call inflation on unemployment the Keynesian direction of fit and unemployment on inflation the classical direction.[4] I im-

[4]Sargent (1999, ch. 7) described how those specification decisions can affect self-confirming equilibrium outcomes.

pute simplified versions of more completely articulated models to the government. These simple models capture the substantially different operating characteristics that drive our stories.

The three stories are about monetary authorities that solve adaptive intelligent design problems that induce them to make decisions that are influenced by their erroneous views about the consequences of actions not taken. The stories differ in the nature of those misunderstandings.

In the first story, the monetary authority's misspecified model misses a chain of causation linking its decisions first to the private sector's expectations of inflation and then to the position of an unemployment-inflation trade-off.

In the second story, there exists a parameter vector $\theta_o = \rho$ that aligns the monetary authority's model with the data generating mechanism on *and* off the chosen stochastic monetary policy path, but except in the limit as $t \to \infty$, the government's temporary misestimates $\hat{\theta}_t$ of θ_o induce it to misunderstand the consequences of policies that it chooses not to implement. These misestimates translate into its underestimating the natural rate of unemployment or the persistence of inflation or the inverse of a "sacrifice ratio."

In the third story, the government mixes across submodels with operating characteristics that give very different readings about the consequences of following a no-feedback low inflation policy.

10 Inflation targeting

Inflation-unemployment outcomes after WWII have caused many countries to adjust what they expect from monetary policy by mandating inflation targeting. That partly reflects extensive cross-country copying and partly a widespread belief that monetary authorities don't have good enough models to do more. When we asked for more, we usually got less.

11 Conclusions

The above passages from Hume and Ricardo identify enduring conceptual and practical problems that continue to preoccupy macroeconomists. The difference between the secure logical foundations of *deduction* and the shaky foundations for induction pointed out by Hume underlies a contrast between the current situations in macroeconomic theory and quantitative methods. Within macroeconomic *theory*, there is little controversy about the value of using backward induction as the keystone of a theory of individual behavior that by construction gives us coherent models that are immune from the criticisms of earlier macro models made by Lucas (1976). For *quantitative* work in macroeconomics, there is much less agreement, and much less comfort, with the diverse calibration, estimation, model selection, and model averaging procedures that we use to grapple with Hume's problem of induction.

By stressing the possibility that learning has propelled us to a self-confirming equilibrium in which the government chooses an optimal policy based on a wrong model, the learning literature puts Hume's problem of induction front and center and challenges us about how we should think about generating the novel data sets and policies that will allow misguided governments to break out of the lack-of-experimentation traps to which self-confirming equilibria confine them.

David Ricardo arrived at his proposal to banish physical commodities from their centuries long monetary roles by paying close attention to historical data and then extending some theoretical insights of his predecessors. But it is wise to remember the observation of Friedman (1991, pp. 249-252) that our fiat money system is historically unprecedented and also the warning of Fisher (1926, p.131) that "Irredeemable paper money has almost invariably proved a curse to the country employing it." Nevertheless, it is easy to admire Ricardo's respect for the struggles of his predecessors and the monetary institutions that they had created, and his confidence that, armed with new models and technologies, at least in so far as money and the price level were concerned, he had solved Hume's induction problem.

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