"Information Frictions in Macroeconomics: The Legacy of Robert E. Lucas, Jr."

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I am very thankful to have been asked to honor Bob Lucas by writing this essay on Lucas' contributions and my thoughts on the most important areas of current macro problems where informational frictions are relevant today.

I shall do this in two steps. The first step fucuses on two of Lucas' papers where information frictions play somewhat different roles, zeroing in on the key elements in each of those two papers. Each is linked to associated branches of the literature. The second step argues that new technologies have now emerged which make those key elements all the more crucial in macro economies today. Monetary policy considerations were forefront in Lucas' mind, and so that is a recurrent theme throughout this essay.

1 Expectations and the Neutrality of Money: Information Frictions in Walrasian Economies

In what follows I describe first Lucas' 1972 paper on expectations and the neutrality of money, its policy and empirical motivation, its general equilibrium aspects and key ingredients, how the model works, its welfare properties, and the connection to forecasting the forecasts of others.

1.1 The policy and empirical motivation

Lucas' motivation for this paper comes from a policy question, taking the position of Milton Friedman over John Maynard Keynes. Specifically, Friedman rejected Keynes' perpetual policy to stimulate demand. In Friedman's view, money is neutral in the long run, and though fluctuations in money matter, the latter are detrimental. To quote Gurley's (1961) characterization of Friedman, "Money is a veil, but when the veil flutters, real output sputters." Lucas' objective is to formalize this statement with a model.

Relatedly, Lucas' motivation has an empirical component which seeks to explain the Philips curve: Higher inflation is associated with lower unemployment and vice versa. Lucas shows that the data generated from his model does yield a Philips curve.

1.2 General equilibrium model and key ingredients

Lucas is featuring a general equilibrium model as the foundation for modern macro. It is written in the language of primitives: preferences, endowments, and technology. At the time it was written, this was a revolution. Lucas was much aware of this, and stated that one of his intended contributions was to break new methodological ground. More generally, Lucas was a champion of innovation, including contributions to math for improved economic understanding.

Within the general equilibrium framework of Lucas (1972) three key ingredients are featured: money, islands, and limited information. Not only was each important to the paper, each has remained important in subsequent macro literature and provides a useful way to look at contemporary developments. The three ingredients are featured throughout this essay.

1.2.1 Money

Money is endogenously determined in the model via an overlapping generations framework (Samuelson 1958). When young, workers provide labor for money. When old they use the money to buy produced goods. It is crucial for Lucas that money be an explicit object in the model and that prices of goods be in nominal terms, that is, money for goods and not some real economy equivalent. Lucas comes back to this overlapping generations framework in subsequent work, for example in his paper featured in Section 2, so it likely means more to him than just an arbitrary construct or trick to get an intrinsically useless object to have value.[1] Of course there are other models of money with frictions.[2]

1.2.2 Islands

Islands are a metaphor for market fragmentation as a real obstacle to trade. That is, traders are not all in one common market all the time but are assigned to markets initially and can switch locations over time. Another way to put this: If islands could be merged, that would generate Pareto superior allocations. This primitive is a fundamental obstacle.

1.2.3 Imperfect information

Imperfect information is the third key ingredient, limited information about the actual common underlying state of the overall economy. Agents know only their own individual state variables and prices. This is a natural outcome with islands if there is no cross-island communication, but a

[1] Lucas refers to money emerging as an intermediation device when direct trade is not possible, as in Cass and Yaari (1966). Money is very much explicit in Lucas (1980), with a model for selling and buying goods which generates a Clower constraint, also used in Lucas and Stokey (1987) to discuss cash vs. credit goods. Lucas (1980) argues that economists need to explore models where money is explicit as an inferior, second-rate asset, unlike Samuelson (1958), that is, when money helps to achieve, but acting alone cannot achieve, a Pareto optimal allocation. Townsend (1987a) used Lucas' (1980) model to explain asset return anomalies in a monetary economy. Lucas (1982) is a model of interest rates and currency prices in a two-country world, but in that model monies become inessential, as there are no further obstacles; nominal prices simply reset as in Lucas (1972) when monetary aggregates are known. Lucas did not insist on monetary models, as in his widely cited work on dynamic asset prices, Lucas (1978).

[2] For example, there are spatial frictions such as trading posts or islands as in Townsend (1980), Manuelli and Sargent (2010) including the coexistence of money and private debt, and an analogue incomplete market models of Woodford (1990) on public debt as private liquidity; search frictions as in Kiyotaki and Wright (1989), Lagos and Wright (2005), Lagos and Zhang (2020); and contributions in which search frictions collapse to spatial island frictions as in Amendola et al (2021).

model can have islands within which resource constraints need to be satisfied, one island at a time, without having imperfect information.

1.3 The mechanisms of the model

The aggregate shock is the random contemporary component in the expansion of the money supply for the old agents holding it, in advance of purchases, a shock to the supply of money. The demand shock is the random allocation of young traders, who supply labor (equivalently a produced commodity) in return for the money, allocated in some proportion to the two islands. This set up induces fluctuations in relative price of the consumption good for money in each island. The amount of money actually supplied in each island is made equal by reallocating the old, so island supply of money is not the driver of the results. Rather the driver is limited information on the economy-wide state, the supply of money from the monetary shock and the allocation of the young to islands, hence in each island, the demand for money from the number of young traders. Island prices as a ratio convey that information imperfectly, and the resulting hedging behavior of agents, unsure what is real and what is nominal, generates the non-neutrality of money. The money price of goods varies across islands, but in Lucas's model agents do not see what is going on in the other island.

1.4 Welfare properties of the model

As a counter factual experiment within the model, a k-percent non-stochastic rule on money growth is imposed, *a la* Friedman, and this generates a Pareto optimal allocation in the space of stationary allocations. Equivalently, valued money achieves an efficient allocation in the Samuelson overlapping generations model with money playing the role of a cross-generation intermediation device. Future generations are equally weighted in this stationary state. In the k-percent counterfactual, the growth of the money stock is entirely forecastable, and so nominal prices reset with the new amount of money in a completely neutral and predictable fashion. There is no information confusion.

1.5 Forecasting the forecasts of others

Lucas assumed the monetary aggregate becomes known with a one period lag. In other words, the pre transfer amount of money in the model is common knowledge. Lucas states that this artificial assumption was for simplicity. If we were to suppose otherwise, that this history in the model were not known, then higher order beliefs would enter the story, but again, Lucas does not go down this path. Though agents live only two dates, we could imagine that the entire history of island specific prices is posted on each island. The value of money for the young acquiring money would still depend on their current understanding of the monetary aggregate, and so the current young would use past prices on the island as part of their information set. But a particular past price, say of the preceding generation, would depend on the expectations of the monetary aggregate of the young at that time, which in turn would depend on how the then-young were forming those expectations, based on the history of posted prices at that time, and hence would depend in turn on what the young generation yet one period earlier were thinking, and so on without end.

Questions about what kind of dynamics would emerge in such contexts without history ever becoming known, motivated my own contribution, Townsend (1983). It focused on the role of beliefs about beliefs and so on without end, an infinite regress problem. Chahrour and Jurado

(Forth.), in this conference volume, review the history of this literature. A key clarifying part of the Chahrour and Jurado paper is the importance of whether or not the set of prices which are seen are enough to reveal the aggregate state of the entire economy. An aggregate price index contaminated by noise, e.g., in the case of the Lucas (1972) model seeing only island-specific prices influenced by demand shocks, or what I did in the context of Lucas and Prescott (1971), lead to the infinite dimensional problem. A take-away from this literature is that equilibrium dynamics come from two factors: From rational but heterogenous beliefs and from whether or not the underlying economy-wide state at a point in time becomes known. If the state at some point in the past becomes known, then there is learning over a finite number of periods. If not, then there are dynamics and math problems that are inherent with the infinity. No finite state space representation is equivalent.

Lucas (1972) takes as given that expectations should be rational. In this he followed the micro work of Muth (l961), who was an undergraduate, graduate student, and then assistant professor at CMU. Muth proposed that individuals make decisions based on the best available information and learn from past mistakes, using information to form their expectations about the future. Muth fully rationalized Friedman's adaptive expectations view of the permanent income hypothesis. At the same time, Herb Simon at CMU was also developing his theory of bounded rationality (Simon 1955). One can imagine that rational expectations vs. bounded rationality must have been debated among these and other authors, in a crucible of sorts in their study production scheduling and inventory management within a Pittsburg paint factory (with other notable co-authors, Holt, Modigliani, Muth and Simon 1960). Lucas took rational expectations into macro with Sargent as in Lucas and Sargent (1979) on Keynesian revolution as did Sargent and Wallace (1973, 1975, 1976). This split in presumptions makes its way into micro axioms for consumer choice and into macro, continuing to the present day.[3]

It would be useful to understand dynamics induced by non-rational expectations as distinct from the dynamics induced by rational yet heterogenous expectations, and further from the dynamics of the infinite regress component. The latter two together do feature disagreements and endless second guessing. Few if any papers do this comparison. Angeletos and La'O (2013) is a model with sentiments and animal spirts, which might seem to be behavioral, but actually features a unique equilibrium rational expectations model. Naturally, it uses Lucas' islands which are heterogeneous in information, and trade opportunities. There is however no learning from endogenous variables. Still, when real business cycles are introduced in additional sections of the Angeletos and La'O (2013) paper, to allow a comparison of TFP shocks with their baseline sentiment shocks, a strong version of rational heterogenous expectations is lost. They impose, though reluctantly, an exogenous heterogenous prior, due to computational issues. To be noted, Chahrour and Jurado (Forth.) offer new solution techniques in the frequency domain that help to make rational heterogenous infinite regress expectations models tractable (as noted in the conference, a solution technique which may yield in turn a good approximation to finite state

[3] Woodford (2013) offers a literature review, echoed in his remarks in the evening panel for this conference. Behavioral expectations are sometimes referred to as diagnostic expectations, as L'Huillier et al (2024) and his literature review. Caballero and Simsek (2022) study opinionated markets. See also in this conference Rebelo et al (Forth.) and Adam et al (Forth.)

representations when the history is finite but long, hence with many states.) This would facilitate a variety of comparisons across the two strands of the literature.

1.6 Macro literature building on the Walrasian framework

More generally, Lucas (1972) with islands, money, and information frictions heralds a branch of macro literature building on the Walrasian framework. To set the stage we can compare and contrast Hayek (1976) and Friedman (1959) on money. Hayek claimed competitive markets solve the information problem through the price system and that government control of money is problematc. Though Friedman's promotion of price theory is renown, his view of money was that a centralized enforced rule was needed. Related, and put in modern language, the first fundamental welfare theorem states that under seemingly weak assumption, competitive equilibrium allocations are Pareto optimal, a formalization of Hayek's decentralization. However, with an infinity of agents as in the overlapping generations model, the first theorem fails in the absence of fiat money.

Hellwig and Venkateswaran (Forth.) in this conference volume contribute to this issue. They show under one set of assumptions in the context of a model close to the new Keynesian benchmark, with monopolistic competition, that without sticky prices allocations are the same in quite different looking economies. One is a full information economy in which the current values and the histories of idiosyncratic and aggregate shocks are known to everyone, and the second is a dispersed information economy in which firms observe only histories of signals generated by their market activities, their price (using a supply function approach), their sales, and market wages. The result is akin to the first welfare theorem. However, under another set of assumptions, with sticky nominal prices and otherwise the same as their baseline New Keynesian model, this equivalence is lost.[4]

Other macro literature in the context of the Walrasian framework is much less recent but has a direct bearing on fundamental macro issues.

1.6.1 The impossibility of efficient decentralized exchange, the limits of money, and a solution

Ostroy and Starr (1974) begin with society's goal as being the achievement of a Pareto optimal Walrasian equilibrium but introduce the islands friction. There is a sequence of pairwise matches of agents, as if on islands, though exchange takes place at the predetermined Walras equilibrium price of the target (and thus distorted prices are not the issue). Agent actions/trades are pre-coded to try to achieve the target allocation. An information structure can be decentralized if any two agents meeting pairwise know their initial excess demands and supplies, their currently unsatisfied demands and supplies relative to the target, and even the name of the trading partner. Under a further but still decentralizated information structure, the pair of matched agents can know their entire histories, that is, pairwise. Ostroy and Starr show the goal cannot be achieved

[4] Farhi and Werning (2007) begin with the sticky prices. Nominal rigidities are shown to generate demand externalities which can be corrected with specified policies, using sparce sufficient statistics. This they contrast with a literature without nominal rigidities but with pecuniary externalities generated from incomplete markets or collateral constraints. The latter is a large literature with macro policy implications. Kilenthong and Townsend (2021) show that pecuniary externalities can be removed with rights to trade in price islands, rights exchanged and valued in advance without the typically-considered policies. The irony within the context of this essay is that price islands in Kilenthong and Townsend (2021) are being used to resolve a problem, not cause one.

universally even in the most informative of these decentralized worlds, with pairwise histories. The proof is by contradiction. In a key counterexample, agents would need to know the histories of yet others with whom neither they nor their trading partners have been paired. This overturns Hayek's conclusion. Information needs to be centralized.

Otherwise, is money enough? A solution to the information problem cannot come in general from a consensus on the use of a money. Ostroy and Starr show that the use of a money for trade falls into the most informationally-decentralized regime. The use of money for trade requires only knowledge of the contemporary position and of the current trading partners, not even the named identity of that partner. But a designated money as an intermediary device is typically insufficient. The environment would have to be such that agents are endowed with enough of that money that they could finance all expenditures in the target before getting revenue from sales. That is a lot of liquidity. In contrast, liquidity saving is the goal of an important macro literature on real time gross settlement (RTGS) -- settlement systems for commercial banks run by central banks. There the goal of specific algorithms is to attempt to conserve on liquidity that is posted in advance for clearing (Martin and McAndrews 2008).

Ostroy and Starr (1974) also evaluates other legacy institutions, specifically credit in the form of overdraft loans, and the use of broker-dealers as points of trade. Each is shown to come with flaws and unable to solve the information problem generally, doing so only under special assumptions about the underlying environment, preferences and endowments. Overdraft and broker-dealer arrangements also suffer from practical limitations, default for the former (which Ostroy-Starr did not model) and market power for the latter (especially if there is only one dealer as with the Ostroy-Starr assumption but market power was not modeled). Yet with centralized information in Ostroy-Starr, knowing the histories of everyone in the economy, the efficient Walrasian target can always be achieved, without these legacy institutions. As a teaser for the discussion below, a common ledger recording trades, constantly updated, and distributed across the agents, provides the requisite information. This is an instance of distributed ledger technology (DLT). The fragmentation that trade must be done within the pairings on an island is respected, but the information used to guide trade is centralized.

1.6.2 A coordination problem with privately-issued monies and a solution

Related to Ostroy-Starr (1974) is Townsend and Wallace (1987). It considers a dynamic setting with agents explicitly maximizing intertemporal utility when there is a pairwise meeting, with goods indexed by time and location. Again, the locations are islands where the agent pairings take place. To achieve the Pareto optimal location and date contingent allocation associated with an Arrow-Debreu complete markets Walrasian equilibrium, agents issue debt as promises to pay at future dates in named islands (no reneging allowed, default is not the problem here). Typically, some of these assets circulate at high velocity, as media of exchange, to buy consumption or other securities. The monies of the model are these circulating private debts.

The problem is that there are multiple such equilibria, with the same real allocations but financial allocations varying with the debt issued across the initially assigned islands. If there is a lack of information on what securities are issued in other islands, then a financial crisis can emerge. That is, if expectations of what is issued in the other island are wrong, due to a mismatch of expectations across islands, then the price of circulating debt will drop precipitously once the truth is out. See Spector and Townsend (2018). Interestingly, the crisis is long lasting in the sense that agents naturally try to mitigate their own problems by adjusting other asset positions.

Arguably we have observed such crashes in history, as with the London money markets in bills of exchange, private IOUs which served as the dominate payment device in England and internationally. Bagehot (1892) discusses this in his book, *Lombard Street*, with a prescription that the Bank of England should underwrite the risk of bills which have lost value. That rationale for central bank intervention is widely accepted today, but is not without its controversies, as it exposes a central bank balance sheet to risk and creates moral hazard.[5]

As for the coordination problem identified in the Townsend and Wallace (1987) model, if agents could commit to security issuance rules across islands, then these coordination problems and crashes disappear. No need to mix that problem with monetary policy. As a teaser for the discussion below, smart contracts running on a distributed ledger allow the requisite coordination. This is quite relevant for consideration of digital assets and ongoing macro policy debates and decisions.

1.6.3 A coordination problem in the context of incomplete markets in general equilibrium, with needed solutions

Makowski (1982) considers a Walrasian economy in which markets are initially and exogenously incomplete. Traded commodities are produced by firms with their standard production sets, but there are "personalized" commodities that only a given firm, or type of firm, can produce, as part of technology as well. In a full Walrasian equilibrium, by definition, no firm has an incentive to create other goods on its own. In this context, inefficiencies, that is, failure of market forces to endogenously complete markets, can be caused by complementarities across firms in intermediate goods, to give one salient example. Remedies require more active public policy, allowing a public entity to help make markets.

Pesendorfer (1995) features financial intermediaries in the context of time and uncertainty, hence assets with state-contingent security returns. Only a subset of securities is tradable in baseline markets, and these securities returns do not span the state space. Hence markets are incomplete. Financial intermediaries can market/sell new securities to households as bundles based on

[5] There is a related literature on real bills vs. quantity theory. The real-bills prescription is for unfettered private intermediation, as in Sargent and Wallace (1982). The quantity theory prescription as per Friedman is for restrictions on private intermediation to maintain a stable monetary aggregate, as in Laidler (1984), and, again, the motivation of Lucas (1972). Indeed, Lucas and Nicolini (2015) note that the liquidity crisis that followed the Lehman failure in 2008 and the massive Federal Reserve response increasing the level of bank reserves which followed, was something about which leading macro-econometric models of the time, and the Fed's own model, had little to contribute. As they wrote, the Fed used only short-term interest rates as an indicator of the stance of monetary policy, joined by influential monetary economists who became skeptical of the usefulness of any measure of liquidity. Yet Lucas and Nicolini (2015) reestablish a stable relationship of monetary aggregates to interest rates by taking into account that currency and deposits at banks are different means of payment.

Ironically, the acknowledgement that heterogeneity in transactions technologies can yield heterogeneous monies seems to go against central banks' "singleness of money" dictum, the origins of which are difficult to track down but which seems to have emerged among regulators who believed multiple money systems suffered from a problem (Bidder et al 2025). Reference to a needed "singleness of money" is used currently in reactions against stable coins. For example, see Garratt and Shin (2023).

baseline securities and securities acquired from other intermediaries. Yet there is a cost of issuance. Though innovation in new securities is featured, in a Walrasian equilibrium with infinitely small price taking agents (thus with no strategic considerations), the set of complete security markets is not created. Rather, there is a coordination problem, a solution to which requires joint innovations and hence information on what others are contemplating.

As a corollary, if markets remain incomplete, then outside money can emerge in equilibrium with positive endogenous value, but that is not by itself a remedy to the coordination problem.

Again, as a teaser, new technologies can help solve supply chain and incomplete market issues.

2 Efficiency and Distribution: Obstacles to Trade

We turn now to the second of Lucas' papers, where information frictions play a somewhat different role, and showcase its link to associated branches of the macro literature.

Lucas was concerned with efficiency and distribution. He addressed this as a question about the Pareto optimality of allocations in general equilibrium models. This is explored in two paired papers: the Harry Johnson lecture (Lucas 1992), and Atkeson and Lucas (1992).

As background, if there is uncertainty about as yet unrealized states of the world, and assuming no further obstacles to trade, then a natural goal for society would be to try to achieve a full risk sharing allocation, that is, an ex ante Pareto optimum (for example, see Wilson 1968 and Diamond 1967). When Lucas was writing in 1992, the question of full risk sharing had been explored empirically, as Lucas notes, in Mace (1991), Cochrane (1991), and Townsend (1994). Lucas again has his eyes on data and empirical work. By now, risk sharing has been explored by many others. With the addition of underlying obstacles to trade, e.g., private unobserved states, moral hazard, and other information frictions, and also limited commitment, we enter another branch of macroeconomic literature utilizing mechanism design and contracts. At the same time, Lucas juxtaposed this literature with assumptions typically made about markets, linking in that way again to Walrasian notions.

2.1 The environment of the model and implementations

The underlying economic environment of Lucas (1992) and Atkeson and Lucas (1992) has idiosyncratic risk as unobserved preference shocks in an economy with a continuum of households. Lucas layers on top of this underlying environment five ways of making predictions: autarky; Bewley (1986) money as cash in advance; pure credit in goods and no money; the full information risk-sharing benchmark; and finally the solution to mechanism design problem with induced truth telling about the privately observed idiosyncratic shocks. There are no aggregate shocks in the model (though we shall tie this literature to macro aggregate dynamics below). Instead, Lucas features how different are these five ways of making predictions. The Bewley solution with fiat money is quite distinct from a permanent income pure credit economy. Likewise, the full information solution displays complete equality in consumption in perpetuity, while the mechanism design solution features inequality and, under some additional assumptions, increasing immiseration, with most of the population approaching a lower bound on utility and a diminishing few gaining.

2.2 Limited commitment and competitive markets

Lucas' view was that the mechanism design solution would not be obtainable in markets. He had in mind, evidently, that trade cannot be so constrained. Indeed, Atkeson and Lucas (1992) have a section on decentralization of the mechanism design problem into component planning problems, one for each level of utility entitlement, which they then critique. That section rested, in their view, on the capability of the model's intermediaries to monitor individual wealth positions, and in their critique, counter to the capabilities of actual financial institutions. They then show that the efficient allocation cannot be supported by private intermediation if households are permitted to engage in unmonitored trading of ordinary securities. They cite Allan's (1985) repeated principal-agent relationships, in which the insurance allocation is reduced to pure credit, as bearing a similar conclusion.

Phelan (2006) shows that the ability to walk away from a contract, limited commitment, does change the dynamic considerably. In particular, with limited commitment made explicit as a constraint in a model with unobserved endowments, one gets a non-degenerate steady state. However, this can be sustained in a non-trivial market for insurance contracts. Prescott and Townsend (1984a, 1984b) show quite generally that solutions to the planner's problem can be achieved exactly in a decentralized competitive equilibrium in the market for ex ante contracts with broker dealers as financial intermediaries. This does require commitment, for example ruling out spot markets. But, as a teaser for the discussion below, we now have the technologies in smart contracts to commit to, perfectly monitor, and enforce dynamic implementations as part of overall market designs that join together ex ante contracts with some ex post trade possibilities. An example was given earlier, Kilenthong and Townsend (2021), when within-islands trade cannot be limited but rights to trade in islands are sold ex ante.

2.3 History dependence and tractability

We return to the role of history that came up in the first section of this essay, though here in the context of mechanism design. In Atkeson and Lucas (1992), the principal--or planner--chooses the incentive compatible allocation for all agents subject to a constraint that the total consumption handed out each period to the population of agents cannot exceed some constant endowment level. A pre-existing literature – Spear and Srivastava (1987), Green (1987), Taub (1990), Phelan and Townsend (1991), Marcet and Marimon (1992), Abreu, Pearce Stacchetti (1990) – used promised utility as a key state variable. Though citing these, the Atkeson-Lucas critique at the time was that most of these papers are "partial equilibrium" in that the planner can deal with each agent separately by borrowing and lending at some outside interest rate. Still, a subsequent literature has made the promised utility method applicable to increasingly complex environments. See Krueger and Perri (2006) and Kocherlakota (1998) for a closed two agent economy with an aggregate state variable determining who has what, and Krueger and Perri (2011) for a model with a continuum of agents. Kehoe and Perri (2007) use the methods of Marcet and Marimon (1992) in their study of international business cycles.

To be more specific, a promised utility is assigned to an agent for the next period as a current control variable of a principal, naturally as utility consequences are what provide incentives, and likewise promised utility of the agent in the current period is the current state variable, a sufficient statistic for past history. Despite an infinite horizon, the revelation principal still applies, though in the proof one has to do more than work backwards from a terminal date. Taking a limit, initial conditions matter less and less; the model in effect allows for infinite histories. In the more complex environments, the planner keeps track of the distribution of promised utilities in the population. In many environments that distribution of promised utilities is stationary and non-degenerate.

However, when underlying individual states are not only unobserved but follow a Markov process, then one needs utility threats as additional state and control variables (Fernandes and Phelan 2000). First-order Markov schemes are tractable, and as Doepke and Townsend (2006) show, non-trivial solutions can be sustained in situations with little shared information, showing Allan's (1985) earlier result, specifically those in Cole and Kocherlota (2001) generating bonds only in a decentralized implementation, to be a knife edge result. Still, dimensions can explode with multiple unobserved states and decision variables, necessitating equivalent computational formulations. On the positive side, algorithms are also advancing, with linear programs can compute with hundreds of thousands of variables and thousands of constraints.

2.4 An empirical literature providing micro foundation for macro models

Empirical applications can use computational methods with maximum likelihood to determine which obstacles to trade, or combinations of obstacles, best characterize actual data. Karaivanov and Townsend (2014) test for full insurance, autarky, permanent income type borrowing and lending, buffer stock savings, and unobserved underlying shocks, among other obstacles. There are essentially the information financial regimes Lucas (1992) highlighted. Information financial regimes which might be thought *a priori* to be similar do place restrictions on data. Moral hazard, unobserved output, unobserved capital, limited commitment, and various combinations of these can be shown to generate distinct patterns, as Monte Carlo simulations reveal. Related literature comparing and contrasting constraints, rather than featuring on one accepted benchmark only, includes the companion papers of Albuquerque and Hopenhayn (2004), Clementi and Hopenhayn (2006) as well as Krueger et al (2024), Broer (2013), Schmid (2008), Kinnan (2022), and Attanasio and Pavoni (2011). These estimated micro foundations are used as building blocks of macro models.

2.4.1 Macro models with underlying obstacles in islands

Moll, Townsend and Zhorin (2017) is a model with two islands, each with a distinct obstacle (or set of obstacles) to trade. The empirical work being used with the two islands construct stratifies by urban vs. rural classifications or industrial vs. agricultural areas. Paulson, Townsend and Karaivanov (2006) show that information-constrained regimes fit best in central and urban areas of Thailand, whereas a limited commitment regime (in combination with other constraints) fits best in northeast and rural areas, similar to the findings in Ahlin and Townsend (2007), and Karaivanov and Townsend (2014), with each of the above contributions using different variables and methods. In the Moll, Townsend and Zhorin (2017) two island model, migration of labor and flows of capital across islands are allowed as part of a given market structure, that is imposing competitive markets in these factor inputs. Urbanization in the model can be attributed to the obstacle-induced movements in factor inputs alone, though of course in reality there are other contributing forces. This is quantified through a counterfactual which also reveals the model's mechanics. Were each island a closed economy, then there would be different wage and interest rate combinations across the islands, which in turn are predictive of actual flows of labor and capital when the economy opens up. Or proceeding in reverse, policy motivated counterfactuals relative to the baseline model -- limits on migration or regional development policies promoting investment -- can have large and often adverse impacts on levels of income and on inequality, even for areas that sought protection.

In contrast to using estimated obstacles to trade, just imposing the muchused Aiyagari (1994) Huggett (1993) and Bewley (1986) financing constraint in all islands, but at distinct levels across islands, does an injustice to the observed data and thus would deliver misleading policy counterfactuals. Using estimated micro underpinning seems a sensible way to proceed in building macro models.

2.4.2 Macro model with aggregate shocks and underlying obstacles

Macro literature has incorporated aggregate shocks into models with obstacles to trade. The seminal Bernanke and Gertler (1989) paper on business cycles features costly state verification. Townsend (1979) in which the condition of borrowers' balance sheets is a source of output dynamics triggered by aggregate production shocks. Carlstrom and Fuerst (1997) feature Bernanke-Gertler without the overlapping generation structure. Bernanke, Gertler, and Gilchrist (1999) draw this into a more empirically focused literature with a financial accelerator. Kiyotaki and Moore (2019) is related, though they start with an exogenous specification of an obstacle: borrowers will not repay dept unless there is collateral. Fluctuations in the price of collateral generate dynamics even when shocks to the economy are small.[6] Gertler and Karadi (2011) model unconventional monetary policy in which explicit financial intermediaries face endogenous balance sheet constraints, which is related to the work of Adrian and Shin (2009).

In Di Tella and Hall (2022), the macro aggregate shock is at the level of entrepreneurs, specifically to the cross-sectional dispersion of idiosyncratic risk. That shock is taken as exogenously uninsurable. This creates a risk premium for entrepreneurs who hire capital and labor in advance. Aggregate risk shocks thus can increase risk premia and create quantitatively realistic business cycle recessions when the model is calibrated against US data.

2.4.3 International macro model models of sovereign debt and default

An international literature features events surrounding sovereign debt crises. Aguiar and Amador (2021) earmark several frictions at play, not just the lack of strong legal enforcement, but also deadweight costs of default, limited commitment generating vulnerability to runs, incentives to dilute existing creditors, incomplete markets, and distortions associated with public rather than private debt. Other models feature a combination of private information and limited commitment (Dovis 2019); and still others the distinction between credit risk and liquidity risk with incomplete markets, limited commitment and search frictions (Passadore and Xu 2022).

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[6]Bigio and Sannikov (2023) is notable for its emphasis on the channels of monetary policy through balance sheets over and above the channel through interest rates. Piazzesi, Roger and Schenider (2022) explore in a new Keynesian model the coexistence of money at the retail level and banking at the wholesale level, with a role for central bank reserves. Related, Piazzesi and Schneider (2022) explore the implications of central bank digital currency for intermediation.

2.5 Models with distinctions across generations

Returning to Lucas (1972), if the processes of the model are viewed as occurring over long periods, then a typical household in the model represents a family of successive generations. In his words, in a positive analysis, households can sell the endowments of their heirs to meet current needs, and in a normative analysis, there is complete altruism in the sense that each household speaks for yet-to-be-born descendants. Lucas thought it might make more sense to think of the theory as applying to individuals in their own lifetime while allowing intrafamily altruism.

Subsequent literature, motivated in part by public finance and taxation issues, hence with macro implications, has explored this. Phelan (2006) assumes a planner puts equal weight on all future generations. This avoids the Atkeson and Lucas (1992) immiseration result because if virtually everyone is poor that minimizes Phelan's welfare criterion. Farhi and Werning (2007) entertain different declining weights on future generations as if each generation had some, albeit limited, altruism to the subsequent generation, then it is still desirable to insure the unborn against the luck of their ancestors, or as they put it, insurance against the risk of the family into which they are born. These papers provide a stark contrast to the immiseration result.

We turn now to explicit macro models with life cycle components.

2.5.1 Macro life cycle models estimated with data

Kaplan and Violante (2014) studies the consumption response of US households to fiscal stimulus. Estimated empirical patterns reveal high marginal propensities to consume. This is explained in the context of a life cycle structural model with a low return liquid asset and a high return illiquid asset with the latter subject to a transaction cost. Wealthy households behave as hand-to-mouth consumers as if liquidity constrained. Heathcote, Storesletten, and Violante (2010) studies American workers experiencing a rising college premium, a narrowing gender gap, and increasing wage volatility. This is explained in the context of an incomplete markets life cycle model in which individuals choose education, intra-family time allocation, and saving. Kaplan (2012) estimates an incomplete markets life cycle model with endogenous labor supply. The key challenge for the model is to generate declining inequality in annual hours worked over the first half of the working life, while respecting the constraints imposed by the data on consumption and wages. There is also a vast literature in macroeconomics on labor supply linked to business cycle research.[7]

Silva and Townsend (2024) models in a life cycle context the coexistence of real capital investments with financial markets. As with Samphantharak and Townsend (2018), Thai data for entrepreneurs are used to get estimates of the risk premium not only for idiosyncratic shocks but also for aggregate shocks. The altruism of one generation for the next is calibrated with a consumption to wealth ratio at the beginning and end of life. This then allows for a study of inequality within and across generations. The Silva and Townsend (2025) paper emphasizes the

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[7] One branch of the literature is motivated by discrepancies between micro and macro elasticities: Chetty (2012), Rogerson (1988), Hansen (1985), and Chang and Kim (2006). Likewise for the topic of long run labor participation rates in Europe (Prescott 2004), Ljungqvist and Sargent (2011) show that the high labor supply elasticity of the representative consumer in Rogerson (1988) also emerges without lotteries when self-insuring individuals choose interior solutions for career lengths.

links between micro and macro. In a policy motivated counterfactual experiment, improved coverage of idiosyncratic risk impacts not only inequality dynamics within and across generations but also macro capital accumulation. The first generation of entrepreneurs benefits from capital gains but subsequent generations of entrepreneurs are worse off than they would have been without the policy reform.

2.6 Risk, insurance, and the family

Lucas (1972) concludes his article with the view that it is time for welfare economics to deal seriously with the economics of the family. This is explored in the literature with empirically grounded theory. In Ru and Townsend (Forth.), family networks are enhanced with the advent of a Thai village-wide financial fund, with the information-financial regime switching from limited borrowing and lending to costly state verification, whereas those households without kin in the village were made worse off, switching from a moral hazard constrained regime to savings only. Ru and Townsend (Forth.) is also a review of models with formal and informal risk sharing.

These results are shown to have implications for investment, hence growth. Related work shows the Thai village fund increased investment, funded by gifts from the network, and decreased TFP gaps, getting at Lucas' paradox, here within-country: Why does capital not flow from rich to poor? The family remains important in more advanced economies, as well.[8]

Doepke and Tertilt (2016) discuss the role of the family as mostly neglected in macro economic models, yet they argue the family plays an important role in savings, labor supply, inequality, human capital, the differences in growth rates between rich and poor countries, and as a driver of political and institutional change. This includes a literature review of key contributions.

3 New Technologies: Money, Islands, and Imperfect Information remain Useful Constructs and are Policy Relevant

This essay honoring Lucas has hinted throughout of new technologies which can alter the picture of macro frictions. These tools are e-transfers, distributed ledgers, smart contracts, and encryption. Townsend (2020) describes these tools in detail and how they can be deployed individually or in combination. The potential to entirely reconfigure markets is featured in Townsend and Zhang (2023), with illustrations from a familiar but non-financial application.

This subject begets controversy in that the new technologies are not universally well understood. Worse, mention of crypto or blockchain evokes polarized points of view, the self-interest of promoters and detractors, with hype and exaggeration. Crypto or blockchain is sometimes equated immediately with Bitcoin, which has suffered from both its proclaimed interest in creating an alternative to fiat money as well as from speculation, liquidity shortages, and an energy intensive validation protocol. Technically, Bitcoin combines a variety of features –

[8] Karaivanov, Saurina, and Townsend (2019) find family connections are an important stratification for the best fitting information/financial regime using investment data of large value firms in Spain. Having common family members across syndicates is much more important than what might have been conjectured *a priori*, namely that the degree of involvement in the formal financial system with loans from commercial banks is not the prime driver.

distributed ledgers, public private key encryption, and cryptographic puzzles – in one package. Ethereum, building on Bitcoin, provides programmability. Yet the power of the technologies cannot be understood until such packages are disassembled and the components studied. This is increasingly happening. The BIS has moved from a sharply critical stance on Bitcoin to embracing 'unified' ledgers and programmability (BIS, 2022; Carstens 2023). Still, less than full interoperability across blockchains, for digital assets and other applications, remains an Achilles heel, a technological limitation which should not be glossed over.

3.1 Components of technology

The principal components of new technologies are distributed ledgers, smart contracts, and encryption. Here we consider them one at a time, in order to distinguish their capabilities.

3.1.1 Distributed ledgers

Put simply, a blockchain is a single common ledger of transactions and contracts, subject to validation, and distributed to participants. Though blockchains are distributed ledgers, not all distributed ledgers use the blockchain data and validation algorithm. Distributed ledgers build on the concept of distributed computing. The components of a distributed system communicate and coordinate their actions by passing messages to one another in order to achieve a common goal. Distributed ledger technology (DLT) refers to these configurations.

To continue the metaphor from earlier, islands are where the computers and servers, or partitions of these, are located. Information flows across islands, and updates within islands, are inherently an intrinsic part of operations. These information flows are separate from money. Indeed, the association of blockchains with money is misleading. The database objects on the ledgers and used in transactions do not necessarily have high velocity, nor must they appear frequently in exchange. As an example, a contract on a blockchain goes beyond payments and can serve a different purpose.

The solution to the Ostroy-Starr decentralization problem was given earlier. Multiple databases, across islands, can be replaced by a single ledger and used to keep track of requisite information to achieve the targeted efficient solution. DLT tracking technologies are being adopted in a variety of settings: Walmart Canada, DeBeers, and relevant to banking, central bank proposals for trade finance in Ghana and Brazil.

3.1.2 Smart contracts

The second component is smart contracts. In Ethereum, a contact is another node which in addition to balances has code and its own data. A contract can receive and send messages from other nodes, but of course a contract node cannot initiate anything on its own. The current state variable of a contract has the meaning we give to it in economics and engineering, in dynamic programming for example. A state could be the balances of assets (or debt) at the beginning of a period, hence the link of Ethereum to its ancestor, Bitcoin, but the concept of states in contracts is of course much more general.

One particular kind of contract is a digital asset issued under the ERC-20 standard, which means it is not a coin or token at all, but rather lines of code which can include stipulations and conditions, such as time and state contingent approval and transfer. Digital assets are divisible and composable with each other. Digital assets allow instantaneous trade and settlement, referred to as atomic.

Complete interoperability of tokens across diverse blockchains, as diverse islands, can be achieved in some instances but more typically interoperability is limited. Tokenization refers to creating cloned copies on a blockchain of an original e-asset representation in a legacy system, holding the original in escrow, minting the new token, then burning the token upon redemption, that is, conversion back to the e-representation of legacy. A 1-1 value of the original with the clone needs to be maintained. Tokenization is used across blockchains, but one has to get into the weeds of interoperability to expose potential limitations. One can think of the interaction of a blockchain with a coexisting legacy system, or the interactions across blockchains, as communication across islands. When interoperability is limited, information is imperfect.

The use of smart contracts to resolve the coordination problem of multiple circulating private monies was given earlier in Townsend and Wallace (1987). This will be increasingly policy relevant in today's world with circulating digital assets. Aronoff and Townsend (2022) show how digitized US Federal Reserve money and digitized Treasuries can be brought together with smart contracts to remove a coordination problem across dealers in the US repo market which otherwise can suffer from a multiplicity of equilibria.

Regarding money, the repo market is also the prime venue for implementation of US monetary policy. Relatedly, observed spikes in the repo rate, out of line with Federal Reserve policy rate, reflect a lack of liquidity and are arguably due the implicit tax on intermediation associated with the new liquidity coverage ratio (LCR) under Basel III. That is, the traditional intermediation of broker-dealers expands balance sheets along the chain of repo transactions, and this is more difficult when repo as an asset is counted in the ratio. The SEC and others are proposing that repo trades be centralized with a central counterparty (CCP). In contrast, Aronoff, Townsend and Virza (2025) in cooperation with the Treasury Office of Financial Research, show that reconfiguring trade agreements into multi-agent smart contracts achieves the goal of facilitating intermediation but at a lower cost and with less market disruption. These smart contracts maintain the current risk guarantees in case of default while netting repo trades which appear as both assets and liabilities on a given dealer's balance sheet.

A key point related to ledgers: Move beyond traditional bilateral representation of value transfer across balance sheets of individual dealer participants to smart contact code which operates on multiple accounts simultaneously.

The central bank of Brazil is developing a wholesale central bank digital contracting platform, DREX, on an Ethereum virtual machine (EVM) and so have central banks in Georgia, Kazakhstan. Some of these applications are developed with the private sector: Registries for real estate and real capital (which can be used as collateral), improved lending to farmers and SMEs via internal tokens, and better liquidity across otherwise fragmented markets. The central bank of Switzerland, SNB, has experimented with an open market operation on the private blockchain of SCX, where bonds can be originated with central bank reserve accounts, tokenized from legacy representations.

3.1.3 Encryption

The third featured component is encryption. This has the potential to revolutionize financial markets and hence macro in the treatment of information frictions. Encryption of outgoing and incoming messages is done with private and public keys. Fully homomorphic encryption (FHE) maps true values of variables 1-1 with encrypted values. Computations with code on the encrypted space allow the algebra of addition and multiplication to be preserved as if done on the underlying true values, which remain concealed. The math of this is grounded in the algebra of cyclic rings. Likewise, multi-party computation (MPC) allows for the preservation of secrets/privacy across agents while creating cross-agent comparisons and utilizable aggregate data. Encryption can be used in layer-2 solutions which have smart contract code operating off chain as separate from but interacting with a blockchain.

In principle, everything could be done on a blockchain, but blockchains were developed with all transactions being public, up to the encrypted node identities, and so innovation on top has been challenging. The Central Bank of Brazil had designed DREX subject to this constraint. To deal with otherwise limited privacy, applications are run on "enclaves" with smart contracts within and limited transactions across. We thus arrive again at information islands. However, the central bank for regulatory purposes needs to see some data and the islands with limited interoperability impede other innovations, undercutting the power of the blockchain.

New technologies that permit FHE and MPC on the blockchain are being created, as described in Aronoff et al (2025c). However, even with these improvements we are still left with crucial choices: What ought to be public vs. private is an intrinsic part of the design of any economic application.

3.2 An application optimally concealing histories: Using DLT, smart contracts, and encryption

We have discussed earlier in the context of Lucas (1972) that revealing past histories helps mitigate confusion among agents in the model and hence the second-guessing dynamics of the infinite regress problem. Under mechanism design, though not addressed in Lucas (1992) or Atkeson and Lucas (1992), the opposite can be true. In mechanism design as in Townsend and Zhang (2022) histories of past announcements can and should be concealed.

The intuition comes from multi-period problems in which current period outcomes are indexed by past announced states. Borrowing and lending is an overly simple example of an incentive compatible scheme. Borrowing in the current period at low income implies paying back the loan in the next period. Likewise, saving at high current period income delivers investment returns in the next period. These intertemporal tradeoffs help to incentivize truthful announcements of income, as in Townsend (1982) and in private information environments more generally. But the simple borrowing-lending schemes are not information-constrained optimal. More insurance is possible.

Relatedly, not knowing past histories also creates tradeoffs that can be exploited to improve social welfare. As an example, consider the two-agent two-period model of Townsend (1988) in which agents suffer from shocks to their balance sheet, or are subject to preference shocks. An agent reporting shocks in a given period has control over what column of the state matrix pertains but does not know the row of the other player associated with past histories. The math of it is that incentive constraints for each player which apply in principle for all dates and all possible histories become less constraining when aggregated across unknown states. One can think of this as a kind of endogenous and desirable stickiness.

Such an application could be run on the multi-currency exchange and contracting platform (XC) that has been proposed by the IMF (Adrian 2022). The objects are certificates of escrow representing the fiat money of participating countries. Participants suffer from shocks to balance sheets. More generally, XC is illustrative of the power of single ledgers for economizing on collateral, with assets divisible and composable, with programmability for multi-country coordination, while maintaining consistency in the sense of there being a unique underlying state of the ledger, though parts of those, and actions, can be concealed by encryption.

3.3 Limitations: Information islands remain

Though the new technologies are powerful, there remain some significant limitations: data partitions, and differences between CS and economics on what is meant by trust. Both can be seen as across-island problems in data storage, access, and communication.

3.3.1 A database theorem; the CAP trilemma.

Even on a single ledger the computer science CAP theorem for databases kicks in. It is impossible to have at the same time all three of these conditions: immediately accessible data, consistency in data when being read by different nodes, and partition tolerance as divergence in common information/data. Even dropping partition tolerance, there remains in practice a tradeoff between accessibility and consistency.

All of these tradeoffs have been present all along in database systems and hence are a useful way to look at legacy systems and thus information fractions in macro. Locally, agents may rely on trust, as in the family, but likewise this comes with pain points and severe limits. Financial institutions may provide some centralization, but then again they have their own accounting ledgers with discrepancies across them that require either periodic reconciliation or an intermediary broker-dealer that takes on risk. CCPs represent another mitigating solution though as noted earlier, with costs.

3.3.2 Design of algorithms: Trust in computer science vs. incentives in economics

Related, the marriage between economics and computer science encounters an obstacle in implementation. In computer science it is assumed that most actors will follow a prescribed algorithm as for validation. Only a limited number of computers are imagined to fail, and likewise most actors do not go rogue. In economics honesty has to be induced via incentives, as with private information in strategic games.

As described in Morris and Shin (1997), consider the Byzantine Generals problem, and equivalently the email problem of Rubinstein (1989). There are two separated generals each on mountain, or island to maintain our metaphor. Attack on the enemy is successful only if the enemy is unprepared and both generals attack. A coordinated successful attack benefits both, no attack yields zero benefit for both, and one attacking and the other not delivers a high loss. In a static game matrix, there are multiple equilibria.

Now suppose the enemy is prepared with probability parameter delta, hence unprepared with the residual probability. The first general knows when the enemy is unprepared and if so sends a message to second general. But that message fails to arrive with small probability parameter epsilon, less than delta. If this first message arrives, the second general sends back a confirmatory message, but, also noisy, may not arrive with the same epsilon. Even if second message arrives, the second general does not know that it did, so the first general sends a confirmatory "second order" message back to second general, and so on, on and on. There is no upper bound on the number of messages.

An intuition might suggest that as more and more information is being shared, a coordinated attack is possible. However, from the standpoint of any individual agent in the back-and-forth message chain, the probability the other general will not attack is always greater than ½. Using the framework of global games, the probability delta that the enemy is prepared infects the chain and dominates the small probability epsilon. The unique equilibrium is not a good one; there is no attack even if the enemy is unprepared. The real problem here is lack of common knowledge, as in infinite regress problems. Schaal and Taschereau-Dumouchel (Forth.), at this conference, use the global games construct.

There is a remedy for the Byzantine Generals problem: Not ignoring strategic behavior and prescribing an algorithm which are all presumed to follow, but instead changing the communication algorithm. Here in context, allow only one message and no confirmation. Learning the enemy is unprepared, the first general sends a message and plans to attack. If the second general get the message, he also attacks. The probability of a successful coordinated attack is large. More generally, as with islands and lack of common information, economics and computer science need to collaborate in information design and algorithmic validation.

3.4 Implications for money and monetary policy

In Lucas (1972), expectations and neutrality of money, young agents are assigned to islands and old agents move across islands. Money emerges as valued in a competitive equilibrium, but with limited information on monetary aggregates there is an inefficient confusion. In Lucas (1992) and Atkeson and Lucas (1992) efficiency and distribution papers, preferences shocks are inherently private, a fundamental obstacle to trade, and honest revelation must be induced. Still, markets with unrestricted trade are part of Lucas' thinking. One can combine these islands, information and market ingredients, in effect combining the two literatures discussed in sections 1 and 2 of this essay, and return to the subject of money and monetary policy.

As in Townsend (1989), there are islands, reassignments, limited information, markets, and a kind of money. There is a common ex ante objective: Maximize expected utility over outcomes. Each of multiple islands has planner branches for implementation. Agents in a given island make announcements in the first date of preference shocks. Some of those agents stay put and their history is recorded on the island ledger, a tie-in for a second period, as in Lucas (1992). But others of those agents move, are assigned as in Lucas (1972) to another island, in some proportion, which could be random. But their history is carried with them in the form of tokens, a money which can be used as evidence of that history to a local planner branch in the island of destination. That is, agents who have moved voluntarily show the planner branch of the new island if they had been patient in the island of origin, as they would have been assigned tokens in that instance. Unobserved trade of tokens for money is allowed in each island before and after exchange with a district branch, a market which is taken as given, as a constraint. This delivers a price level of goods for money, important to Lucas. If there are multiple waves of movers, one first wave carrying money based on the best information available at that time, with a second wave to follow when additional information is revealed, the issuance of money for the second wave and changes the price level of goods for money for the first wave, with consequences for them. The optimal policy is to vary the number of tokens in the system with the configuration of aggregate movers and preference shocks. This can be thought of as optimal activist monetary policy, flipping the Lucas/Friedman paradigm on its head.

One can go further along this line. In Townsend (1987b) on economic organization with limited communication, there are multiple goods and multiple preference shocks, with urgency shocks over particular goods and over time. Here multiple colored tokens are useful as conveying more history relative to a single money. 'Traditional money' disappears, a threat to conventional central bank thinking, but a new form of money appears with implications for policy. A similar idea of colored coins emerged in the early days of Bitcoin to reflect and distinguish various histories. In computer science, tokens are less burdensome, as tokens scale up more easily than hashed data registries. In economics, there is a related literature.[9]

The point is that given advances in computer science we seem to be on the edge of a new era in which money and information get comingled and the island paradigm takes on new meaning. The paradigms of islands and information with money allow us to think through these distinctions and the implications for monetary policy.

4 Epilogue: Lucas as pathbreaker in science and technology

Lucas viewed mathematics as a fundamental and indispensable tool for economic theory. I can easily imagine that Bob would have championed a larger vision that includes computer and electrical engineering.

We continue to have these 'conversations' with Bob as we think about his models and contributions. His legacy is much with us today.

[9] In money as memory, Kocherlakota (1998) argued that money can serves a partial substitute for conveying all history, not that all history can be encoded with money. The insufficiency of money was formalized earlier in Ostroy-Starr (1974). In Wallace (2014), on optimal activist money creation in pure currency economies, policy should be active almost surely relative to a fixed money stock rule, but the direction of intervention is unclear in the sense that it depends on the details of the environment and trading histories. Perhaps the latter can be seen in the Chicago School Friedman tradition, on long and variable lags. Lucas and Wallace were classmates and students in Friedman's price theory class. Lagos and Zhang (2020) in the tradition of Kiyotaki and Wright (1989) deliver an activist monetary policy which in the limit is Friedman's dictum, deflate at the rate of intertemporal time discount.

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