Fiat Money in Laboratory: Foundations of Experimental Macroeconomics

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An Overview: What We Have Learned about Money and Inflation

• Work over the past 25 years
• Starting with micro-foundations of macro
  – Equilibrium selection in presence of multiplicity: stationary solution is favored over non-stationary solutions
  – Learning: adaptive solutions favored
  – Sunspot and intrinsic volatility possible
  – Laboratory is credible test-bed for monetary policies
  – Does constant money growth stabilize inflation?
• Introducing market institutions
  – Market institutions make important differences to market outcomes
  – Economy with personal money
  – Value of fiat money with an outside bank
• Method
  – Question(s) being addressed
  – Specificity vs. generality of results in a “fractal” world
• Future of experimental macroeconomics
Equilibrium Models

• Help us understand, and depict our understanding of economic environments
• Framework for design of economics policies, especially if unique prescriptions
• Multiple equilibria => one goal, many policies
• Uncertainty about which equilibrium (if any) => caution about policy prescription
• Pressure on policy makers may lead them to act as if theory provides a unique prescription => policy mistakes and failures
Deficit reduction is a classic policy prescription to lower inflat. Cagan (1956), Woodford (1986): multiple equilibria including two stationary eq. Low inflation stationary state (LISS) is consistent with classical prescription. But the high inflation stationary state (HISS) is not; Sargent and Wallace (1987). How can we know whether the economy to be managed is in the neighborhood of LISS, HISS, or neither? May help if we knew that some of the possible equilibria possess a robustness property that others don’t: plausibility. No evidence, yet classical prescription is the rule in policy circles.
Figure 1.—Rational expectations equilibrium dynamics for inflation (Eqn. 7b). (Low ISS = low inflation stationary state, High ISS = high inflation stationary state).
Study of Historical Economies

• Couldn’t we find out from historical data about various economies which equilibrium each of them was in?
• Answer depends on their underlying parameters which are uncertain at best, often not known
• And there is no assurance that such economies were in any equilibrium at all
• We cannot even distinguish if a historical economy was on some equilibrium or some disequilibrium path
• Political and economic consequences of field experiments on monetary policy make them essentially infeasible
Two Approaches to Money

• Today, I shall review two experimental approaches to the questions about money
• First, the work with Prescott and Marimon which built an experimental lab version of Cagan’s (1956) model of hyperinflation using OLG (Sargent and Wallace 1987): two stationary, continuum of non-stationary and sunspot equilibria
• Second, the work with Shubik and Huber on minimal strategic games (sell-all, buy-sell and DA) with outside, inside, and personal money: CGE, NCE equilibria
• Each body of work, with human and minimally intelligent agents has yielded important insights
Equilibrium Theory is Silent

- On distribution of equilibria
- On behavior of agents when they observe non-equilibrium price paths (as they almost always do)
- Any equilibrium requires a high degree of coordination among agent beliefs about the evolution of future paths
- Many sets of agent beliefs can be mutually consistent; equilibrium selection involves agents learning to form and coordinate their expectations (theoretical literature)
- Lucas (1986): suggested that experiments may help identify how agents learn and help select equil.: adaptive or RE
- Apply stability analysis to learning rules
- Parallel work in equil. selection in experimental game theory
Overlapping Generations Model

• One non-storable good (young endowed with 7, old with 1 units); U (c1, c2), constant consumption (c1 = c2 = 4) is Pareto optimal but is not an equilibrium under positive fiscal deficit
• Old can use their money balance to buy units from the young
• Fiat money
  • Fixed quantity, or
  • Deficit financing through seigniorage,
– Various monetary policies (common knowledge)
Three Methodological Challenges

• Fixed number (N = 13) of agents learning (through repetition) to implement OLG economies
• Generation size (n = 4), play for two periods, exit, sit on side lines for one or more periods, than randomly picked to re-enter the game; play forecasting game when on the sidelines (ABCD, EFGH, IJKLM)
• Use forecasting results for termination of the “infinite” game (proof that the re-entry of individuals generates opportunities which are also present in the OLG game without re-entry)
• The “young” play a supply game with the old to determine prices and allocations
Indeterminacy: Experimental Evidence

**Figure 1.**—Rational expectations equilibrium dynamics for inflation (Eqn. 7b). (Low ISS = low inflation stationary state, High ISS = high inflation stationary state.)
OLG Model of Fiat Money: Stationary Solution favored over Non-stationary

• No deficit, amount of money in the economy is fixed
• A continuum of Nash stationary equilibria (competitive to strategic)
• A continuum of non-stationary paths leading to demonetized economy (prices increase without bound)
• Results: In spite of non-stationary paths, and opportunity to go that way, economy shows strong tendency to settle in the neighborhood of range of stationary equilibria.
Fig. 3. Transaction prices
Fig. 4. Transaction prices
Conclusions

• Stationary solutions to the OLG model of fiat money form the domain of attraction for these experimental economies
• Large deviation in initial prices gave economies the opportunity to follow non-stationary paths but they don’t
• Conclusions robust to two market institutions (DA and supply schedule game)
• Nash eq. (young exploit their market power)
• Adaptive forecasts
OLG Model of Fiat Money with Deficit Financing: LISS Stable under Adaptive Behavior favored over RE

• Introduced fiscal deficit financed by seigniorage
• Set up with two stationary equilibria (LISS and HISS) and continuum of non-stationary equilibria
• LISS stable under adaptive and HISS stable under RE
• Learning: LISS favored over HISS (stable under adaptive)
• Constant consumption (Pareto optimal but not an equilibrium) favored over LISS, but tends to disappear
Figure 1.—Rational expectations equilibrium dynamics for inflation (Eqn. 7b). (Low ISS = low inflation stationary state, High ISS = high inflation stationary state).
Figure 2.—Observed inflation normalized between high and low inflation stationary state: 
\[ \hat{\pi}_t = (\pi_t - \pi^L)/(\pi^H - \pi^L). \]
Figure 3.—Inflation and real balances for Economies 4A, 4B, and 7C.
Panel A: Price level (Money/chip).

Panel B: Inflation.

Panel C: Money Earned.

Figure 4.—Evidence on bias toward constant consumption in Economy 2.
Figure 5.—Observed inflation normalized between low inflation stationary state and constant consumption inflation rate: $\hat{\pi}_t = (\pi_t - \pi^L)/(\pi^L - \pi^{CC})$.

(Economy 1: Four observations at the top and eight at the bottom are out of scale.
Economy 3: Four observations at the top and thirteen at the bottom are out of scale.)
**Figure 7.**—Demand, and actual and theoretical supplies for last periods of three economies.
Conclusions

• Agents learn to form beliefs, and coordinate in a dynamic competitive environment, behave adaptively, no evidence for a specific learning rule

• No paths to High ISS => doubt if indeterminacy observed in RE models is a serious problem in historical economies

• Learning models could be modified to better include the considerable complexity of the decision environment

• The data support Low ISS (classical prescription of lower deficit to reduce inflation)

• Could not know this without lab data
Expectations and Learning under Alternative Monetary Regimes


• Same OLG model, RE paths and adaptive learning dynamics: can agents learn through policy changes, or does inertia/persistence generate path dependence?

• Constant real deficit financed by seigniorage

• Deficit adjusted to follow a monetary policy to achieve a target level of inflation

• Economies with pre-announced changes in levels of deficit
Figure 2. Inflation patterns (economies 1, 3, 5, 6A, 6B, 7B, 9B, 9C, and 12C).
Figure 5. a Inflation paths in target economy 7A (target inflation 50 percent). b Inflation paths in target economy 9A (target inflation 55 percent). c Inflation paths in target economy 12A (target inflation 200 percent). d Inflation paths in target economy 12B (target inflation 200 percent). Legend: —— actual; —— adaptive path.
Figure 8. a Inflation with rational expectations path (economies 8 and 11). Legend: □ actual inflation; + low ISS; ◊ high ISS; × RE path. b Inflation with LSQ squares path (economies 8 and 11). Legend: □ actual inflation; + Low ISS; ◊ LSQ path.
Constant Money Growth and Stabilizing Inflation


- Data provide weak support for the simple rule (constant money growth) for stabilizing inflation (Friedman 1948, 1960)

- Time consistency problem (rules vs. discretion)

- Stability analysis of the underlying parameters of the economy provide a better explanation of observed price volatility than policy differences do

- In unstable economies, subjects base their forecasts (and decisions) on observed fluctuations instead of announced stable policies
Deficit vs. Money Growth Rules

- Fixed real deficit with endogenous monetary policy (Economy 1 and 11B; latter has smaller contraction factor)
- Fixed money growth with endogenous real deficit (Economy 7 vs. 4 and 8, latter have smaller contraction factor)
- Economies with high eigen values show higher volatility
- Theoretical stability analysis appears to be important
- But how do we find out the stability parameters of a historical economy?
Fig 2a. Inflation (Eco. 1).

Deficit rule (r(1) = 0.71).

Fig 2c. Inflation (Eco. 11B).

Deficit rule (r(1) = 0.54).

Fig 2b. Inflation (Eco. 7).

Money growth rule (r(1) = 1).

Fig 2d. Inflation (Eco. 4 & 8).

Money growth rule (r(1) = 0.69).
Fig 3a. Inflation (Eco. 5).

Deficit rule. High eigenvalues.

Fig 3b. Inflation (Eco. 3).

Money growth rule. High eigenvalues.

Fig 3c. Inflation (Eco. 10).

Deficit rule. High eigenvalues.

Fig 3d. Inflation (Ecos. 2A, 2B and 2C).

Money growth rule. High eigenvalues.
Sunspots and Extrinsic Volatility

- Examine existence and robustness of expectationally driven price volatility in OLG economies.
- Theoretical model: existence of pure sunspot equilibria which can be learned through an adaptive rule.
- We observe expectationally driven cycles but only after subjects exposed to and learned a real cycle.
- Evidence of path dependent price volatility.
Method

• How do you create a sunspot economy in the lab, i.e., lead them to think of or believe in something that is not in fact the case without lying to them

• We held back information about a feature of the economy and manipulated this feature—the size of overlapping generations between 4 and 3—which inflicted a real shock to the economy in alternate periods, and then, without telling them, stopped delivering the shock

• We wanted to see if they cycle of the economy they had learned in presence of the real shock could be sustained simply by the expectations they had developed when the shock was no longer there
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<td>Are Predicted Prices OK (Y or N):</td>
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Legend: 
- Dark gray square or background = red on computer screen 
- Light gray square or background = yellow on computer screen 
- = Blinking square on computer screen 

Best FE = Error in the winning price forecast 
Mean F = Mean price forecast 

Fig. 2. Main subject screen.
What We Learned

• Sun spot behavior does not arise without experience with economies with real shocks so subjects have a reason to related the extrinsic variable to their decisions
• Greater fluctuations under real shocks
• Fluctuations persist after real shock disappears
• If agents have reasons to expect that sun spots matter, they can matter
• Why should they so expect?
• Experience, communications, can trigger coordination
Fig. 3. Actual and equilibrium prices and generation-size shocks.
Exploring Market Institutions and Money in the Lab

- Huber, Shubik and Sunder, “Three Minimal Market Institutions”
  - Market institutions make important differences to market outcomes
- Huber, Shubik, Sunder, “Economy with Personal Currency”
  - In spite of theory to the contrary, economy does not function efficiently unless all moral hazard associated with it is eliminated
- Huber, Shubik, Sunder, “The Value of Fiat Money with an Outside Bank”
  - Fiat money can work as an inexpensive debt instrument to shift consumption through time
Three Institutions

• Three minimal market designs (sell-all, buy-sell, and double auction)
• Experimental implementation
• Results compared to three benchmarks:
  – General equilibrium
  – Non-cooperative equilibrium with 10 traders
  – Minimally intelligent traders (simulation)
  – Autarky
Market setup (in all three settings)

- Two goods (A and B) traded for money
- Each trader endowed with either A or B and money
- Multiplicative earnings function:
  \[ \text{Earnings} = \sqrt{A \cdot B} + \text{net money} \]
- Money carried over from period to period (except in double auction)
Three Minimal Market Institutions

1. The sell-all model (strategy set dimension 1: all commodity endowment sold; each trader bids an amount of money to buy each commodity)

2. The buy-sell model (strategy set dimension 2: each trader offers the quantity of endowed good and bids money for the other good)

3. The simultaneous double auction model (strategy set dimension 4: each trader offers to sell each good and bids to buy each good)
Endowments
(Good A/Good B/Money)

- 200/0/6000 or 0/200/6000 in sell-all
- 200/0/4000 or 0/200/4000 in buy-sell
- 20/0/4000 or 0/20/4000 in double-auction

- 10 traders in each market (5+5)
- One buy-sell market with 20 traders (10+10)
Comparison of markets I

Avg. Earnings as percentage of maximum

- Sell all: 98%
- Buy sell: 92%
- Double auction: 88%
Comparison of markets II

Standard deviation of final wealth

Sell all
Buy sell
Double auction

0.00
0.05
0.10
0.15
0.20
0.25
Avg. Prices

Buy-sell

Sell-all

Double auction

Foundations
Trading vol.  
Buy-sell  
Sell-all  
Double auction
Conclusions

• The non-cooperative and general competitive equilibrium models provide a reasonable anchor to locate the observed outcomes of the three market mechanisms

• Unlike well known results from many partial equilibrium double auctions, prices and allocations in our double auctions reveal significant and persistent deviations from CGE predictions

• The market form has a significant influence on allocative efficiency and the return distribution: the outcome paths from the three market mechanisms exhibit significant differences among them.
Personal vs. Government Money?

- Is outside or government money necessary to operate an economy efficiently?
- Proponents of alternatives to government money suggest that if all individuals and institutions could issue debt as means of payment, market will sort out the risk and reputations of accepting such paper;
- For example, Black (1970); rates of interest in the City of London for “prime” and “lesser” names, discounting of bills issued by hundreds of banks in the free banking era of the U.S.
Strategic Market Game

- Outside or government money is not needed if the is perfect clearing and no default
- Result is valid under conditions which are clearly counterfactual (like M&M on neutrality of cost of capital with respect to leverage)
- Logical possibility of such an economy does not mean that an economy will actually function smoothly with private money under exogenous uncertainty, and dispersed and imperfect information
- Process dynamics, trust and evaluation are core issues in functioning of a financial system and are absence in Black or M&M equilibrium models
Laboratory Modeling

- Computer implements the sell-all model
- Uses the quantities endowed and money bid for each good to calculate a market clearing price for each good and exchange rates for each trader’s money
- Computer acts as a clearing house as well as a perfect reputation enforcement mechanism (no reneging, no bankruptcy)
- Examines every-one-a-banker model in absence of uncertainty-related explanations for government money
- Yields high efficiencies
- Key theoretical claim that government money is not needed for efficiency exchanges is supported experimentally under these circumstances
  - Ideal contract enforcement, credit evaluation, and clearing arrangements
Conclusions

- This powerful market mechanism and clearinghouse puts enough structure to prevent non-correlated or at best weakly correlated behavior at a mass scale to go far wrong.
- With small size of strategy sets, even economies populated with minimally intelligent agents perform reasonably well.
- With more complex evaluative tasks, expertise may exhibit more value.
- Design of future experiments with roles for reputation and expertise (e.g., non-delivery).
  - Social context problem in laboratory.
Conclusions

• In the meantime, results reveal considerable power of market structure in producing efficient outcomes when reputation is not an issue
• Under such circumstances, the claim that government money is not needed for efficient exchange is supported analytically as well as experientially
• Future experiments under weaker conditions
• In the free banking era in the U.S., different bank notes sold at different discount rates depending on their individual reputation and acceptability
A Note on Methods

• Focus on aggregate outcomes of institutions which may have discoverable laws and properties whose validity is robust to their discovery
• Use of minimal institutions and properties of institutions when they are populated by minimally intelligent agents as benchmarks
• Level of detail/realism vs. simplicity/abstraction in experimental economies (NYSE vs. Smith’s DA)
• Mandelbrot: Fractal structure of the universe
• Spectrum of laws from general to specific, science to engineering (Boyle’s Law vs. Log Tables)
• Where should experimental economics locate itself?

March 26, 2009
Sunder: Fiat Money: Exp. Macro Foundations
Questions to Address in the Laboratory

- Lab economies cannot capture the complexity of a historical economy, not even close
- Theoretical models can’t either
- Simple economic environment, little communication, irrationality, perturbations, small number
- How useful could such data be in advancing our understanding of historical economies?
- What kinds of questions for lab might usefully advance our understanding of economics?

March 26, 2009  Sunder: Fiat Money: Exp. Macro Foundations  147
History and Laboratory

- Figure 13: Annual consumer price index vs. money (M1) growth rates—raw data US 1959-88
- Figure 11: Annual consumer price index vs. money (M1) growth rates—smoothed data US 1959-88 (see Lucas for smoothing)
- Figure 14 shows the raw data for our laboratory economies 7-12 in a similar chart (money vs. inflation)
- Figure 12 shows the laboratory data smoothed by the same method Lucas used to show infer that money growth drives inflation
- You draw your own conclusions
M1 Growth Versus CPI Inflation
(Unsmoothed US Data for 1959-88)
Figure 14

Inflation Versus Money Growth for Economies 7-12 (Unsmoothed)
Figure 12

Inflation Versus Money Growth for Economies 7-12 (Smoothed by beta = 0.95)
My Conclusions

• Our lab economies based on a deterministic OLG model give a sharp picture of the quantity theory of money when the data are properly averaged even though you do not see that in the scattered raw data for US or for the lab.
• To an econometrician, the two data sets may not be qualitatively different.
• But behind the lab data are clear predictions about which stationary equilibrium is likely to have generated them.
• Can we infer anything about which equilibrium might have generated the historical data.
Care Needed in Inference

• Further, we know from the analysis of the data on individual decisions (I did not get the chance to show you, but they are included in the papers) subjects based their decisions on current events and observations.

• Announced policies and averaged trends were fed back to subjects and cycling behavior persisted even when there were no equilibrium cycles.

• In the lab data, the quantity theory of money holds more strongly than in the US data, yet there is only weak support for Friedman’s k-percent money growth rule.

• How well will Friedman’s rule work in historical economies?

• Just because quantity theory holds does not mean that the k-percent rule for long run would be effective.
Thank You

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