Learning as a Rational Foundation for Macroeconomics and Finance

George W. Evans, University of Oregon and University of Saint Andrews

and

Seppo Honkapohja, Bank of Finland

Introduction

Recent crisis has shown that occasionally circumstances can change quickly.

=> Information and understanding become very imperfect.

=> Agents then try to improve their knowledge.

=> Learning behavior becomes a major driver of economic dynamics.

- Implications of learning have been analyzed a lot in the past 20 years or so. Messages:
  - Standard rational expectations (RE) may emerge if the agents' environment remains stationary for sufficiently long period.
  - From policy point of view it is important to take into account the learning process.

- This paper reviews the main methodological issues concerning learning and discusses three recent applications:
  (i) status of Ricardian Equivalence,
  (ii) how should monetary policy be conducted from learning perspective,
  (iii) price-level targeting in a liquidity trap due to zero lower bound on the interest rate.

Methodological issues in bounded rationality and learning

- Many macroeconomic models are summarized in the reduced form

$$y_t = F(y_{t-1}, \{y^e_{t+j}\}^{\infty}_{j=0}, w_t, \eta_t), \tag{1}$$

where y_t is a vector of endogenous aggregate variables, and w_t is a vector of stochastic exogenous variables, often taken to be a VAR.

- Comments:

- (1) assumes a representative agents setting. This can be easily relaxed.
- Agents are assumed to know their own characteristics (utility, technology ...), but otherwise structural knowledge is imperfect.

- Comments (continued):

  - Must specify the degree of structural information: do agents only use a reduced form; if so, is it correctly specified?

  - The horizon for decisions and expectations must be specified.

  - The precise information set of agents.

- Cognitive consistency principle: economic agents are about as smart as good economists (theorists or econometricians).

  => we mostly focus on adaptive or econometric learning.

  => economic agents use time-series econometric techniques.

LS Learning and E-stability

- **Simple model**

$$y_t = \mu + \alpha y_t^e + \delta' w_{t-1} + \eta_t. \tag{2}$$

y_t is a scalar endogenous variables, w_{t-1} is a vector of exogenous observables, and η_t is an unobservable random shock. $y_t^e = E_{t-1}^* y_t$ is is the expectation of y_t based on observables dated $t-1$ or earlier.
The unique REE is

$$y_t = \bar{a} + \bar{b}' w_{t-1} + \eta_t,\ \bar{a} = (1-\alpha)^{-1}\mu, \bar{b} = (1-\alpha)^{-1}\delta. \tag{3}$$

Examples: Muth market model, (version of) the Lucas island model.

- **Learning:** Agents estimate the parameters a, b of their forecasting model

$$y_t = a + b' w_{t-1} + \eta_t, \tag{4}$$

and to use the estimates a_{t-1}, b_{t-1} to make forecasts

$$y_t^e = a_{t-1} + b'_{t-1} w_{t-1}.$$

Temporary equilibrium at time t: w_{t-1} and η_t and y_t^e determine actual y_t according to (2).
Agents update the parameters a, b in t to (a_t, b_t) using least squares (LS).
This defines a sequence of temporary equilibria for $t, t+1, \ldots$RE are attained asymptotically if $a_t, b_t \to \bar{a}, \bar{b}$ as $t \to \infty$.

- **Result:** (Bray & Savin 1986, Marcet & Sargent 1989) There is asymptotic convergence to RE with prob. one if $\alpha < 1$. If $\alpha > 1$, the system diverges.

E-stability (recent discussions: Evans & Honkapohja 2001, 2009) is a general technique to derive the convergence condition. In the current example, inserting (4) into (2) yields the temporary equilibrium

$$y_t = \mu + \alpha a + (\delta + \alpha b)' w_{t-1} + \eta_t$$

and a corresponding mapping $T(a, b) = (\mu + \alpha a, \delta + \alpha b)$ in the parameter space. E-stability is stability of $(\bar{a}, \bar{b})$ under $d(a, b)/d\tau = T(a, b) - (a, b)$, where τ is virtual time. One immediately sees the condition $\alpha < 1$.

- Further directions:
  - When the model has multiple REE, E-stability is a selection criterion to find REE that are attainable under learning.
  - The approach generates new learning dynamics not found under RE hypothesis.

Further issues

- Numerous questions/issues about the basic setting:
  - **Misspecification** of the forecasting model (Evans & Honkapohja 2001, Sargent 1999):
  (i) missing variables => restricted perceptions equilibria.
  (ii) too many variables => learning to eliminate extraneous variables (strong E-stability).
  - **Structural change** of unknown form: constant-gain learning
  => approximate convergence, sometimes "escape dynamics" (e.g. Cho, Williams and Sargent 2002, Orphanides & Williams 2007).
  - **Heterogeneous expectations** (Evans & Honkapohja 1996, Giannitsarou 2003, Honkapohja & Mitra 2006).
  - **Dynamic predictor selection** (e.g. Brock & Hommes 1997, Branch & Evans 2007 de Grauwe 2010).

Learning and empirical research

- Inflation
  - Rise and fall of inflation (e.g. Sargent 1999, Primiceri 2006, Orphanides & Williams 2005a,c)
  - Latin American inflation (Marcet & Nicolini 2003).
- Real business cycle applications (e.g. Williams 2004, Giannitsarou 2006)
- Asset prices and learning (e.g. Timmermann 1993, 1996, Brock & Hommes 1998, Branch & Evans 2010, Adam, Marcet & Nicolini 2010)
- Estimated models with learning (e.g. Milani 2007, 2010):
  - "expectation shocks can account for roughly half of BC fluctuations."

Further issues in modeling learning

- The **planning horizon** of agents (e.g. Preston 2005, 2006)

- **Structural knowledge**:
  - Eductive learning under common knowledge of rationality (Guesnerie 1992, Evans & Guesnerie 1993)
  - Partial structural knowledge (Evans, Honkapohja & Mitra 2009)

Application: Ricardian Equivalence (Evans, Honkapohja & Mitra 2010)

- Consider a standard Ramsey model with identical agents:
  - Exogenous government spending, lump-sum taxes

- Agents only know
(i) their own characteristics and
(ii) the government flow budget constraint.
- Agents assume that intertemporal government budget constraint holds under their own price expectations
- They aggregate their own and government budget constraints.

- **Result:** Ricardian Equivalence holds under learning if expectations do not depend on current government financing variables.

Learning and monetary policy

- Choice of interest rate rule
  - **Taylor-type rules**: requiring learning stability implies constraints on policy coefficients (Bullard & Mitra 2002 and others).
  - **Optimal rules** (Evans and Honkapohja 2003, 2006):
  (i) If policymaker mistakenly assumes that agents have RE, the *fundamentals-based reaction function* leads to indeterminacy and learning instability.
  (ii) *Expectations-based optimal rules* yield uniqueness and learning stability of REE.

- **Application: Price-level targeting and optimal policy**
  (see Preston 2008 for related material)
  - A fundamentals-based PLT rule implements the commitment optimality condition under RE.
  => This rule does not guarantee learning stability. Instability arises when policy objective has very small weight on output gap.
  - An expectations-based PLT rule yields learning stability for all structural parameter values.

- **Application: PLT and the Zero Lower Bound**
  (for ZLB, Taylor rules and learning see Evans, Honkapohja & Guse 2008, Evans & Honkapohja 2010)
  - Assume a Wicksellian PLT rule: the gross interest rate R_t follows

$$R_t = 1 + \max[\bar{R} - 1 + \psi(p_t - \bar{p}_t), 0],$$

  where trend inflation is $\bar{p}_t/\bar{p}_{t-1} = \pi^*$ and π^* is the inflation target.

- A steady state that satisfies $p_t = \bar{p}_t$ for all t, implies $R_t = \bar{R}$. If $\bar{R} = \beta^{-1}\pi^*$, the steady state satisfies the Fisher equation, and the usual targeted steady state obtains under price-level targeting.
- There is also a second steady state in which ZLB on interest rates binds. If $p_t - \bar{p}_t \leq 0$ and $R_t = 1$, we can set

$$\pi_t = p_t / p_{t-1} = \beta,$$

where β is the subjective discount factor.
Result: Price-level targeting does not rule out a deflationary outcome.
- Learning: assume "steady-state" learning (agents estimate a constant as their forecasting model).
Result: An active PLT rule ($\psi > \beta^{-1}$) implies E-stability of the targeted steady state.
Result: The deflationary steady state is usually not E-stable under PLT.
- It is usually a saddle-point and there exists a deflation trap region.

Conclusions

- Expectations is the most fundamental way in which economics differs from natural sciences.

- RE as a consequence of avoidance of systematic errors is a benchmark, but how can economic agents arrive at RE? Coordination requires some form of learning.

- There are diverse ways to formulate bounded rationality and the choice depends on the problem at hand.

- Adaptive learning approaches have been fruitful in looking at a range of macroeconomic phenomena.

- Many applications were referenced. A few were discussed in more detail:
  - Ricardian Equivalence along learning paths,
  - Monetary policy rules and learning,
  - Price-level targeting as optimal policy,
  - Zero interest rate bound and PLT.