Inferential Expectations: A Paradigm for Dysfunctional Markets

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We propose that the formation of beliefs be treated as statistical hypothesis tests, and we label such beliefs *inferential expectations*. If a belief is overturned through the build-up of evidence, we assume agents switch to the rational expectation. The test size α therefore becomes a metric for rationality, since $\alpha=0$ implies complete insensitivity to evidence and $\alpha=1$ implies continual rational expectations. This suggests a different paradigm to efficient markets since observed under- and over-reaction to information in financial data can be attributed to the stock of useful information, rather than pure chance (as in Fama 1997).

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JEL Classification Codes: C91, D84, E50, F31.

1 Introduction

Rational Expectations (RE) applies the principle of rational behaviour to the acquisition and processing of information and to the formation of expectations (Maddock and Carter, 1982). That is, modelers who use RE as a working hypothesis bestow upon their representative agents the ability to calculate mathematical expectations, and, when information is limited, to continually calculate unbiased and efficient parameter estimators.[1]

This theory has had a central role in finance and economics since the 1970s, due to its undoubted ability to impose discipline on model building. Prior to its introduction, model predictions could be driven by ad hoc expectational assumptions that were inconsistent with the structure of the model itself. In finance, RE has become an integral part of the efficient markets paradigm, which is the joint hypothesis of RE, trivial transactions costs and risk neutrality. Fama (1997) defends this approach, claiming equal occurrences of under- and over-use of information in predicting long-term returns which he then attributes to chance. In economics, RE has been used to model phenomena as diverse as aggregate supply, exchange rates, consumption and economic cycles (Lucas, 1972; Dornbusch, 1976; Hall, 1978; Kydland and Prescott, 1982). Important empirical predictions about exchange rates (Frankel and Rose, 1995) and the term structure of interest rates (Mankiw and Miron, 1986), employ RE as one of their key assumptions.

There are, however, a number of puzzles that call RE into question. We list three in particular, to motivate an alternative model of expectations.

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[1] The name RE emphasizes the use of mathematical expectations. But any realistic theory of 'rational' belief formation must take account of parameter estimation. In her model of rational forward discount bias, Lewis (1989) describes rationality as the efficient use of available data.

Puzzle 1: The failure of Uncovered Interest Parity

Under the joint hypotheses of RE, risk neutrality and zero transaction costs, the slope coefficient in a regression test of UIP should be unity.

$$\Delta S_{t+1} = \beta \ (I_t - I_t^*) + u_{t+1} \qquad (1)$$

Instead, the estimated coefficient in the UIP regression, (1), is typically less than unity, and sometimes it is even negative (Frankel and Rose, 1995 and Froot and Thaler, 1990).

The failure of UIP is particularly significant since it is a *predictive* failure. Friedman (1953) argued that a theory may be valid even if the assumptions are unrealistic, provided it predicts better than an alternative. The rational representative agents of financial economics do indeed appear unrealistic,[2] but the predictive failure of UIP erodes the justification for RE as an ‘as if’ assumption, at least in the foreign exchange market.

The failure of UIP cannot be attributed to transition dynamics, as countries have moved *en masse* away from fixed exchange rate regimes to floating exchange rate regimes. The demise of UIP has been repeatedly demonstrated in a vast literature which spans the entire floating rate period since the 1970s. Boudoukh et al. (2005, pg. 1) even claim to have counted ‘well over a hundred papers’ where UIP fails. Although Chinn (2006) has shown that the failure is not as pronounced for long-term securities, he also shows that the extent of the downward bias for short- to medium-run securities is not disappearing with the passage of time.

[2] Bacchetta and van Wincoop (2006) note that the extent of trading on the basis of interest differentials is small relative to cross-border wealth, that foreign exchange traders use a variety of forecasting tools since they know that they are not likely to improve upon a random walk (Meese and Rogoff 1983 and Cheung et al. 2005), that agents trading equities respond to information with a significant lag (Froot et al. 2001), that mutual funds trade under restrictions of asset classes (Lyons 2001) and that many large investment companies fail to adjust their portfolios for long periods (Investment Company Institute 2002).

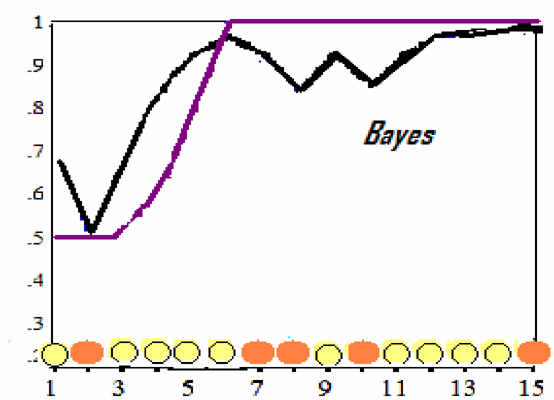
Burnside et al. (2006) note that the literature has explored time-varying risk premia (perhaps as a result of endogenous market segmentation), the interaction of risk premia and monetary policy, statistical considerations such as peso problems and non-cointegration of forward and spot rates, learning, biases in expectations, and, the cost of actively managing foreign exchange portfolios. Some of these approaches assume RE, and blame the failure of UIP on auxiliary assumptions.

Puzzle 2: Experimental Evidence and Anecdotes Against RE

Although it is logically possible to blame the failure of UIP on auxiliary assumptions, it is not particularly plausible, since there is direct experimental evidence that counts against RE. In individual choice experiments, RE predictions are not rejected as null hypotheses in some contexts (see Dwyer et al., 1993), but the most common outcome is that individuals do not hold RE (e.g., Schmalensee, 1976; Blomqvist, 1989; Beckman and Downs, 1997; Swenson, 1997). In addition, experimental research often finds either under-utilization or over-utilization of priors (e.g., el-Gamal and Grether, 1995).

A recent example of an experiment that counts against RE is furnished by Menzies and Zizzo (2004). In that experiment there were two urns, each with different combinations of white and non-white balls. Each urn represented a different state of the world. One urn was selected randomly, by the flip of a coin, and subjects received signals about its contents by the means of random ball draws with replacement from the chosen urn. The prior probability that the chosen urn had a majority of white balls was 0.5 at the start of the experiment, but should have then evolved according to Bayes' rule with each new ball draw. In particular, each drawn white ball should have increased the probability, and each non-white ball should have reduced it. Figure 1 shows how one subject's probability guess diverged from Bayes' rule (the continually changing line) in an interesting way. Despite the information about the urns being free, he or she sometimes did not appear to use it.

Figure 1: Ball Draws, Bayesian Probability, and Observed Probability Guesses
(the probability that chosen urn contains majority white balls)



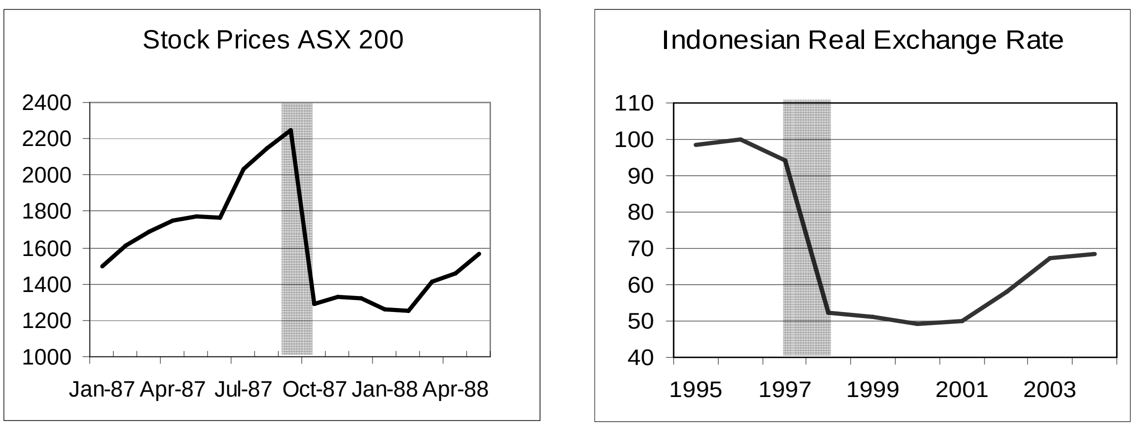
Alternatively, perhaps this subject adopted a 'hold then move' belief strategy. That is, they waited for a threshold of information, and then rapidly 'made up their mind', before settling firmly on another belief. We should not suppose that such a 'hold then move' belief strategy is confined to relatively young and unsophisticated experimental subjects (Menzies and Zizzo used university students). Alan Greenspan made the following comments in an interview on the sub-prime mortgage crisis:

“While I was aware a lot of these practices were going on, I had no notion of how significant they had become until very late. I didn't really get it until very late in 2005 and 2006."[3]

As much as Greenspan’s comments, or the urn experiment results, may accord with our experience of people, they cannot be said to be consistent with RE. In RE, agents to use every piece of free information instantaneously.

Puzzle 3: Tiny Parcels of Information Causing Sudden Changes in Equilibrium

Figure 2: Sudden Changes in Equilibria



It is sometimes the case that dramatic shifts in economic equilibria occur at puzzling times. For example, the timing of both the 1987 stock market crash and the Asian Crisis a decade later (see Figure 2) remain something of a mystery. The puzzle is not that there were no fundamental reasons for either event, but that the adjustments happened so rapidly, without an obvious ‘trigger’. To put it colloquially, one might expect a big shift in an equilibrium to be precipitated by a ‘large’ – in some sense – parcel of information.

[3] Interview with Lesley Stahl, 60 minutes, September 16 2007.

2 The Idea of Inferential Expectations

These puzzles (and others) have not been lost on theoreticians, who have in recent decades been backing away from RE. Alternative theories include: (1) near rationality (Akerlof and Yellen, 1985), (2) parameter uncertainty and econometric learning (Evans and Honkapohja, 2001), (3) model uncertainty and robustness (Hansen and Sargent, 2001), (4) information processing constraints and 'rational inattention' (Sims, 2003) and (5) utility-based beliefs, or 'optimal' expectations (Brunnermeier and Parker, 2005).[4]

While academics in finance and economics have become uneasy with RE in recent decades, a parallel debate has been carried on in the physical sciences on the status of hypothesis testing as a model of belief formation. Mayo (1996) and Mayo and Spanos (2006) have argued that there is a paradoxical reluctance of scientists to describe their own belief changes in terms of Neyman-Pearson testing. A Bayesian account is more popular, despite the widespread use of hypothesis testing by scientific practitioners (Chang 1997). The crux of the argument is that the actual practice of scientists ought to have some bearing on the way they think about the process of scientists changing beliefs.

"In reality, scientists do not proceed to appraise claims by explicit application of Bayesian methods. They do not, for example, report results by reporting their posterior probability assignments to one hypothesis compared with others." (Mayo 1996, pg. 89)

While we would not wish to dismiss Bayesian models of belief formation in markets under all circumstances, we do accept the basic thrust of Mayo's argument. If we, as

[4] Near rationality has been applied to the failure of UIP in Gruen and Menzies (1995) and more recently in Bacchetta and van Wincoop (2006). Econometric learning has been applied to the failure of UIP in Chakroborty and Evans (2006).

scientists, habitually use hypothesis testing to help form our own beliefs, why is this not acknowledged when we think about how agents, in general, form beliefs?[5]

We therefore propose a belief formation paradigm based on a Neyman-Pearson hypothesis test, which we call *Inferential Expectations* (IE). We assume that when a belief is overturned agents switch to RE.[6] Thus, RE is a special case of IE if agents are unconcerned about mistakenly changing their beliefs (the test size α equals unity). The nesting of RE within IE is a theoretical move, rather than an empirical one. By grounding our expectations theory ultimately in the structure of the model, we purchase modeling discipline and avoid opening the 'floodgates of nonsense'. Furthermore, α becomes a metric for rationality. If α=0, agents are completely unresponsive to evidence, while if α=1 they make the best possible use of evidence, converging to the RE solution.

Our idea is closest in spirit to Goldberg and Frydman (1996) and Frydman and Goldberg (2003), who allow agents to conduct hypothesis tests over models. Their program, in turn, can be traced back to a nascent discussion by Rappaport (1985). IE is also related to Foster and Peyton Young's (2003) game-theoretical work on hypothesis testing by bounded-rational agents on their opponents' repeated games strategies. It can be considered as a 'fast and frugal heuristic' (see Gigerenzer et al., 1999) of belief formation characterized by information-gathering and information-processing costs.[7] A final link to existing literature can be seen by considering econometric learning (Evans and Honkapohja 2001). Learning, like IE, gains some legitimacy from the practice of

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[5] One author received criticism from a referee of a top-tier journal because significance was accorded to a test in the submitted paper with a *p*-value of 0.052.

[6] An implication of this is that Bayesian methods and IE need not conflict. Agents could be infrequent Bayesians, with the time interval between updates determined by a hypothesis test.

[7] Bacchetta and van Wincoop (2006) show how infrequency of belief adjustment can be formally related to the size of the adjustment cost.

econometricians, and is actually a sub-case of IE. If we take account of *both* the recursive least-squares estimates *and their standard errors*, then regression-based IE with $\alpha=1$ becomes econometric learning.

In the remainder of the paper we outline our IE research program. We show that it has the potential to explain why agents do not appear to use free information (Section 3), how belief changes could drive events like the Asian Crisis (Section 4), and how the IE paradigm could explain how volatility effects belief formation in financial markets (Section 5).

3. IE and the Cumulative Use of Information

The key feature of a hypothesis test is the maintenance of a belief in spite of contrary evidence, until some threshold is reached. To an outsider, the agent appears to be under-reacting to information, and then over-reacting to information. In reality, such an agent is using information *cumulatively*.

Here is how Fama interprets the evidence of under- and over-reaction in markets:

"…an efficient market generates categories of events that individually suggest that prieces over-react to information. But in an efficient market, apparent under-reaction will be about as frequent as over-reaction. If anomalies split randomly between under- and over-reaction, they are consistent with market efficiency" (1977, page 1[8])

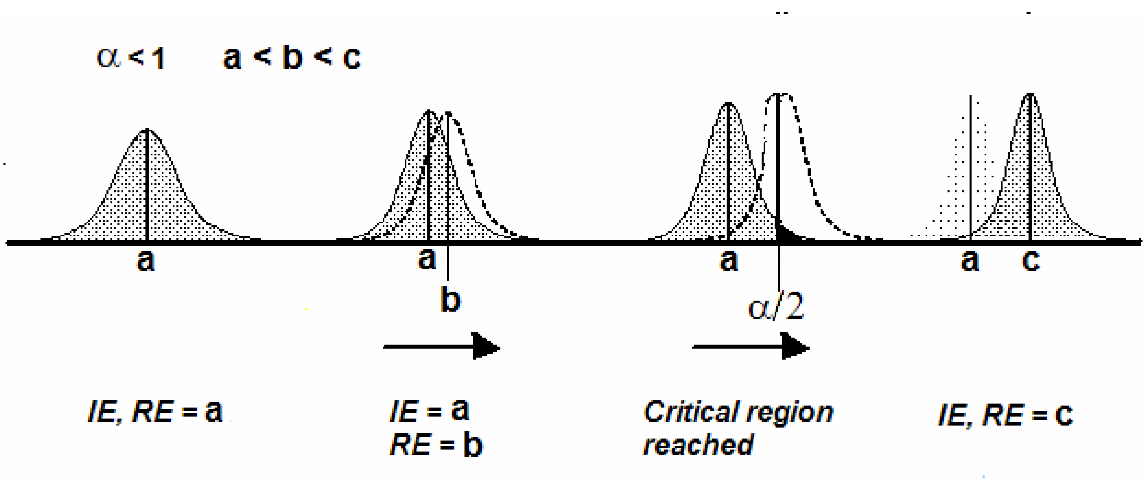
But it is also possible to say that agents 'under-' react when they are building a useful stock of knowledge and 'over-' react when they are ready to change their minds.

We now illustrate this within an IE context. In Figure 4, agents receive continual signals that indicate that the true value of a population parameter is higher than 'a', and

[8] For completeness, we should add that Fama goes on to say that empirical evidence of under- and over-reaction is not robust to different specifications.

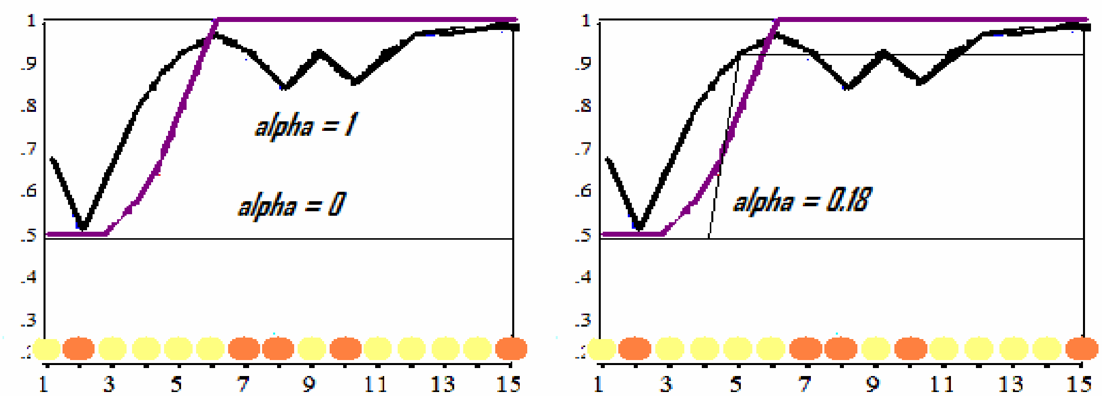
update a sample mean. The sampling distributions of $\overline{X}$ are shown. Initially, IE agents appear not to be using the information, but the RE agents revise upward their belief about the parameter as the sample mean rises to ‘b’. In fact, IE agents *are* using the information, but they are calculating a hypothesis test H_0: μ=a vs. H_1: μ>a. Until the RE estimate reaches the critical region, beliefs do not change. But at ‘c’ IE agents jump to the rational expectation as H_0 is overturned.

Figure 4: Under- then Over-use of Information in a Sample Mean Context



Menzies and Zizzo (2004) estimated least-squares alphas for the probability guesses for a group of subjects (one of whom was shown in Figure 1) under the assumption that they use IE. For each subject’s guess, the residual sum of squares is calculated for deviations from IE profiles. The IE profiles are created by incrementing alpha from zero (which means the subject believes the probability that the majority-white-ball urn is 0.5 irrespective of evidence) to unity (which means subject believes Bayes’ rule). Figure 5 shows the IE profile for a subject who believes alpha is zero, unity and 0.18. The latter, it turns out, is the least-squares alpha for the subject in Figure 1. Note that when the null (the probability is 0.5) is rejected, the IE agent with alpha =0.18 jumps to the RE given by Bayes' rule.

Figure 5: Least-squares Alpha for Subject in Figure 1



IE with alpha equal to 0.18 captures the 'hold then move' pattern of beliefs. Parcels of information are 'under-utilized' and then – at the point of rejecting the null – 'over-utilized' as we described in Figure 4.

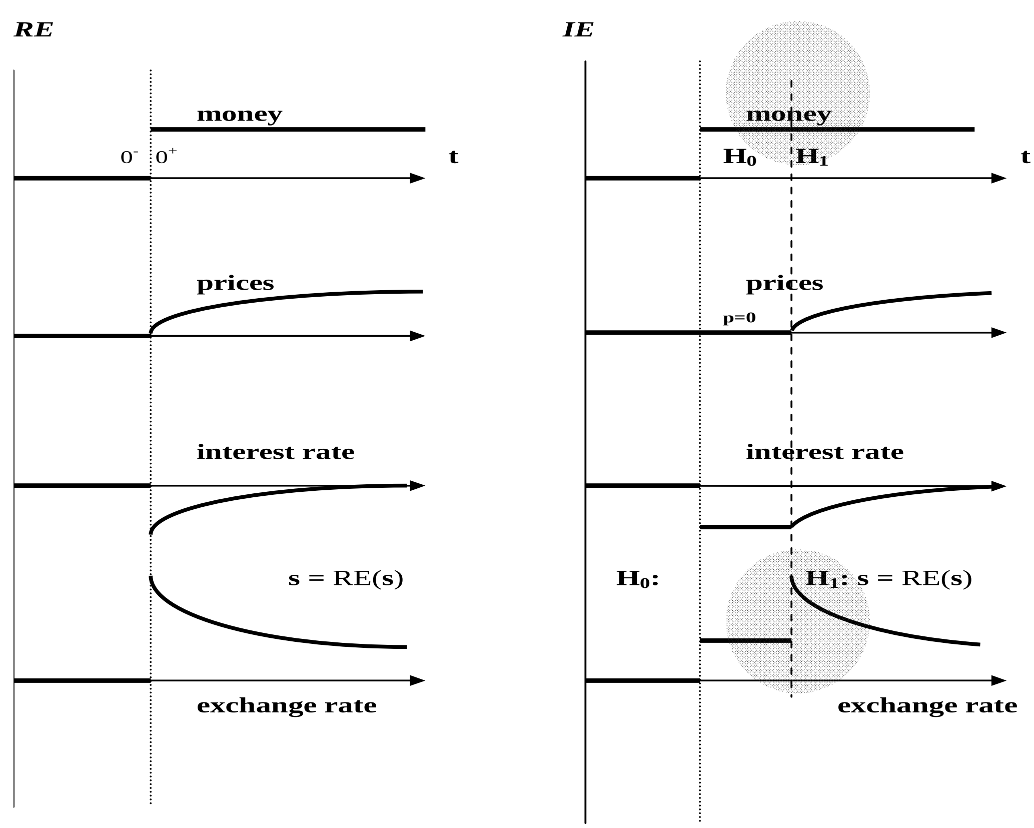
The distribution of α's calculated by Menzies and Zizzo suggest this 'hold then move' IE pattern of belief change is common. Around half of the experimental subjects had experimental α's that were strictly less than 0.9.

4 IE and Sudden Belief Changes

The discussion of section 3 makes it clear how an equilibrium could change dramatically in response to a small parcel of information. Greenspan 'got it' about the sub-Prime mortgage market in late 2005, and the process of many agent 'getting it' at the same time can potentially create market havoc. As news about, say, the quality of bank lending in Asia in early 1997 arrived, forex traders could have changed their views about prospective fiscal bailouts (Burnside et al. 2001). With IE agents, this could have been sudden, even if the last parcel of information was a proverbial straw.

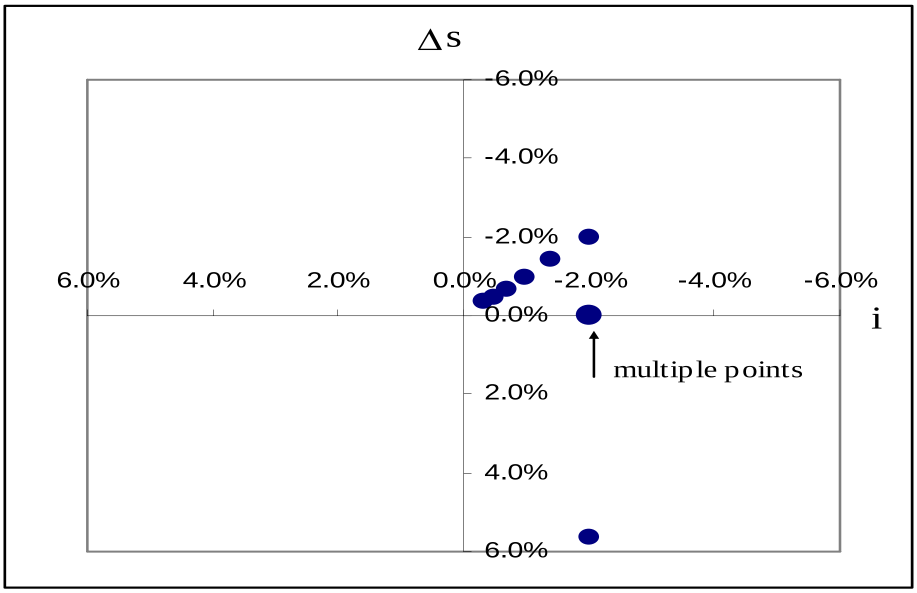
Menzies and Zizzo (2004) incorporate this into a model. They take the structure of Dornbusch (1976), and create an expectational environment where agents do not believe the monetary expansion is permanent until it has endured for a while. The resultant model has 'double overshooting' where a second jump depreciation occurs at the moment where the only parcel of news is that the money shock has remained in place for one more period. Agents realize monetary laxity is permanent, and depreciate the currency.

Figure 6: Sudden Dornbusch Depreciation in Response to Small News



As shown in Menzies and Zizzo (2004), the pattern of interest rates and future exchange rate changes in this ‘double overshooting’ model imply the downward bias in the UIP coefficient in their model. Figure 7 reproduces a scatterplot from a particular simulation.

Figure 7: IE and the Failure of UIP



Clearly, a least squares line will have a slope less than unity. The intuition comes from considering the Southeast point. The moment immediately prior to the second overshoot – just before people ‘get it’ about the permanence of the monetary expansion – the interest differential is negative and the future change in the exchange rate is positive. This point on the scatterplot will pull down the least squares slope estimate.

5 Volatility and Belief Formation within the IE Paradigm

The IE paradigm makes explicit the various elements involved in changing beliefs. An agent doing inference is always noting the difference between the evidence measure (say a sample mean) and a belief (say a hypothesized mean), while taking into account the volatility of the evidence measure. In the simplest of all cases, the null hypothesis (H_0: mean = μ) is rejected in a standard test[9] if:

$$Z_{calc}{}^2 = (\frac{\bar{x}-\mu}{\sigma/\sqrt{n}})^2 > Z_{\alpha/2}{}^2$$

If σ is fixed, then an increase in the sample size will eventually reveal an upward shift in the true mean, as in Figure 4. A larger sample size will shrink the sample variance (the rightward distributions in Figure 4 cluster more tightly around the mean).

This describes a financial or economic environment where agents somehow have a volatility measure given to them on a platter. An example would be inflation targeting, where many central banks give a spread for acceptable inflation. The provision of a volatility measure invites agents in the economy to change their expectations if the inflation leaves the band, thereby providing discipline for the central bank.

However, *it is often the case in financial markets that volatility is unstable.* Imagine a version of Figure 4 where the distribution happens to rise coincident with the increase in the sample mean (driven, we assume by an increase in the true mean).

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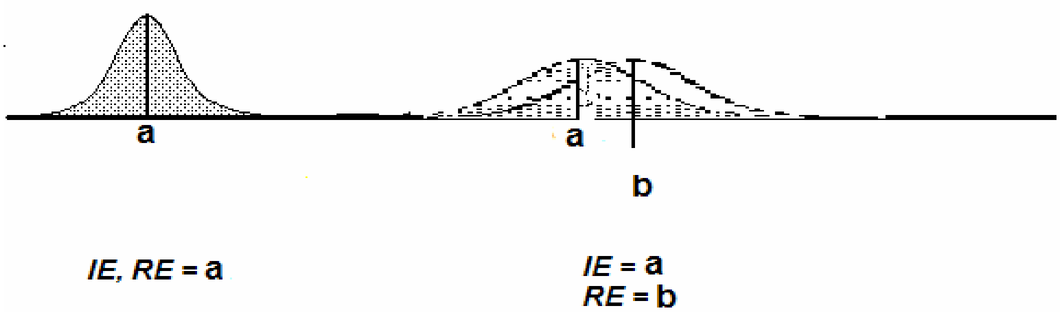
[9] To avoid writing a double inequality, we define the rejection region in terms of squares.

Figure 8: Inconclusive Inference in a Sample Mean Context



If the variance rises too much in tandem with the sample mean, then *the rejection region might not be reached*.

Naturally, the test statistic here embodies a grossly simplified model of a financial time series (that is, the data generating process of a constant plus i.i.d. noise[10]). However, it makes an important point which is not to be passed over lightly. While the impact of volatility on the construction of optimal portfolios has been exhaustively analyzed, the IE paradigm stresses that *volatility can create a safe haven for crazy beliefs*.

In the presence of volatility, agents can become confused about the relative performance of, say, indexed and managed funds. In IE terminology, agents *cannot reject the hypothesis that their active fund manager is really unable to beat the market*, in spite of them doing so in a particular quarter. This, together with the relatively high fees of active managers, may make it difficult for active managers to drive out passive managers who are trading on crazy beliefs. Yet the efficient markets hypothesis relies upon this very mechanism, to reverse the tendency for investors to opt for passive

[10] Under these circumstances the sample mean is a good estimator for the true mean.

management (Woolley and Bird 2003).[11] Thus the IE paradigm makes it clearer how volatility *allows all kinds of misconceived beliefs to be maintained*, for good or ill.

To put this point another way, while it is obvious that heterogeneous beliefs can create volatility, IE spells out a reverse feedback mechanism - volatility allows a large degree of heterogeneous beliefs to survive. This two-way feedback between volatility and misconceived beliefs raises the spectre of a 'belief shock' in markets. Some new idea or view gains sufficient credence in the market to create volatility. This volatility in turn allows other outlying beliefs (perhaps even less well-founded than the new idea) to hide under the umbrella of high variance, as decisive inference becomes impossible.

6 Conclusion

This paper has flagged a number of possible uses of hypothesis testing belief formation 'inferential expectations' within finance and economics. Although we use a new term, we do not believe that IE is a new idea at all. It always lies beneath, when agents as inexperienced as undergraduates or as well-informed as Alan Greenspan use statistical language like 'significant' about information.

Although theoretical work is at an early stage there are a number of reasons why the whole approach is potentially fruitful. They relate to the reasonableness of the assumptions, and the reasonableness of the implications.

Consider first the assumptions. Introspection, some experimental evidence, and the 'testimony' of Alan Greenspan about the sub-Prime mortgage market all suggest that agents (including firms and governments) like stable beliefs. This can be justified in a number of ways. Philosophically, the advancement of scientific knowledge mostly

[11] Paradoxically, as Woolley and Bird point out, the drift towards passive management is built upon the presumption of efficient markets. Thus belief in efficient share markets makes it less likely that efficient markets will occur.

follows a hypothesis testing approach on a micro-scientific level, as argued by Deborah Mayo and others. On a macro-scientific level, stable beliefs are an implication of Kuhn's (1970) model of paradigm shifts. Psychologically, there seems to be a 'hold then move' pattern whereby some agents process information for a time before 'making up their minds' (or 'getting it' as Greenspan put it). Bureaucratically, organizations may find change difficult since information processing is costly.

On the implications, IE seem reasonable. It can explain both periods of 'no response' (while the null hypothesis is maintained) and sharp discrete responses (when the null hypothesis is overturned). The latter may be either because there was a sufficiently big parcel of evidence, or because of mounting evidence in the environment. Thus IE addresses the challenge of Fama (1997), who argued that any alternative to RE must explain when under- and over-use of information occurs.

"the literature does not lean cleanly toward either [over-reaction or under-reaction to information] as the behaviourist alternative to market efficiency. This is not lost on behavioural finance researchers who acknowledge the issue:

'We hope that future research will help us understand why the market appears to overreact in some circumstances and underreact in others' (Michaely, Thaler, and Womack (1995, pg. 606).

The market efficiency hypothesis offers a simple answer to this question – chance. Specifically, the expected value of abnormal returns is zero, but chance generates apparent anomalies that split randomly between over-reaction and under-reaction"

(Fama 1997, pg. 5)

While it is too early to say what the IE paradigm will deliver, our tentative answer to the question of why markets over- or under-react is not ‘chance’. We instead believe that, at least sometimes, *the stock of relevant information* determines the use of marginal information. In attempting to explain examples of market dysfunctionality, such as the failure of uncovered interest parity, the sub-prime mortgage crisis or the prevalence of passive management, an IE research program will therefore turn the spotlight onto the quality and quantity of relevant information.

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