

Chaos, Prediction and International Financial Crises

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“A way of seeing is a way of not seeing” – Mark Twain

Preamble

There are a variety of possible ways of viewing the landscape of international finance. Each will reveal a different vista. Each offers a unique perspective. However, new perspectives may be disconcerting and controversial. When this happens there seems to be something about the human condition that encourages selecting from the multiple, sometimes dishabituating and uncertain images those most compatible with our routinized “ways of seeing” and evaluating the world. Indeed, conventional theories are often so pervasive that they hinder the emergence of alternatives. Not surprisingly, we tend to focus on the more habituated and purportedly rational scene, which may be a serious mistake.

Abstract

The lasting theoretical significance of the South East Asian financial crisis of 1997/98 is that it poignantly offers a critical empirical assessment of equilibrium-centered (first generation) models of international financial crisis. Situating discussion initially in a vignette and commentary on recent events in Argentina, and while reflecting upon the S.E. Asian crisis, we comment upon policy and protocol shifts evident in the International Monetary Fund. These are indicative of a demand for greater rigor in theorizing and modeling of international financial crises. From problematizing first- and second-generation models the paper turns to explore the conceptual basis for, and possible meanings of a third generation of models grounded upon Chaos Theory. At this juncture the domains of prediction and financial crisis instability are explored in formal terms. In this connection, the Lyapunov exponent is presented as an indicator of chaos or crisis instability that may be used to address such issues as the relative (in)stability of the international financial system. This proposed third generation of models could hold the middle ground between the often-formalized first generation of conventional neoclassical economic analysis and generally under-formalized Post-Keynesian second generation.

A Vignette and Background Commentary

During the 1990s, a number of emerging market economies experienced well-publicized financial crises: Mexico in 1994/95; South East Asia during 1997; Russia in 1998; and Brazil in 1999. By some estimates, the frequency of financial crisis has increased since the 1980s. For example, the World Bank documents 69 instances of systemic crisis since the late 1970s. The cost--

often lying between 10% and 20% of annual pre-crisis GDP-- and frequency of financial crises suggests that crisis prevention and crisis resolution are major international public policy concerns. Of central concern then are the models we employ in framing policy; for we decide and act not in response to concrete reality, rather our decisions are model-based. Indeed, Conant and Ashby insisted that, "every good regulator of a system must be a model of that system" (1970: 89). If our models are inadequate the governance of international finance is likely to be inadequate.

In the waning months of the year 2001, we were once again witness to a financial crisis the analysis of which, in the main, was grounded upon an equilibrium-centered rational agency theory long embraced by conventional economic analysis (Kindleberger, 1978; Wolfson, 1986). Confronted with then merely the prospect of crisis and in a pragmatic turn, Argentina's Economy Minister Domingo Cavallo sought to negotiate with both local banks, to lower rates on \$20 billion in provincial debt, and with pension funds, to swap \$3 billion in high-yielding government paper for bonds paying one-third of the original interest rate. Such an arrangement was considered by international ratings agencies, such as Standard & Poor's as a virtual default. The Financial Times reported on October 17, 2001 that some IMF officials were openly speculating when, not if, Argentina would default. At that time average yields on Argentina's existing bonds, with the country risk premium—relative to US Treasury bonds—rose to nearly 23 percentage points on October 31, 2001 surpassing the previous high reached in March 1995 at the height of Mexico's "tequila crisis."

Indeed, early analyses suggested that, while Argentina would default on its debt, and that the event would negatively bear upon a fragile Brazilian economy and possibly instigate a Latin America recession, a global contagion would, however, be forestalled. Pundits were provisionally right when they claimed that it was unlikely that we would observe an acute shock comparable to that which followed the Thai and Brazilian devaluations or the Russian debt default of the late 1990s.

Financial institutions have taken a stronger interest in analysis of currency fluctuations. In the wake of the financial debacles in Asia, Russia Brazil, and Argentina these institutions have become decidedly more wary about international investing, especially when it comes to emerging markets. Relatively recent institutional protocol shifts were foreshadowed by recommendations from the Basel Committee on Banking Supervision that called for new capital risk assessment models (Euroweek 2001). Subsequently, the International Monetary Fund observed in its World Economic Outlook report, "internationally active financial institutions and other asset managers appear to have engaged in a wholesale reassessment and re-pricing of

financial risk.” Consequently, the situation in today’s emerging markets is allegedly different from what it was in 1998 and it is different in several respects.

It is argued that while the Thai and Brazilian devaluations and the Russian debt default caught most of the world unaware, global markets substantially discounted an Argentine default. With respect to the Russian experience, given its significant dependency upon oil revenues (approximately 25% of its budget), the oil glut and depressed prices of 1998 may have been a trigger mechanism for the Russian default. The country saw the sharpest decline in its risk rating in 20 years. Though oil revenues today provide 25% of the national budget, Russia relies increasingly on longer-term natural gas contracts and income. That its debt obligations are apparently being met and its credit rating repaired suggests that it may assume additional credit even in the event of another OPEC-initiated oil glut.² At the same, and with lingering memories of 1998, and the re-pricing of financial risk, investors have lessened their exposure in emerging markets. The Institute of International Finance predicted that net private capital flows to emerging markets would drop to \$106 billion in 2001 from \$167 billion in 2000. With less exposure in emerging markets now than in 1998, there is less speculative financial capital to be withdrawn when a shock comes. To cushion the shock the International Monetary Fund announced in early October 2001 it would provide an \$8 billion emergency aid package to Argentina. This raises the International Monetary Fund’s total disbursement to Argentina since December of 2000 to \$22 billion.³ Moreover, the combination of poor performance of the established European, American and Japanese equity markets in the fall of 2001, and declining short-term economic prospects in developed economies meant that appealing alternatives were few and far between for institutional investors. With these fundamentals in mind, it is argued that the consequence of an Argentine default on the global economy were muted, and that global markets were better positioned to weather a storm than in earlier episodes of financial crisis.

To purportedly minimize the damage from the financial collapses, the IMF’s crisis forecasting capabilities are being addressed.⁴ And while this brings us to the very point of this

² Indeed, oil prices fell 10 percent after the November 14, 2001 OPEC meeting where ministers refused to cut production. The organization elected to link production cuts to proportional action by non-OPEC producers. And, with Russian output now comparable to that of Saudi Arabia, Russia may engage a price war.

³ The IMF also granted Brazil a \$15 billion package to help insulate its economy in the event Argentina defaults on its \$132 billion of foreign debt. However, before Argentina defaulted on its \$141 billion sovereign debt late last year, IMF officials indicated that no new funding would be available to it.

⁴ The IMF “has launched a number of initiatives to enhance its ability to contribute to international financial stability: identifying and monitoring weaknesses and vulnerabilities in international financial markets; developing early warning systems for international financial market imbalances; conducting research into the nature and origins of international financial crises and the channels of contagion; and seeking ways to contain and resolve crises quickly and smoothly”

paper, the argument is that if the rest of the world has enough advanced warning, investors can build firewalls around the doomed economies, thereby minimizing that damage to other markets. Such a strategy allegedly worked in Argentina's case. Pursuant to this strategy, while arguing the case for transparency and accountability (World Bank Development News 2001) the IMF is apparently refashioning its global strategy. In those instances where problems are beyond IMF reserves, i.e., Japan, the objective is not to impose conditionalities and seek structural reforms, but simply to buy time so exposure is minimized in the event of collapse.⁵ With this strategy in mind one can expect emerging market country risk indicators to rise and creditworthiness to suffer a further decline. Kindly note that such a policy shift places an onus on crisis forecasting models. Ostensibly, equipped with better forecasting models, the likelihood of a repeat of the Asian contagion or a recurrence of the Russian default is allegedly diminished. It purportedly follows that such future events will be neither as severe nor as long lasting as the Russian default or the Asian currency devaluations.⁶

Eccentric Fundamentals or Terrified Rabbits

What we shall refer to as first generation of international financial crisis models were motivated largely by the Latin American crises of the late 1970s and 1980s. In these models, the actual and expected deterioration of fundamentals, for instance, domestic credit expansion, purportedly pushed economies into crisis. Building upon rational expectations hypotheses about these fundamentals and among atomistic investors, the currency collapse is anticipated (in the model). Most analysts tried to explain crises in terms of fundamentals factors, either an abrupt changes in international market conditions that affect the ability of debtors to repay outstanding loans, such as shifts in interest rates, commodity prices, (i.e., oil), or trade conditions; or shifts in the debtor country that cause creditors to reassess that country's ability or willingness to service the foreign debt. Paradigmatically coherent, the theory embraced by conventional economic

writes Gerd Häusler, Counsellor and Director of the IMF's International Capital Markets Department (Häusler, 2002).

⁵ In the case of Argentina, the IMF is demanding harsh austerity conditions, including cuts in public spending amounting to about 4 percent of Argentina's output in order to discourage other countries from defaulting on their debt. The argument is made that this is for the benefit of developing countries as a whole. But one must ask about the concept of justice sustained by holding Argentina accountable for failed policies that were the joint project of the IMF and the Argentine government. "The IMF led a whole series of mistakes, from exchange rate policy, to fiscal policy, to the privatizations, that culminated in disaster in Argentina," notes Nobel prize-winning economist Joseph Stiglitz.

⁶ While conventional economic analysis suggests a contained problem, politically the Argentine default has rendered problematic the further pursuit of a hemispheric free trade agenda. As a result, U.S. relations with Latin America have take a different turn, including a closer focus on the US's third-largest foreign supplier of oil—Venezuela. This is evident in the wake of the April 11-14, 2002 military coup d'état and reversal and allegation of US involvement (The Observer, April 29, 2002).

analysis provides us with a measure of comforting assurance suggesting the possibility of crisis avoidance and containment (Yip 2001; Chan-Lau & Chen 2001).

The policy recommendations flow from the analysis argued that the optimal way of lessening the probability of crisis (as well as cultivating sustainable economic and social development) is through prudential monetary and fiscal policies. In this connection, multilateralization within the framework of the WTO meant harmonization of fiscal and accounting regulations in banking and other financial sectors.

While national authorities and the international financial institutions aggressively pursued such policies, it is questionable whether prudential monetary and fiscal policies are a sufficient condition to avert a collapse. Possibly excepting the Russian case, a striking feature of the recent crises in emerging markets is that the typical international factors were not present. In the crises of 1994 and 1995 (in Argentina, Mexico, Turkey, and Venezuela), international financial conditions were believed to be stable. The East Asian crises of 1997/98 are even more remarkable. Not only were the international factors seemingly absent—with benign conditions in international financial markets, commodity markets, and the trading system—but the domestic factors that contributed to the crises in Mexico and Argentina did not apply either. Indeed, Paul Volcker, former Chairman of the Board of Governors of the U.S. Federal Reserve remarked: “the timing, nature, and force of the Asian financial crisis [cannot] be explained in terms of ...structural factors, important as they may be over time. None, of them is new. None of them has been unknown nor, to the best of my knowledge, suddenly gotten worse” (Volcker, 1999: 4).

The chief weak spots in the first generation models stem from the assumptions of the underlying economic theory on which they rest: assumptions about the rationality of human behavior, about the availability of information that real decision makers do not have, and about equilibrium. Many economists acknowledge the concerns with idealization and abstraction of these assumptions. However, a growing number of prominent economists argue that these assumptions are not just abstract—they are false. In his presidential address to the British Royal Economics Society, E. H. Phelps-Brown said: “The trouble here is not that the behavior of these economic chessmen has been simplified, for simplification seems to be part of all understanding. The trouble is that the behavior posited is not known to be what obtains in the actual economy” (Phelps-Brown, 1972: 4). Nicholas Kaldor was not less blunt: “in my view... equilibrium economics is barren and irrelevant as an apparatus of thought” (Kaldor, 1972: 1237). Nor can we ignore the concerns of Herbert Simon, whom in his acceptance speech for the 1978 Nobel Prize in economics, concludes: “There can no longer be any doubt that the micro assumptions of the theory—the assumptions of perfect rationality—are contrary to fact. It is not a question of

approximation; they do not even remotely describe the processes that human beings use for making decisions in complex situations" (Simon, 1979: 510).

Turning from theoretical concerns to factual ones we know that the countries beset by the Asian contagion had, in the main, enacted prudential policies in advance of their problems. Evidently crises can occur even with "robust fundamentals." Where creditors—acting like a herd of terrified rabbits—behave "strategically," rather than atomistically, coordination failure driven by "animal spirits" rather than rational calculus presents itself (Stokes, 2000). J.M. Keynes understood that financial markets do not respond to objective truths, or to prevailing opinions about objective truth. They react to perceptions of how others perceive the likely behavior of the markets. Our expectations and decisions depend upon what we believe others will do, and what we believe others will do depends upon what they believe we will do, and so on. It is a case of expectations about expectations about expectations.... We encounter a problem of infinite regress that cannot be circumvented unless actors know in advance about each other's capabilities, expectations, and policy decisions. Unless we have homogeneous information—there is no way out of this regress.⁷ There is thus no determinate way to accurately anticipate creditors decisions. If some chance event is sufficient to unfavorably revise creditor's collective expectations, then those expectations can become self-fulfilling. In such a manner, a nation can hurtle into crisis driven by little more than herd mentality and stampede behavior; all of this operating blissfully independent of long-sanctioned "fundamentals" and the reified rational choice model. Economies as a whole can be subject a classic panic bank-run. Such behavior on the part of the creditors, although rational within their own terms, makes crisis and default a self-fulfilling prophecy.

Apart from irrational social psychology of the herd, the apparently eccentric nature of the so-called fundamental suggests the possibility, not only of the endogenous nature of financial instability (Minsky, 1986; Papadimitriou & Wray, 1997; Schumpeter, 1934), but of intrinsic crisis instability in the international financial system where it is impossible to predict the direction that the system will follow at a bifurcation.⁸ Under such circumstances clearly the challenge is to

⁷ The infinite regress created by rational expectations hypothesis demonstrates the questionable coherence created by this of mode of analysis. Paradoxically, the overstatement of rationality made by rational expectations is at the same time an understatement of rationality. Creditors are presumed to know too much (for example, each other's expectations), but also to know too little. It would be irrational for creditors to deny their own ignorance or to avoid responding to it, yet this is exactly what the rational expectations hypothesis appears to require. Rational expectations thus offer an example of Jon Elster's (1989) characterization of hyper-rationality as a form of irrationality.

⁸ The policy conclusions one might draw from this are: (i) the real problem lies with banks and their regulation rather than debtors; (ii) international capital mobility may not maximize economic efficiency if banks are guaranteed and under-regulated; and, (iii) there should be no bailout since the collapse for example from speculative bubbles is

consider another generation of models that paradoxically offers the possibility for predictability in an otherwise unpredictable situation.

Because countries can be driven into crisis independently of fundamentals, the second-generation models admit multiple equilibria; for there is a range of state of affairs over which an economy is susceptible to crisis. That a trigger for crisis is a random, unpredictable event, from conventional theoretical perspectives thwarts public policy analysis because it is problematical within welfare models to determine what optimal policy measures might avert a crisis because an equilibrium is not precisely identified. The purpose of this paper is not to elaborate upon or mitigate neoclassical or Post Keynesian models, but, (with some abandon), to explore the potential predictive role of chaos theory. Our interest in speculatively exploring chaos theory is all the more relevant in view of the evident interest in upgrading the IMF's crisis forecasting capabilities.

As we have seen once we depart from the determinacy in the land of rational choice modeling and slip uneasily from economics to psychology things become decidedly messier. As Tobin (1980) points out, there exists no determinate basis on which any one individual can rationally form such expectations. Yet were we to turn to other modes of analysis the picture may decidedly less reassuring. Here so-called fundamentals and their indicators, by any definition, may be neither sufficient nor indeed necessary conditions to determine the likelihood of a crisis, nor are they positively indicative of policies enabling crisis avoidance.

Although pundits and respectable theorists alike may assure us that the processes set in action are unequivocally logical within the context of international financial modeling, the lived reality seems to many—not excluding Argentine officials—decidedly illogical. Chaos theory may offer a way of seeing that puts to rights the often sharp distinction between the theory of international finance and its reality—to understand how the ordered, deterministic processes of the theorists lead to a disordered, prediction-resistant real world (Prigogine & Stengers, 1984; Radzicki, 1990).

inevitable. Indeed, it appears as if the IMF may heed these conclusions and selectively retreat from conventional modes of reducing systemic risk, by acting as a lender-of-last-resort a condition that purportedly exacerbates moral hazard. Lender-of-last-resort action virtually assures that crisis will follow crisis unless legislated and/or administered policy changes prohibit (or at least discourage) fragility inducing financial practices. There being no legislative body in the conduct of international affairs the issue is moot. Theoretically we are invited to revisit J.M. Keynes's theory of the non-neutrality of money (Davidson 1988).

A Way of Seeing Where Prediction Becomes Impossible

Financial crises and speculative attacks are evidently increasingly frequent events. However, in the case of East Asia years went by with little hint of a pending currency collapse. In Argentina it matured at a different pace. During these episodes of relative stability, one might jump to the conclusion that international financial markets really are very stable and predictable or are converging toward a stable equilibrium state.

The first generation of international financial models employed in country risk analysis is grounded in linear dynamics (comparative statics) and where proportionality reigns. Here one seeks fundamental solutions from which one can build all other solutions. Were the IMF and global institutional investors to more broadly examine crisis-forecasting methodologies, they would do well to explore nonlinear dynamical models admitting the aperiodic behavior we actually bear witness to in international affairs. In this regard, the questions they ask themselves are likely to change; for in nonlinear dynamics, the main questions are: What is the qualitative behavior of the system? At this juncture it is possible to describe a set of behaviors typical of chaotic or dynamical systems.

The presence of unstable aperiodic behavior in deterministic nonlinear dynamical systems (Kellert, 1993: 2) that is of chaotic patterns in international finance threatens to render long-term forecasting impossible as it admits fundamental uncertainty and makes nonsense of notions of rational global decision-making. But it also increases the risk associated with even short-term international flows and lead to a further de-linking of the financial from the real economy. As obliquely implied above chaos in financial markets may contribute to a wider chaotic condition; one that invests international politics and security.

The outcomes of chaotic systems are not regular patterns that exhibit smooth cycles or well-behaved equilibria. Rather, a key characteristic of chaotic systems is the seeming randomness or unpredictability of the patterns and flows generated. In a non-chaotic system, a close study of the past offers insights that allow us to anticipate the future. Here the past is *not* prologue.

For a chaotic system, however, no matter how long we accumulate data on the past positions of the system, we cannot accurately predict its transition from the present position to the next one (or to any of the future ones). In this case, we can only make probabilistic forecasts, if any at all (Medio, 1992: 5-6).

As second generation models of international financial crises suggest the system is dynamical, not static. It is not a system of eloquent equations to be solved simultaneously for equilibrium, but rather a description of a movement through time, in which each instant's

condition is related to the moment before and determines the condition of the next moment (Setterfield, 1998). Most economic analysis is static because this allows us to work on mathematically tractable quantification with an interest in optimization. But while the resulting models are theoretically tractable their empirical performance is questionable (Boland, 1992; Cassidy, 1996; Hosseini, 1990; Shiller, 1989: 78).

Chaos occurs when the systems are nonlinear, and for this reason the term “nonlinear dynamics” is often applied to what we call chaos theory. In a linear system, patterns of behavior are regular and potentially reversible. Actions respond to their stimuli proportionately and in a constant direction at a constant rate and display the same behavior going forward and backward. Linear systems are convenient for theory because they are so well behaved. The world is generally nonlinear, however. As stimuli increase, actions increase and decrease at varying rates of acceleration and deceleration. With entropy as time’s arrow, nature does not always work the same going forward and backward. While a linear system may provide a workable description of nonlinear behavior within a very local region, the resemblance breaks down over time in a dynamical system and as the focus of attention shifts from local to global (Cerny, 1994).

One common feature of chaotic systems is that small changes in parameters ultimately cause enormous changes in outcome or behavior, as the tiny initial differences are magnified and transformed by the nonlinear dynamical processes at work. It is not very difficult to understand how sensitive dependence manifests itself. In chaotic systems, sensitive dependence suggests that small differences in starting points or pathways can create both quantitative and qualitative differences.

For our purposes here, a final property often cited is the presence of the somewhat ambiguously named “strange attractors.” It means that there is a tendency for chaotic patterns to veer suddenly from one local range of observed values (an attractor) to another and perhaps back again at unpredictable intervals. The property of strange attractors is related critically to the notion of unstable aperiodic behavior referred to above.

The American meteorologist Edward N. Lorenz in his most famous paper, “Predictability: Does the Flap of a Butterfly’s Wings in Brazil Set Off a Tornado in Texas?” (1993: 181-184) argued that the earth’s atmosphere is a complex space and it is not unreasonable to believe that small causes can have large effects – the butterfly effect. The Lorenz Attractor shows patterns of atmospheric convection modeled by simulating the flow of fluid in a pot that is heated from the bottom (Prigogine, 1972: 552-553). This process is nonlinear and dynamical. The outcome is unstable and aperiodic. The two strange attractors are the most obvious visual

evidence of instability. The movements between and within each attractor are aperiodic. As Henri Poincaré wrote of this condition: “La prédiction devient impossible” (in Lorenz, 1993: 118).⁹

Models of international finance that fail to take into account the chaotic behavior of financial markets risk exaggerating the value of conventional analysis and risk belittling the importunate impact of endogenous factors in the economy.

There is little doubt that economics and finance give us examples of chaos and unpredictable behavior, but economists seek the same sort of deep understanding of social phenomena that physicists have of natural behavior, the onto-epistemological as well as methodological constraints of social science limit what can be accomplished. In economics chaos theory may offer little in the way of quantitative analysis, rather its *qualitative* understanding. William Baumol and Jess Benhabib have argued that the most important contribution of chaos theory to economics currently is its ability to broaden our vision, “revealing sources of uncertainty, and enriching the list of recognized *possible* developments” (1989: 80). Chaos theory suggests that unstable fluctuations may be at least as common as other sorts of economic behavior and that the seemingly random need not, in fact, be random. Armed with this appreciation, the axiomatic dimensions of first generation models, are subject to serious questioning. Admitting chaos theory may mean, for instance, that the benefits of allocative efficiency may be neutralized by unforeseen stability problems. As Ruelle noted: “The complicated system obtained by coupling together various local economies is not unlikely to have a complicated, chaotic time evolution rather than settling down to a convenient equilibrium” (Ruelle, 1991: 84-85).

International financial markets may prove to be one of the most successful application areas for chaos theory. Indeed, Paul De Grauwe, Hans Dewachter, and Mark Embrechts (1993) produced some of the most cogent analysis of the chaotic behavior of international financial markets on the basis of daily exchange rate data for the period January 4, 1971, through

⁹ Lorenz (1993: 118-119) writes that Poincaré “raises the possibility that what we generally regard as chance, or randomness, may in many circumstances be something that has of necessity followed from some earlier condition, even though we may be unaware that it has done so. He notes that in some cases we might be completely unable to detect the relevant antecedent conditions, while in others we might observe it fairly accurately, but not perfectly. In the later case the uncertainty might amplify and eventually become dominant. Is he not describing chaotic behavior?”

“Although Poincaré posed the problems of chaos, he lacked the technology to explore them fully. Pointedly, he lacked the computing abilities that today allow us to make millions of calculations in a moment and hence to explore the richness of dynamical processes.”

December 30, 1990, for the deutschmark-dollar, pound sterling-dollar, and Japanese yen-dollar rates. De Grauwe et al. (1993) found that relatively simple models of foreign exchange behavior could produce chaotic patterns of exchange rate movements under reasonable conditions. Ghashghaie, Breymann, Peinke, Talkner, and Dodge (1996) analyzed data from the dollar-deutschmark exchange rate from 1992–1993 and found cascading effects over time that paralleled the cascading behavior in dynamical systems. Although neither the De Grauwe et al study nor the Ghashghaie et al. (1993) analysis offers conclusive evidence of chaos, it does support the view that chaotic processes are worthy of investigation in international financial markets. The argument that obtain from the studies of Baumol and Benhabib (1989), Ruelle (1991), Ghashghaie et al. (1996), as well as De Grauwe et al. (1993) invites us to widen our analytical domain and they challenge us to rethink the complex relationships we study in international finance. Indeed, with chaos theory as our guide, the “future history” of the international financial system may be substantially unknown.

Non-Linearity and Dependence on Initial Conditions

Chaotic systems are acknowledged as exhibiting sensitive dependence on initial conditions that, as Poincaré reminded us, makes long-range planning and prediction impossible. Sensitivity to initial conditions unceremoniously indicates that our knowledge can never be sufficient. In other words, the problem is not epistemological; it is ontological. More substantively it means, “that two states differing by imperceptible amounts may eventually evolve into two considerably different states. If, then, there is any error whatever in observing the present state-- and in any real system such errors seem inevitable--an acceptable prediction of an instantaneous state in the distant future may well be impossible” (Lorenz, 1963:133). To show in general terms what non-linearity infers for the evolution of a system, and specifically how dependent such behavior is on initial conditions, is trivial. Following De Vree (1991:44) let us assume that the state of a system at time n is illustrated by a scalar magnitude x_n , and that the change of the system’s state at n into $n+1$ is governed by a scalar function f , such that

Equation 1

$$X_1 = f^{(1)}(x_0)$$

$$X_2 = f \{f(x_0)\} = f^{(2)}(x_0)$$

$$X_3 = f \{f \{f(x_0)\}\} = f^{(3)}(x_0)$$

Depicted more generally as:

$$x_n = f(x_{n-1}) = f^{(n)}(x_0)$$

and where $f^{(n)}(x_0)$ represents an iterated function illustrative of the evolution of a system over a period of time n .

However, for non-linear relationships, the manner in which x_n varies with x_{n-1} , i.e. the dependency of descendant system states on their predecessor states, is itself a function, g , of the predecessor state. This may be represented as

Equation 2

$$\partial x_1 / \partial x_0 = g(x_0) = g\{f^{(0)}(x_0)\}$$

$$\partial x_2 / \partial x_1 = g(x_1) = g\{f^{(1)}(x_0)\}$$

$$\partial x_3 / \partial x_2 = g(x_2) = g\{f^{(2)}(x_0)\}$$

Depicted more generally as:

$$\partial x_n / \partial x_{n-1} = g(x_{n-1}) = g\{f^{(n-1)}(x_0)\}$$

As for the dependency of the system's subsequent states on its initial condition, applying the chain rule, we obtain

Equation 3

$$\partial x_1 / \partial x_0 = g(x_0) = g\{f^{(0)}(x_0)\}$$

$$\partial x_2 / \partial x_0 = g(x_1) \cdot g(x_0) = g\{f^{(1)}(x_0)\} \cdot g\{f^{(0)}(x_0)\}$$

$$\partial x_3 / \partial x_0 = g(x_2) \cdot g(x_1) \cdot g(x_0) = g\{f^{(2)}(x_0)\} \cdot g\{f^{(1)}(x_0)\} \cdot g\{f^{(0)}(x_0)\}$$

Depicted more generally as:

$n-1 \quad n-1$

$$\partial x_n / \partial x_0 = \prod_{n=0}^{n-1} g\{x_n\} = \prod_{n=0}^{n-1} g\{f^{(n)}(x_0)\}$$

$n=0 \quad n-0$

Evidently the effect of an n -step iteration of a non-linear function, or, the state of a system after evolving for a period n is strongly dependent on the function system's initial state.

Therefore, minute disparities in a system's initial state are manifest in terms of a significant difference. This, once again is indicative of the Lorenz Attractor.

When studying social phenomena we must apparently be prepared for minute disparities giving rise to disproportionately differences in such things as the development of individuals, the working of the economy, the evolution of political organizations, and, for our more immediate purposes, in matters of international finance. Thus, statistically insignificant perturbations in the international financial system may well trigger spectacular and devastating positive feedback loops. Financial crises can flow from relatively minor shocks or perturbations, such as might have occurred in the case of the sudden rises in oil prices in the early 1970s, the case of South East Asia in 1997-98, and the Argentine crisis of 2001-02.

Crisis instability, chaos, and predictability: a model of the outbreak of an international financial crisis

In constructing a predictive model of the outbreak of an international financial crisis let us begin from the following conception of prediction. Let us represent the present state of the international financial system by X_0 . A vector of parameters, λ , is assumed to change that state into a different state X_n . Furthermore, assume that different vector of parameters will result in different futures, i.e. different values of X_n . Prediction, then, implies knowing X_n given X_0 and a specific vector, λ . This introduces a dynamical system that can be expressed mathematically as a function:

Equation 4

$$X_{n+1} = f(X_n, \lambda)$$

Where λ represents the vector of parameters that define the form of the function f . Different specifications of λ , imply different functional relations between present and future states of the international financial system. Equation (4) relates the system state at time n to the next time $n+1$. Through iterating the function it is possible to advance into the future. For example, to go from the present, X_0 , to the future, X_n , we iterate as follows:

Equation 5

$$X_1 = f(X_0, \lambda), X_2 = f(X_1, \lambda), X_3 = f(X_2, \lambda), \dots, X_n = f(X_{n-1}, \lambda)$$

The eventual outcome of any process is the value of X iterated into the future: $X_n = X_\infty$ as n approaches infinity. This set of values is known as the attractor of Equation (4) and varies as the

parameter λ is varied. Thus, the problem of prediction may be reformulated as: “given X_0 and λ , what is the attractor X_∞ ?”

A second assumption obtains from the concept of crisis instability, which may be defined in terms of an extreme sensitivity of system behaviour to small changes in input or system parameters. Small perturbations, such as may occur in context of the international financial system, may lead to significant phenomena. What we need to ascertain is when otherwise insignificant variations lead to crisis instability and the outbreak of an international financial crisis.

Illustrative of such instability is the case in the fall of 1929, when the flow of bond financing from the United States to Latin America suddenly evaporated, leading to widespread defaults by Latin American sovereign borrowers that took nearly a generation to resolve as the US lapsed into depression. Sixty years later the world's markets shuddered under the stress of the Russo-Asian financial crisis and many were asking: Whether the break in the Russian markets would destroy what was left of the Russian financial system. Was there a bottom under the Asian markets? Were the American stock markets about to plunge, turning a regional crisis into a global depression? History did not repeat itself. Indeed, rather than suffer a financial “melt down,” with Russian Central Bank reserves at \$38.4 billion, (the highest in Russian history) and seeking to mitigate its financial burden, Russia announced in October 2001 it would pay off a portion of its \$160 billion debt foreign debt ahead of schedule.

These examples suggest that while the international financial system was “crisis unstable” in the 1920s and 1930s, it was relatively “crisis stable” in the late 1990s. In the latter case otherwise significant perturbations did not trigger global changes in the system output. More generally, it appears that some system states may be crisis stable, whereas other tends to be “crisis unstable.” In terms of Equation (4) this means that for some ranges of λ small changes in X_0 will lead to small changes in X_n , whereas for other ranges of λ small changes in X_0 will lead to small changes in X_n , whereas for other ranges of λ small deviations in X_0 may produce highly disproportionate shifts in X_n . The major purpose of the model is to get to know whether a present system state, X_0 , and/or vector of parameters, λ , will lead to the desired end state, X_∞ , i.e. *crisis stability* (a system state where the outbreak of financial crisis is unlikely) or to an undesirable – that is strange – attractor, X_∞ , i.e. *crisis instability* (a system state where the onset of financial crisis is expected).

The underlying concept of crisis instability is clearly inspired by the extreme sensitivity to small changes often displayed by non-linear systems, a quality that is now commonly referred

to as “chaos” (Waldrop 1994; Brown 1995; De Vree 1991). Of special interest is that the same non-linear system may reveal both non-chaotic behaviour and chaotic behaviour. In the first case prediction is possible because the future risk is of the same order of magnitude as present risk.¹⁰ As a result small variations in input, δx_0 (due to disturbances and measurement errors), lead to commensurate variations in system output, $\delta x(t)$ (see Figure 1). Put differently, the trajectories from closely neighboring starting points remain close.

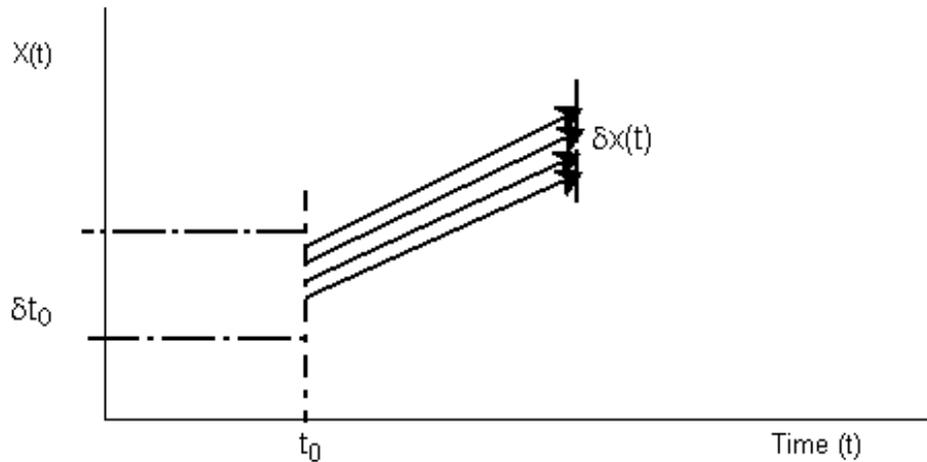


Figure 1

In the second case, prediction is not possible as the model system is extremely sensitive to small perturbations, δx_0 , resulting in disproportionate shifts in system output, X_n (see Figure 2). More specifically, as the trajectories diverge “exponentially,” the rate of increase of the divergence is itself proportional to the separation; hence it increases as the latter increases, leading to an explosively increasing separation. Consequently, the final outcomes admit all possibilities allowed in the system. Therefore, prediction becomes impossible, as every future outcome is possible, meaning that we are wholly ignorant of what is to happen. Such a situation is typically chaotic.

¹⁰ We need to make a distinction between risk and uncertainty and are aided in this endeavour by J.M. Keynes, G. Shackle and F. Knight. Keynes views probabilities as beliefs attached to propositions about events while Knight to events themselves. While for Frank Knight uncertainty is a property of external material reality, for Keynes it is a property of knowledge, expressing degrees of belief. For Shackle, as for Knight, uncertainty is epistemic, in the sense that it is a property of knowledge rather than reality. All depart from narrow accounts that reduce uncertainty to probabilistic risk, by which genuinely uncertain situations are expressed in terms of certainty or certainty-equivalents.

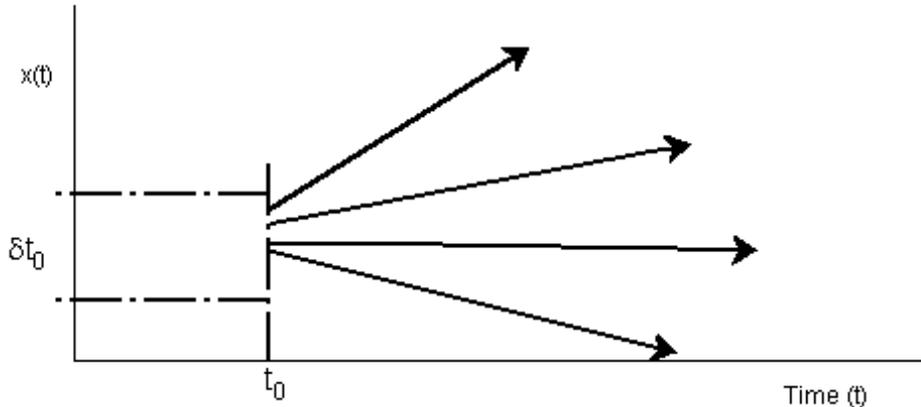


Figure 2

In the model, the outbreak of international financial crisis is comparable to the onset of chaos. As a provisional hypothesis, we assume that the transition from stability to crisis in the system can be represented by a transition from non-chaotic to chaotic behaviour in the non-linear model representing the interactions of the complex adaptive systems (Anderson, Arrow & Pines 1988a; Arrow, 1988b). In other words, if the onset of financial chaos is predicted in the model, then crisis instability, and therewith the outbreak of financial crisis, might be expected in the actual system being modeled.

Predictability or unpredictability of non-linear systems: the Lyapunov Exponent

In speculatively positing a third generation model, we need a technique to identify the absence or presence of chaos. We need some measure of chaos. For the sake of argument we use the model as specified in Equation (4), i.e. a dynamical model evolving from the present to the future via discrete, iterative and recursive relations. The possible starting points, δx_0 , present a path towards the future by means of the model mechanism. If the paths from closely neighboring points cohere, prediction is possible (Figure 1). Were the trajectories to separate “exponentially,” prediction is impossible (Figure 2). A useful numerical indicator of trajectory separation is the Lyapunov Exponent¹¹ (see Brown 1995: 22-26). To give an idea of how this exponent is calculated,

¹¹ The Lyapunov exponent (Ψ) is quantitative measure of the sensitive dependence on the initial conditions. Alternatively, it could be understood as a numerical indicator of path separation and one that is indicative of a “prediction horizon” beyond which even qualitative predictions are impossible. In effect, the Lyapunov exponent is also an indicator of risk and uncertainty.

let X_0 and X'_0 be any two neighboring starting points separated by a small distance δ_0 ¹. Applying the iterative procedure of Equation (5) these points evolve respectively to the configurations X_n and X'_n , separated by the distance $\delta_n = |X'_n - X_n|$, which may be written in the exponential form

Equation 6

$$\delta_n = \delta_0 e^{n\Psi(X_0)}$$

Equation (6) defines the Lyapunov Exponent $\Psi(X_0)$ that (see Equation (4)) depends on the initial system state as well as the specific history of the system represented symbolically by the parameter λ and otherwise indicative of path dependency. Through an inversion of Equation (6), and considering that the interest is in the long-term evolution of the system, that is $n \rightarrow \infty$, starting from closely neighboring points ($\delta_0 \rightarrow 0$), we arrive at

Equation 7

$$\Psi(X_0) = \lim_{\delta_0 \rightarrow 0} \lim_{n \rightarrow \infty} \frac{1}{n} \log \left| \frac{X'_n - X_n}{\delta_0} \right|$$

If $\Psi < 0$, closely neighboring starting points will remain close to each other over time (t). Such systems may be defined as stable and admit the prediction of their behavior (Figure 1). If, on the other hand, $\Psi > 0$, initially closely neighboring starting points drift ever further apart, we encounter the domain of fundamental uncertainty and prediction becomes impossible. Thus, positive values of the Lyapunov exponent are indicators of chaos or crisis instability.

There exist simple determinate non-linear models, consistent with Equation (4), that oscillate between non-chaotic to chaotic behavior as a model parameter is increased. As long as parameter vector λ remains below critical thresholds λ_c , the model has well-defined attractors. All starting points in a given region, δ_{x_0} , evolve towards the same limit surface, δ_{x_t} , within which initially neighboring points remain adjacent. Under these conditions predicting the evolution of the system is possible. If the critical thresholds λ_c are violated, no stable end point exists. Consequently, the path originating at any starting value may, in the course of time, range over the entire set of possibilities open to the system¹²; any two neighboring paths will diverge, making prediction impossible. Such a chaotic system is said to have a “strange attractor” – very

¹² The entropy of the system suggests that the set of possibilities excludes that which logically demands the reversibility of phenomena.

different from the simple collection of points, smooth curves, or topologies, which are the attractors of predictive systems associated, for instance, with ergodic world of equilibrium-centered analysis.

For our purpose, the essence is that the critical transition thresholds can be determined within the model. Although the model no longer allows for prediction of a specific trajectory to the future, once the critical threshold vector λ_c is exceeded, its major point of attraction is that it makes possible the prediction of this class of unpredictability.

Starting from the assumption that the presence or absence of chaos in a non-linear model indicates stability or instability in the system being modeled, the third generation model may be used to deal with such problems as the relative stability of the international financial system; and the relative crisis-proneness of thereof. Although different models are developed to deal with each problem the method of analysis is basically the same. In each case the appropriate Lyapunov coefficients are computed to determine the relative regions of model stability: where the greater the region, the more likely that the system will be crisis stable. The results obtained are interesting and are suggestive for further inquiring and experimenting; even though it is clear that at present no claims of empirical validity can be made.

Concluding Remarks:

"History," Jawaharlal Nehru observed, "is almost always written by the victors" (1946: 287). The creditors (emboldened by a reliance on first generation models), it seems, write financial history. Within that reified way of seeing when a financial crisis arises, it is the debtors who are asked to take the blame. Indeed, in the case of the East Asian crisis, the International Monetary Fund, which led the official international response, assigned primary responsibility to the shortcomings of East Asian financial markets. The IMF's principal strategy was to seek the restructuring of their financial systems. One prominent diagnosis was that East Asia had exposed itself to financial chaos because of "crony capitalism" and that a weak structure of governance had led to inefficient investment weakening the stability of the banking system. In the financial circles today we are given assurance that the contemporary situation in emerging markets is different, as the factors that triggered Mexico's "tequila crisis" or the Asian contagion are absent, that defensive IMF disbursements, inflated risk premiums and under performing global equity markets are thought to provide the necessary attenuation for an Argentine crisis. In the event no doubt other uncomplicated causes will be identified. But with Mark Twain's adage ringing in our ears we note that were the IMF to view the international financial system through the lens offered by chaos theory, identifying causal factors and apportioning blame would be decidedly more

problematic if not impossible. Indeed, if causality involves constant conjunction of events (Hardy, 2000; Lawson 1994, von Wright 1974) then, with an embrace of the chaos theory, causality fades as bifurcations produce ever more complex causal fields and causality falls from its dominant status to a merely tentative conjecture. Thence first- and second-generation models of international financial crises are “rather more untidy than one would wish” (Penrose 1989:154).

In our still-speculative third generation reference model we noted that the Lyapunov exponent is a candidate indicator of chaos or instability that may be used to address such issues as the relative (in)stability of the international financial system, and the endogenous crisis-proneness thereof. As long as the parameters remain below a critical threshold, the model has reasonably well defined attractors and under these conditions predicting the further evolution of the system may be possible. If the critical threshold is exceeded, no end point exists and indeed, it is the case that “la prédiction devient impossible.” Here we enter the domain of the “strange attractor” – very different from the attractors of predictive systems latent in conventional modes of international financial analysis.

Perhaps absurdist playwright Eugene Ionesco had international financial forecasting in mind when he wrote: “You can only predict things after they’ve happened.” Yet chaos theory broadly hints that real change in the system of international finance may require substantial restructuring. Were we to accept the strong premise that the dynamic of the international financial system exhibits chaotic behaviour, conventional long-term international financial planning is rendered ineffective. In the absence of any ability to plan or control the future, our international institutions are urged to develop an adaptive stance and a preparedness to react to unexpected and unanticipated events. Indeed, even while apparently adhering to first generation models, the IMF may be pragmatically pursuing the policies and protocol implications drawn from the Theory of Chaos.

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