International Finance from Macroeconomics to Econophysics*

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Resumo. Este trabalho faz um apanhado crítico dos desenvolvimentos ocorridos no campo de finanças internacionais para mostrar como a agenda conhecida como "econofísica" relaciona-se com o previamente ocorrido na macroeconomia da economia aberta.

1. Introduction

Economists working in the field of international finance traditionally felt uneasy with the ideas in modern finance theory, in particular with its notion of efficient markets. Instead, foreign exchange markets are widely believed to behave like the unstable and irrational asset markets described by Keynes (Krugman, 1989).

Even the efficient markets assumption itself has been challenged recently by studies in behavioral finance. One argument, for instance, against the role of mass psychology in speculative markets is that since real returns are nearly unpredictable, the real price of stocks is close to the intrinsic value, i.e. the present value with constant discount rate of optimally forecasted future real dividends. Shiller (1984, p. 169), however, remarked that "this argument for the efficient markets hypothesis represents one of the most remarkable errors in the history of economic thought".

International finance has thus been in practice *open economy* macroeconomics. As it happens, macroeconomics seems to have failed as well to satisfactorily address exchange rate behavior, as this paper will show briefly. That circumstance makes international finance economists more prone to welcome the new ideas coming from physics. In so-called econophysics, the behavior of exchange rates and other financial assets are seen as *complex*. In complex systems with many interacting units, everything depends on everything else.

2. Macroeconomics and expectations

Macroeconomics is the study of the economy as a whole by focusing on the forest and abstracting the trees. The discipline was practically single-handed launched by Keynes (1936). Contrary to the view of classical economists like Adam Smith, Keynes' basic insight was that a market economy is inherently unstable, and that the source of instability lies in the logic of financial markets. According to Keynes, market capitalism should be neither left alone nor abolished, but stabilized. After the developments that took place in macroeconomics after Keynes, what still arguably survives of Keynesian economics today is the insight above (Skidelsky, 2000).

Keynes' book was greatly simplified in a paper by Hicks (1937). The original ideas collapsed to a graph which is the standard in macroeconomics textbooks for undergraduates—the

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so-called IS-LM model. For tractability, the IS-LM model assumed stationary expectations, i.e. people forecast no change for future prices. Stationary expectations is a reasonable assumption in a zero-inflation stable environment, but it is not when inflation is not nil.

Adaptive expectations came up to take the possibility of a non-zero inflation into account. Here people forecast by looking at previous inflation. Adaptive expectations is a fair assumption if prices are growing up at a constant rate. However, it is not if prices accelerate. Even if prices accelerate at a constant rate, people with adaptive expectations will make systematic forecast errors.

So rational expectations is the assumption that people also consider an accelerating inflation together with all past and current information, including what a government is doing. But rational expectations assumes too that people behave as if they have the "true model" of the economy in their minds, and this is too demanding.

As Shiller (1990) observed, our (economists') economic models require their (the people in the economy) economic models, models that they use to generate their expectations. Rational expectations collapses the two models into one: to assume that people know (or behave as if they now) the true model that describes the economy.

Collapsing two models into one is a quite convenient insight that helped to solve complicated models analytically. After all, these can be studied without collecting any data about the models in people's minds. Rational expectations (which is a mere stochastic version of perfect foresight) is then a wonderful theory, but unfortunately for the wrong species. One must seriously accept that the models used by real world people ("popular models") are not the rational expectations one. Economic modeling has thus no choice but collecting data on the popular models themselves.

By using questionnaires to evaluate the popular models among U.S. and Japanese (institutional and individual) investors during the stock market crash of 1987, Shiller (1990, pp. 496-497) and colleagues concluded that "the suggestion we get of the causes of the crash is one of people reacting to each other with heightened attention and emotion, trying to fathom what other investors were likely to do, and falling back on intuitive models like models of price reversal or continuation. There appears to be no recognizable exogenous trigger for the crash. With such popular models, a feedback system is created with possibly complicated dynamics, and we do not need to refer to a trigger to explain a crash".

That rational expectations is a quite restrictive particular case can be illustrated with reference to the *El Farol* bar problem put forward by Arthur (1994). Suppose that one hundred people must decide independently each week whether to show up at their favorite bar (*El Farol* in Santa Fe). If someone predicts, say, that more than 60 will attend, he will avoid the crowds and stay home. If he predicts fewer than 60 he will go.

Surely, predictions of how many attend depend on others' predictions of how many attend because that determines their attendance. But others' predictions depend in turn on their predictions of others' predictions. Deductively there is an infinite regress. No "correct" expectational model can be assumed to be common knowledge.

If all use an expectational model (say, rational expectations) that predicts few will go, all will go, invalidating that model. If all believe most will go, no one will go, invalidating that belief. Expectations will be forced to differ, i.e. expectations should be necessarily heterogeneous. Needless to say, this is also at odds with expected utility maximizers with unchanging tastes.

The example above shows that people cannot assume or deduce expectations but must discover them. As people visit the bar, they act inductively, i.e. they act as statisticians, each

starting with a variety of subjectively chosen expectational models (the popular models above).

Each week they act on their currently most accurate model. People's beliefs compete for use in an "ecology" these beliefs create. By employing a computer simulation, Arthur showed that the mean attendance quickly converges to 60. The predictors "self-organize" such that 40 per cent on average are forecasting above 60, and 60 per cent below 60. So predictors split into a 60/40 average ratio that keeps changing in membership forever.

At the end of the day, one finds himself too far from the uniform forecasting models with rational expectations that are on average validated by the prices these forecast. In a sense, expectations were thus "endogenized".

Arthur and colleagues (1997) extended the *El Farol* economy with endogenous expectations for an artificial financial world and generated out-of-equilibrium outcomes, of which the equilibrium with rational expectations is just a possible particular outcome.

Since mainstream economists feel somehow uneasy with "out-of-equilibrium" stories, it is worthwhile to illustrate their plausibility with reference to an example from behavioral finance.

Out-of-equilibrium decisions are likely to be the norm in the initial public offering (IPO) market, for instance. Stockbrokers in such markets seem to behave like impresarios (who manage musicians and entertainers) (Shiller, 1990). The public interprets empty seats as a signal of low quality. The impresarios then price tickets below equilibrium to create excess demand and long queues, and this will lead to greater demand the next days. People thus manifest "shortage illusion".

Likewise, underpricing IPOs creates the high initial returns that leave the impression that a stockbroker is giving good investment advice. Underwriters then let the high initial returns run for a while to generate publicity for an IPO.

Back to the model of Arthur and colleagues, they have designed artificially intelligent computer programs to generate and discard expectational hypotheses, and to make bids or offers based on their currently most accurate hypothesis. Endogenous expectations compete in the ecology the expectations create. The stock price forms from bids and offers, and thus ultimately from expectations.

They have found two possible regimes: (1) if parameters are set so that the artificial agents update their hypothesis slowly, the diversity of expectations collapses quickly into the homogeneous rational expectations one; (2) if the rate of updating of hypotheses is turned up, the artificial market displays several of the “anomalies” observed in real markets, such as unexpected price bubbles and crashes, random periods of high and low price variation, and technical trading.

These anomalies are thought of as out-of-equilibrium phenomena. It has to be said that mainstream macroeconomics and finance have also developed some equilibrium stories for such anomalies (Blanchard, 1979; Lux and Sornette, 2002). But although “rational expectation bubbles” might still be useful as a limiting case, from the discussion above it would not be sensible to assume rational expectations from the start.

From the discussion above one can too infer that if expectations are endogenous they also have to be heterogeneous.

3. International finance and complexity issues

A prevalent attitude in macroeconomics and finance alike is to heavily employ mathematics to develop models. Here arguments of "tractability" are commonly used to grasp

(for instance) real world financial phenomena analytically. But a problem with such a tractability procedure is that it eliminates many models that are a priori possible from actual financial time series.

If financial data are complex then mathematics will be of no great help in building up relevant models. Mathematics is not that good at dealing with complex phenomena; a computer would be far more useful (Wolfram, 2002). The success of mathematical models in traditional physics led to attempts to imitate them in other fields (including economics), but for the most part these did not succeed. Wolfram argues that for the physics of complexity computer experiments are more appropriate.

So international finance economists are likely to welcome the notion of complexity and indeed preliminary attempts have already been made (Krugman, 1996). A reason good enough for that to happen is the failure of modeling attempts in the framework of open economy macroeconomics. In what follows, that will be discussed in some detail.

4. Open economy macroeconomics

In the open economy macroeconomics field, nominal and real exchange rate volatility of the floating period following Bretton Woods was explained by "overshooting" in the Dornbusch (1976) model. In such a benchmark model of the field, output is exogenous and goods price stickiness is the critical reason for the exchange rate to overshoot its long run value in response to monetary shocks.

However, overshooting is possible in other models, and empirical evidence for it is thin (Obstfeld and Rogoff, 1995, p. 644; 1996, p. 678; Eichenbaum and Evans, 1995). In particular, one empirical regularity inconsistent with overshooting is the well documented (Flood, 1981; Obstfeld and Rogoff, 1995, p. 644 n25) tendency for spot and forward exchange rates to move in tandem.

Despite the fact that its empirical performance is not very successful (Taylor, 1995, pp. 28-30), the Dornbusch model played a dominant role in shaping the literature on exchange rate dynamics through the early nineties (Isard, 1995, p. 124). That demonstrates "undeniable time-tested appeal of the traditional sticky price Keynesian model" (Obstfeld and Rogoff, 1995, p. 625). Its prominence might also be related to the analytic simplicity of the model.

For macroeconomists, however, the Dornbusch model presents limitations related to its lack of microfoundations. The model provides a specification of the price determination process that they call "ad hoc", and ignores the current account in the exchange rate determination (Isard, 1995, p. 124).

The quest for microeconomic foundations for macroeconomics is an almost consensus among macroeconomists, and is reminiscent of the so-called reductionism in physics. Wolfram (2002, p. 3) observed that "in the existing sciences much of the emphasis over the past century or so has been on breaking systems down to find their underlying parts, them trying to analyze these parts in as much detail as possible. And particularly in physics this approach has been sufficiently successful that the basic components of everyday systems are by now completely known. But just how these components act together to produce even some of the most obvious features of the overall behaviour we see has in past remained an almost complete mystery". Wolfram argues that he finally addressed such a question in his recent book, i.e. why complexity arises was finally made clear.

The research on microfoundations has begun when rational expectations stepped in. But reductionism is not useful when complexity is involved, as seen in the paragraph above. So

microfoundations are not the issue if macroeconomic phenomena are complex.

Other criticisms on the model of Dornbusch by macroeconomists are as follows. The model disregards the intertemporal budget constraints needed to describe the current account and fiscal policy consistently, provides no clear description of how monetary policy affects production decisions, and has no meaningful welfare criteria, which may mislead policy prescriptions (Obstfeld and Rogoff, 1995, p. 625).

There are a number of reasons why open economy macroeconomists still continue to research using the Dornbusch model, though. First, most of the stories appearing in media reports on exchange rates are consistent with the Dornbusch model (Stockman, 1987, p. 12). Also, despite its general empirical collapse, evidence is also emerging that data provide support for some of the long run relationships suggested by the model, an example being long run purchasing power parity (Froot and Rogoff, 1995).

The empirical evidence supportive of the other macroeconomic models that are traditional alternatives to the Dornbusch model, namely the monetarist model and the portfolio balance model, is thin as well.

Despite some initial success, the monetarist model has failed empirically (Taylor, 1995, pp. 28-30 presents a discussion). In particular, estimates of equations for the US dollar-Deustche mark rate in the late seventies and beyond often produce coefficients implying that increases in Germany's money supply during this period caused its currency to appreciate. This has been called "the mystery of the multiplying marks" (Taylor, 1995, p. 29).

Although less empirical work had been carried out on the portfolio model, the supportive evidence has notwithstanding been weak (Taylor, 1995, pp. 30-31 shows details).

The traditional flexible price models of the exchange rate have been developed theoretically by the so-called intertemporal approach to the current account (Sachs, 1981; Obstfeld, 1982; Frenkel and Razin, 1996).

A widely accepted standpoint by international macroeconomists is, however, that most important problems—such as the effects of macro policies on output and exchange rates—cannot be satisfactorily addressed in the framework of perfect price flexibility. That is another reason why empirical macroeconomists and policymakers have continued to use the traditional aggregative Dornbusch model (Obstfeld and Rogoff, 1995, pp. 624-625).

Overall, it can thus be said that modeling with the standard macroeconomic models has failed empirically. Such a poor performance was highlighted when studies demonstrated that a random walk predicts exchange rate behavior better than models based on the fundamentals of the economy.

The studies of Meese and Rogoff (1983a; 1983b; 1988) showed that the traditional open economy macroeconomics models could not outperform a simple random walk in out-of-sample regressions. Since then, the inability to beat the random walk has been regarded as the standard by which to judge the empirical failure of the models of the open macroeconomy.

Usually the random walk hypothesis is tested by considering the exchange rate dependent on its past value plus white noise. In such a first order autoregressive process, a coefficient equaling one means that there is a unit root, i.e. the exchange rate series is non-stationary.

Several empirical studies found that exchange rate data do exhibit unit roots, but the error term does not have a constant variance (Meese and Singleton, 1982; Corbae and Ouliaris, 1986; Baillie and Bollerslev, 1989; Baillie and McMahon, 1989). The series is thus non-stationary and the error term shows time dependent heteroskedasticity.

To revive the standard macroeconomic models, Koedijk and Schotman (1990) estimated an "error-correction" *real* exchange rate equation and showed that it is superior, in-sample, to a

random walk.

The bilateral real exchange rates between the United States, the United Kingdom, Germany, and Japan for the period February 1977 to June 1987 were considered in an econometric model (based on the Dornbusch model) and a significant mean reversion component was found.

However, despite the fact that the major trends of the non-dollar exchange rates could be explained by macroeconomic fundamentals, Koedijk and Schotman also discovered that the dollar bubble between March 1984 and February 1985 cannot be understood by appealing to fundamentals.

Also using dynamic error-correction techniques, Mark (1995) considered an equation (derived from the Dornbusch model) to investigate the performance of the monetary exchange rate models concerning long run predictability. In forecasting tests over long horizons for several quarterly dollar exchange rates, evidence was found that macro fundamentals help to predict the nominal exchange rate, particularly at the four-year horizon.

The study by Chinn and Meese (1995) also suggested that over long enough periods there is indeed a stationary relationship between the exchange rate and the fundamentals of the open macroeconomy models.

The revival of fundamentals is sometimes also associated with the rebirth of long run purchasing power parity (Froot and Rogoff, 1995, present a comprehensive discussion on this).

Despite the revival of the standard fundamentals of macro models, the hypothesis that the exchange rate follows a random walk is still to be taken seriously. An interesting development that makes it possible to conciliate the apparent divergence between random walk and fundamentals is the model of De Grauwe and Dewachter (1992), and De Grauwe, Dewachter, and Embrechts (1993, Chapter 5).

De Grauwe and colleagues' model gives supplementary speculative dynamics to the Dornbusch model by considering chart rules concerning forecasting, and explains exchange rate movements by chaos. An advantage of chaotic models is to mimic the random walk pattern of the exchange rate with the "stochastic" behavior produced by deterministic solutions.

The models above have been extended to incidentally show that massive foreign exchange intervention can remove the chaos (Da Silva, 2000).

In the mid 1980s the general sentiment among open economy macroeconomists was that the research into exchange rate economics appeared to have grown tired of searching for new macro models (Dornbusch, 1987, p. 1). As a result, attention shifted from examination of macro models toward work related to the foreign exchange market as a financial market *per se*.

That trend was reinforced by the studies pointing out that the nominal exchange rate shows much greater variability than the important fundamental variables of the structural models (Dornbusch and Frankel, 1988; Baxter and Stockman, 1989; Marston, 1989; Frankel and Froot, 1990; Flood and Rose, 1993).

Accounts of short run exchange rate movements based solely on fundamentals were then believed not to prove successful, owing exactly to the presence of speculative forces at work in the foreign exchange market. Speculation was not reflected in the usual set of fundamentals of the macro models (Taylor, 1995, p. 30).

Thus the literature on foreign exchange market microstructure focused on the behavior of agents and market characteristics rather than on the influence of macro fundamentals. One motivation for such work has been to understand the mechanisms generating deviations from fundamentals. A survey on this is provided by Flood (1991), and another useful reference is Frankel, Galli, and Giovannini (1995).

Other studies adopted the modeling strategy of reducing all structure of a model to just one single variable. This was intended to focus analysis on the effect of "news", i.e. unexpected changes in the exchange rate resulting from changes in the fundamentals that come as a surprise.

The news approach thus relied on the existence of unexpected shocks to explain every exchange rate movement. It was shown however that only a small proportion of movements of the spot exchange rate is caused by news (Goodhart, 1989). A survey of the papers dealing with news is provided by Frankel and Rose (1995).

If compared with the news approach, an advantage of chaotic models is that they do not rely on random shocks to explain shifts in the exchange rate. Indeed currency crashes can happen in these models with no change in their exogenous variables.

As an offshoot of the closed economy macro literature on real business cycles, the equilibrium exchange rate model (Stockman, 1980; 1987; Lucas, 1982; Svensson, 1985; Grilli and Roubini, 1992; Da Silva, 2002) gives a full account of the supply side.

At this stage it is not possible to draw any firm conclusions concerning the empirical validity of the equilibrium model (Taylor, 1995, p. 32). The emerging challenger of the equilibrium model is that of Obstfeld and Rogoff (1995; 1996, Chapter 10). The studies collected together in Van Der Ploeg (1994) allow a general appreciation of other new developments.

The model of the exchange rate developed by Obstfeld and Rogoff—the "redux" model—is a dynamic intertemporal two country model that assumes monopolistic competition and sticky nominal prices in the short run.

While preserving the sticky price feature of the Dornbusch model, it provides a more rigorous framework than the latter model by incorporating the intertemporal approach to the current account. This allows for evaluating the welfare effects of macro policies on output and the exchange rate, a possibility not contemplated by the flexible price intertemporal approach.

The results of Obstfeld and Rogoff sometimes differ sharply from those of either the Dornbusch model or the flexible price intertemporal approach to the current account. In particular, the model gives a different view of the international welfare spillovers due to monetary and fiscal policies.

The testable results of the redux model—such as whether the distortions affecting the welfare effects of international monetary policy are empirically significant (Obstfeld and Rogoff, 1996, p. 688)—still have to stand up to empirical scrutiny. If they succeed, macroeconomists might claim that lack of microfoundations partly explains the bad empirical performance of the Dornbusch model.

The wave of research initiated by the redux model is sometimes labelled "new open economy macroeconomics". Lane (2001) and Sarno (2001) present surveys.

Lane questions the relevance of this literature for policymaking because many welfare results are highly sensitive to the precise denomination of price stickiness and the specification of preferences. But the widespread commitment with microfoundations and the many unanswered questions that remain should ensure that the literature is likely to grow yet further in the coming years among macroeconomists.

The speculative dynamics side of the model of De Grauwe and colleagues has also been blended with the model of Obstfeld and Rogoff to produce a chaotic nominal exchange rate (Da Silva, 2001).

Where do we then stand in the open economy macroeconomics literature? The Dornbusch model demonstrates undeniable time-tested appeal. But the redux model comes up to update the Dornbusch model as regards microfoundations and a supposed breakthrough is to

allow an explicit welfare analysis as far as policy is concerned.

The welfare results of the new open economy macroeconomics literature are highly sensitive to the precise denomination of price stickiness and the specification of preferences, though. For that reason, the literature is of only limited interest in policy circles.

Notwithstanding, the lack of welfare criteria of the Dornbusch model is claimed to yield misleading policy prescriptions; and this will encourage macroeconomists to further research on the new open economy macroeconomics.

5. The econophysics agenda

Like economists, physicists also use models—which they call "artificial worlds". Unlike economists, however, physicists are fundamentally empirical in their approach to science. Indeed, when doing their everyday research some physicists never make reference to models at all. Unlike mainstream economists, physicists usually think of the macroeconomy as a complex system with many interacting subunits. They also have decided to examine empirical economic and financial facts prior to the building up of models.

For the physicist's eye, the economy is a collection of interacting units where everything depends on everything else. The problem is then *how* does everything depend on everything else? Here physicists are looking for empirical laws that will describe this complex interaction. In particular, they are mostly interested in fluctuations (Stanley et al., 2001).

For a start, take the biased random walk model of Bachelier (1900), which is somewhat like a drunk with a coin and a metronome. Here a biased coin is one that has a tendency to go up. One might think of heads meaning one step to the right, and of tails as one step to the left.

By adapting the biased random walk for the S&P500 data which encompass the crash of 19 October 1987, Stanley and colleagues (2001) showed that the 30 per cent drop of Black Monday is virtually impossible in the model. They observed that the probability that a walk will move two steps in the same direction is p^2, three steps is p^3, and the probability of many steps in the same direction is exponentially rare.

The biased random walk has a probability density function that is Gaussian. With returns (fluctuations) normalized by one standard deviation, the probability of having more than 5 standard deviations is essentially zero. However, there are many shocks in the S&P500 returns that exceed 5 standard deviations (30 or 40 hits on the positive side). And Black Monday is more than 34 standard deviations (Stanley et al., 2001). Research in econophysics that take empirical data into account aims at showing that catastrophic, rare events like Black Monday should be considered as part of the overall picture; they are not (in a sense) "anomalies". Even the great stock market crashes would be simply ordinary (although infrequent) events.

Black Monday was the largest single-day free fall in market history. The crash was nearly twice as severe as the stock market collapse of 1929, although this time it did not trigger a depression. What made the Dow Jones industrial average sink? It is difficult to believe that there could be a sudden change in the fundamentals which would lead people simultaneously within half a day to the view that returns in the future had gone down by over 20 per cent. A dubious explanation is that the crash was caused by portfolio insurance computer programs which sold stocks as the market went lower.

In an efficient market, when supply matches demand, prices have their proper values, i.e. values that correspond to the underlying fundamentals. Market prices could still bounce up and down erratically, but huge fluctuations could not be accounted for. Price changes would behave like the bell curve. Greater than some typical size, price changes ought to be extremely rare.

Prices would somewhat follow a gentle random walk.

As observed (Stanley et al., 2001), almost everything in nature, including disordered things, has scale. We can find the scale of even raindrops on a road by zooming in or out. Most functions in physics have a characteristic scale and almost all physics comes down to solving a differential equation. Once the scale is determined, a function can be expressed in an exponential form whose derivative is also an exponential. Solutions to this look like tractable Gaussian functions.

But some systems in nature lack a scale. In particular, systems with many interacting units (like the macroeconomy) generally do not have scales, i.e. they exhibit scale invariance that can be expressed by power laws. Indeed price fluctuations in the S&P500 were found to become about sixteen times less likely each time the size is doubled (Gopikrishnan et al. 1997). A scale-invariant power law has also been found for financial market volatility: the market does not have a typical wildness in its fluctuations (Liu et al., 1999).

Mandelbrot (1963) looked at how random changes in cotton prices were distributed by size and did not find a bell curve. Instead, he discovered that price changes do not have a typical size, thereby being governed by a non-Gaussian power law. This allows one to see large fluctuations in market prices as a result of the natural, internal workings of markets; they can strike from time to time even if there are no sudden alterations of the fundamentals. Mandelbrot suggested a stable Lévy distribution (Dugué, 1976) to model the cotton prices.

Financial asset prices are also unlikely to follow Gaussian distributions (Lo and MacKinlay, 1988). Sky-high peaks and fat tails are pervasive in financial data. Although leptokurtosis could be accounted for by stable Lévy distributions, these have never been established in mainstream finance. One reason is related to their property of infinite variance. The number of data points of real world financial series is always finite, and so it is the variance. (The debate in the early days of modern finance can be appreciated in Cootner, 1964).

To remedy such a deficiency, a truncated Lévy distribution has been put forward (Mantegna and Stanley, 1994; Mantegna and Stanley, 1995). A truncated Lévy flight aims at modeling financial series through a non-stable distribution which features non-normal scaling power laws and finite variance. The truncated Lévy flight is then a candidate to satisfactorily model financial data. Indeed, that has been shown for the S&P500 (Mantegna and Stanley, 1995) and other stock markets (Miranda and Riera, 2001; Gleria, Matsushita, and Da Silva, 2002; Skjeltorp, 2001), as well as foreign exchange rates (Figueiredo et al., 2003). An earlier study that found power laws in foreign exchange markets is that of Müller et al. (1990).

Non-Gaussian power laws are expected to coexist uneasily with mainstream finance theory, which is built on the efficient market hypothesis. However, econophysics does not clash with mainstream finance. Overall physicists see the efficient market as an idealized system and real markets as only approximately efficient. They think the concept of efficient markets is still useful to model financial markets. But rather than simply assuming normality from the start, they try to fully characterize the statistical properties of the random processes observed in financial markets (Mantegna and Stanley, 2000).

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