A guide on empirical tests of the EMH

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Abstract

Purpose – The efficient market hypothesis (EMH) states that asset prices in financial markets always reflect all available information about economic fundamentals. The purpose of this paper is to provide a guide as to which predictions of the EMH seem to be borne out by empirical evidence.

Design/methodology/approach – Rather than following the classic three groups of tests for the different forms of EMH that are common in the literature, the authors consider how the two alternative definitions of the EMH and the joint hypothesis problem impact on the tests and leave the controversy unsolved. The authors briefly report the antecedents, the main theoretical and empirical contributions and recent literature on each type of tests.

Findings – Eventually, as a summary for each type of tests, the authors provide a critical view on the main sources of acrimony between the alternative schools of thought in understanding asset price formation.

Originality/value – The paper may be seen as an up-to-date introductory review for researchers on the different tests of the EMH performed, and for newcomers to understand the key sources of acrimony between rationalists and behaviorists.

Keywords EMH, Financial market anomalies, Joint hypothesis problem

1. Introduction

The debate about financial markets efficiency is one of the most controversial in all the social sciences (Lo and MacKinlay, 2001). Asset prices have probably been the most analyzed economic data and thousands of articles have covered the topic. However, researchers have not reached a consensus. The empirical evidence supports the EMH on issues such as short-term asset price movements and professional investors rarely outperforming the market on a consistent basis. However, the debate continues in many instances. The controversy reached Main Street in year 2013, when the "fathers" of the two opposing theories, Eugene Fama and Robert Shiller, were two of the recipients of the Nobel Memorial Prize in Economic Sciences. This article reviews the sources of dispute.

Behind the controversy lie two aspects of the efficient market hypothesis (EMH). First,

the existence of two alternative definitions: Fama (1970) defined efficient markets as those where prices fully reflect all available information. The information set includes the events that have already occurred and those the market expects to take place in the future (Fama, 1965a). An alternative interpretation is that of Jensen (1978): there is no free lunch in financial markets. An extension of the zero-profit competitive equilibrium under uncertainty saying that in an efficient market, it is not possible to make economic profits by trading on the basis of the information set. However, these two definitions of market efficiency may not be equivalent. This is a classic critique that may be traced back to Shiller (1984): unpredictability does not imply that prices are rational.

A second reason why researchers reached a dead end street is the joint hypothesis problem. The EMH, by itself, is not a well-defined and empirically refutable hypothesis; it only has empirical content within the context of a model of market equilibrium (Fama, 1970). A test of the EMH implies a test of the auxiliary hypotheses as well; if rejected, it may be that the asset pricing model is incorrect, or some assumptions (risk aversion, stochastic process of consumption, dividend smoothing.. .) are wrong. Put it other words, it is not an EMH issue; it is the issue of an asset pricing model or lack thereof. This makes the market efficiency battle futile (Statman, 1999): no matter how many anomalies are found, rationalists may always modify the asset pricing models or offer a rational interpretation. Indeed, two rational people can have differing degrees of rationality. Simon's (1955) notion of bounded rationality and satisficing – as alternative to optimization – is criticized by rationalists because it does not determine the point at which a rational individual would stop optimizing and reaching a satisfactory solution. Evolutionary frameworks such as the adaptive market hypothesis (AMH) by Lo (2004) provide an answer: it is determined not analytically, but through trial and error and natural selection.

The purpose of this article is to provide a beginner's guide to the current state of arts on tests of the EMH. Our review does not intend to be exhaustive. Indeed, a myriad of tests have been performed yet, what would make such goal unfeasible. Moreover, many reviews on this topic are already available, including classic ones by Fama (1970, 1991), Campbell et al. (1996), Lo (1997) and Nobel Prize (2013). Further, recent reviews update the main contributions on specific areas of research. Examples are Lim and Brooks (2011) on empirical tests of the weak-form EMH on stock markets, Bamber et al. (2011) on event studies, and Atilgan et al. (2015) on research in emerging markets. Rather, we contribute in three ways. First, providing a list of tests that goes beyond the EMH taxonomy that is commonplace, to focus on how the two alternative definitions of the EMH and the joint hypothesis problem leave the controversy unsolved. Second, for each type of test we list some early papers to provide a background, and focus on

recent theoretical and empirical contributions. Third, we observe whether the current state of literature on each type of test would favor or oppose to the EMH, to highlight the main sources of acrimony between both sides.

Fama (1970) argued that expectations use three subsets of information: a weak form set that contains past events, a semi-strong form set with information that is publicly available, including events the market expects to take place in the future and the rapidity to which markets adjust to new information revealed, and a strong form information set that contains both public and private inside information. Weak form tests are concerned with the forecast power of past returns, semi-strong form tests with how quickly security prices adjust to public information announcements (denoted event studies in Fama, 1991) and strong form tests on private information that is not fully reflected in market prices.

We list the tests in an alternative way, for two reasons. First, it is not always obvious which tests fall under each category. Thus, Fama (1991) changed the categories in Fama (1970) to make the first one cover the broader topic of tests for return predictability, while Fama (1998) compared the behavioral literature of long-term return anomalies with tests of the semi-strong form. Tests for over and underreaction in the long term may be listed as past performance predicting future prices or as markets not adjusting information into prices. Second, our list disentangles the sources of the controversy. The joint hypothesis problem is not relevant for tests of short-term return predictability. Event tests and tests of the strong form EMH rely on an appropriate asset pricing model; hence, they are joint tests of efficiency and asset pricing, like return predictability tests when they extend over the long term. Moreover, tests of relative efficiency test the EMH in an alternative fashion that avoids the joint hypothesis problem, but they leave the door open to suggesting that anomalies are a consequence of limits of arbitrage in financial markets.

The remainder of the article is laid out in six sections. Section 2 surveys tests of short- term predictability. These are tests of the weak form EMH for serial correlation, runs tests, filter tests and calendar effects. Section 3 focuses on long-term return predictability, including cross-sectional return predictability, excess volatility, momentum and herding. Event studies, the classic tests of the semi-strong form EMH, are covered in Section 4. Section 5 includes the tests of relative efficiency, which test the law of one price to trace anomalies of the semi-strong form EMH. Section 6 is devoted to the tests of insider trading (strong form EMH). Finally, Section 7 concludes our review.

2. Tests of short-term return predictability

These are tests of the weak form EMH, concerned with the forecast power of past returns. An efficient market is a fair game with no systematic difference between the actual return and the expected return before the game is played. Hence, markets will be in a continuous stochastic equilibrium if EMH holds: returns will change randomly to new information available, since it comes in a random fashion. Tests of the random walk hypothesis include tests for serial correlation, runs tests and filter tests (Fama, 1965b). Besides, following Fama (1991), these tests also include calendar effects. They are summarized in Table I.

2.1 Tests of short term predictability

2.1.1 Tests of statistical independence. Tests of statistical independence trace evidence of short-term predictability (within days or weeks) due to statistical correlation between consecutive prices or returns (Samuelson, 1965). Early serial correlation tests and methods of spectral analysis supported the independence assumption (Kendall, 1953; Granger and

Morgenstern, 1963). Later, literature in the 1970s and 1980s (French and Roll, 1986; Lo and MacKinlay, 1988) found a serial correlation of short-term returns, but agreeing that predictability would be small in magnitude.

Early tests assumed that returns are generated by a linear stochastic process – an assumption shown to be false (Taylor, 1982). Thereupon, several authors modeled non-linear stochastic processes using models of conditional variance such as ARCH (Engle, 1982) and GARCH (Bollerslev, 1986). Guidi and Gupta (2013) provide a recent review of the unit root, variance ratio, nonparametric and cointegration tests. Alternatively, authors like Hinich and Patterson (1985) and Onali and Goddard (2011) followed chaos theory (Eckmann and Ruelle, 1985) and fractal analysis (Peters, 1994). Recent papers seek to trace robust results to alternative non-linear and autoregressive models, including Shively (2003), Narayan (2006), Borges (2011) and Enninful and Dowling (2013).

Finally, runs tests determine the randomness of a price series by analyzing whether a run of successive price changes of the same sign happens more frequently than could be as a result of chance. Recent examples are Worthington and Higgs (2009) and Urquhart and Hudson (2013), with results showing returns go through periods of independence and dependence, consistent with the AMH. A critical view offers mixed evidence: the validity of the weak-form efficiency often depends on the characteristics of the market tested. Results change with the frequency or granularity of returns, different countries and periods may show varying levels of inefficiency, while there is often more evidence of inefficiency for some emerging markets and for small-cap stocks.

2.1.2 Tests of trading rules. If the random walk hypothesis holds, no trading rules should give excess profits above a buy-and-hold strategy. Since Fama (1965b) tested Alexander's filter rule in particular (Alexander, 1961), they are often named filter rule tests. Fama and Blume (1966) showed that any potential profits were exceeded by trading costs. Later, Brock et al. (1992) and Conrad and Kaul (1998) traced some profitability. Results are mixed, however, when it comes to compare potential profits and transaction costs. Some authors suggest some trading rules may be profitable, such as Yu et al. (2013), who observe that moving average trading rules had strong predictive power in Asian stock markets. Others find they are not profitable (Curcio et al., 1997), suggesting evidence against EMH are often a result of sample selection bias, data mining, hindsight bias and other common biases by researchers (Fang et al., 2014).

2.1.3 Tests for seasonality of returns. Tests for calendar effects pioneered the research on market efficiency (Wachtel, 1942; Osborne, 1962). They search for any patterns of seasonality in prices or returns, but two classics are the day-of-the-week effect and the January effect (Officer, 1975). Keim (1983) showed the latter, which implies returns are on average higher in January, is basically a size effect as in Banz (1981). The day-of-the-week effect, instead, seeks for return patterns for different days of the week. The Monday effect, whereby Monday returns are on average lower, is a classic one (Cross, 1973). Other regularities are the weekend, holiday, end-of-month and turn-of-the-year effects.

Some rational interpretations follow. The January effect has been attributed to tax effects: investors sell losers in December to avoid paying taxes. Market microstructure would explain the Monday effect – returns deviate by less than the bid-ask spread (Lakonishok and Smidt, 1986). In addition, these effects would be spurious and tend to disappear once identified (Gu, 2003). The debate continues today. Grinblatt and Keloharju (2004) and Starks et al. (2006) support the tax-loss selling result, Berument and Kiymaz (2001) observe a Monday effect, Yuan

et al. (2006) a correlation between lunar phases and stock returns and Auer and Rottmann (2014) only a weak Friday the 13th effect. Floros and Salvador (2014) find that seasonal anomalies in futures markets vary with volatility, while Urquhart and McGroarty (2014) show that the anomalies appear only under certain market conditions.

2.2 Critical assessment of the state of arts

Of the two sources of controversy between rationalists and behaviorists, the joint hypothesis problem is not relevant here, as the expected return in the short term of any risky assets is negligible. However, the existence of two alternative definitions of EMH does pervade the dispute: behaviorists accept the no-free-lunch interpretation (Statman, 1999), but Shiller's critique that randomness does not imply efficiency is still valid.

In this context, academics do not agree about how negative results should be interpreted. The general view favors efficiency regarding serial correlation and trading rules, especially after transaction costs are included. Here, market efficiency became orthodoxy, being anomalies the exception or caused by malfunctioning markets (Malkiel, 2003). Recent research on trading rules and seasonality offer mixed evidence, with results refuting the efficient hypothesis depending on the type of market and period of analysis, but often supporting the view that these inefficiencies tend to disappear once they are exploited, in line with the behavioral interpretation of the AMH (Lo, 2004).

3. Tests of long-term return predictability

Tests of return predictability over the long term need to go beyond statistical correlation of prices or returns: observed rates of return need to be compared with estimates of the required return adjusted for risk (which depends on fundamentals). The longer the term, the more relevant the joint hypothesis problem. Notwithstanding, cross-section anomalies and excessive volatility seek evidence against EMH, while tests of herd behavior trace evidence of investors following other investors rather than fundamentals. Hence, we may find three broad areas of research: the excess volatility and tests of return predictability due to mean regression; the evidence of over and underreaction; and the trading strategies associated to them, such as contrarian investing, momentum and herding; and a cross-sectional analysis of public information, where the size effect and the predictability power of some financial ratios are the most typical. They are listed in Table II.

3.1 Tests of long term predictability

3.1.1 Excessive volatility and mean reversion. Long-term predictability of stock returns contradicts the EMH, since markets are not properly incorporating information into prices. The volatility tests by Shiller (1979, 1981) and LeRoy and Porter (1981) confirmed that markets fluctuate much more than they should if prices only followed fundamentals. The critique for using a constant discount factor[1] lead to a refined alternative that makes it equal to the intertemporal marginal rate of substitution for consumption in the ICAPM. Later, Hansen and Jagannathan (1991) generalized a lower bound of volatility of the marginal rate of substitution. Other classics are Roll (1984) on volatility in the futures market, Odean (1999) on the excessive trading volume in stock markets, and Campbell et al. (2001), who find a dramatic increase in the idiosyncratic volatility of stock returns. Recent research includes behaviorists such as Blasco et al. (2012), who observe herding increases volatility, and rationalists such as Gabaix (2012) and Wachter (2013), who model the excess volatility as a consequence of a time-varying probability of a large negative economic shock. As excess volatility implies that returns should be mean

reverting, researchers focused on the predictability power of dividend yields (Shiller, 1984) and price-to-earnings (Campbell and Shiller, 1988). Malkiel and Jun (2009) provide a method that enables to extract the predictive power of this value effect and to isolate periods when it is likely to be particularly effective. In bond markets, two variables with a predictable power are default spreads between corporate bonds and long-term government bonds (Chen et al., 1986), and the slope of the yield curve (Campbell and Shiller, 1991). Finally, in foreign exchange markets, a currency carry trade – borrowing low-yielding currencies and lending high-yielding ones – should not offer excess returns, as the uncovered interest rate parity predicts that the difference on interest rates will be equivalent to the currency depreciation (Bekaert et al., 2007). However, the forward premium puzzle (Section 5) would be evidence against it. Recent literature favors the EMH. Thus, the excess volatility of bond returns might arise as a result of time-varying illiquidity (Bao and Pan, 2013), varying degrees of investor information about the dividend process might explain the volatility of stocks in the long-run (Lansing and LeRoy, 2014), and the time-varying exposure of countries to rare but extreme disasters in asset markets explains the excess volatility in exchange rates and the forward premium puzzle (Farhi and Gabaix, 2016).

3.1.2 Contrarian, momentum and herding strategies. A vast field of research on return predictability deals with tests of overreaction and the contrarian investment strategy and tests for underreaction and momentum. Evidence of overreaction in classic articles include Poterba and Summers (1988) of slight negative autocorrelation in stock returns over long horizons, Pontiff and Schall (1998) of low dividend yields and book-to-market ratios predicting a low return, and Campbell and Kyle (1993) on news about fundamentals. Recent research in line with the overreaction hypothesis includes Schmeling (2009) and Duong et al. (2014). Implicit in the hypothesis is the ability of the contrary investing strategy to outperform over long horizons (De Bondt and Thaler, 1985). However, Jegadeesh and Titman (1993) offered evidence in the opposite direction: markets may underreact as well, and momentum strategies might work. Recent evidence includes Moskowitz et al. (2012), who extend the profitability of momentum strategies to portfolios of different asset classes, and Menkhoff et al. (2012), who contribute to the scarce literature of momentum in the cross- section of currencies, to obtain evidence of behavior consistent with investor under and overreaction in currency markets. For years, this implied a controversy on overreaction versus underreaction and momentum. A full reconciliation of both anomalies, under the behavioral paradigm, would follow: models showing that over and underreaction may coexist include Barberis et al. (1998), Hong and Stein (1999) and Vayanos and Wooley (2013). Finally, long-term returns may suggest investors, both amateur investors and professional traders, mimic other investors' decisions. The antecedents of herding are Scharfstein and Stein (1990) and Banerjee (1992). Some authors (Clement and Tse, 2005; Jegadeesh and Kim, 2010) support the classic interpretation predicting low-reputation analysts are more likely to herd. Others conclude that analysts herd toward consensus (Wermers, 1999). Hwang and Salmon (2004) analyze the cross-sectional evolution over time in factor sensitivities (e.g. CAPM betas) and find that periods of market stress were critical turning points where herding diminished. Recent tests in favor of the hypothesis include Yao et al. (2014), who contribute to analyze a segmented market setting, and Galariotis et al. (2015), who address major macroeconomic announcements.

3.1.3 Cross-sectional analysis. The evidence of cross-sectional return predictability suggests that markets do not properly incorporate firms' fundamentals into prices. However, the joint-hypothesis problem allows modifying the asset pricing models to account for the observed anomalies. Early tests of the CAPM (Douglas, 1969; Black et al., 1972) led to biased inference due to the strong cross-sectional correlation in stock returns. The Fama– MacBeth regressions

(Fama and MacBeth, 1973) solved it and are today a standard method for testing multi-factor cross-sectional asset pricing models (Nobel Prize, 2013).

Some empirical contradictions of the Sharpe–Lintner model were later observed. The first was the size effect (Banz, 1981): small-cap stocks tend to exhibit higher risk-adjusted returns than those predicted by the CAPM. Recent works include Fama and French (2008) and Hou et al. (2011), who advocate for implementing a comprehensive examination of the factors related to firm-level characteristics that can explain the cross-sectional and time- series variation in global stock returns. Most theories suggest that small firms carry risk factors not included in classic pricing models (Fama and French, 1993), such as a liquidity premium due to a lower trading volume (Amihud, 2002). For a review on liquidity as a risk factor, see Lichewski and Voronkova (2011).

A second group of cross-sectional anomalies includes some scaled-price ratios with a predictive power. First, stocks with low PER ratios tend to outperform (Basu, 1977); the same applies to the earnings yield (E/P), even controlling for differences in firm size (Basu, 1983). Recent research includes Dechow et al. (2010). Second, Stattman (1980) finds a positive relation between average stock returns and book value to market value (B/M), whereas Rosenberg et al. (1985) show that a B/M strategy that buys (sells) stocks with high (low) ratios is profitable. Related articles are Chan et al. (1991) and Dong et al. (2006). More recently, Hou et al. (2011), provide evidence that the explanatory power of a value-based factor relies on C/P measures. Third, Bhandari (1988) observes a positive relationship between debt-to-equity ratios and expected returns, even once size and betas – used in the CAPM model to capture leverage risk – are considered. Frazzini and Pedersen (2014) analyze how to bet against beta when some investors are leverage-constrained. Recent articles on cross-sectional anomalies include Cakici et al. (2013), who find a strong evidence of the value effect in 18 emerging stock markets, Gomes and Schmid (2010) and Bali et al. (2011).

Finally, two recurrent cross-sectional anomalies are the value line effect (Copeland and Mayers, 1982; Porras and Griswold, 2000) and the neglected firms' effect: stocks not followed by security analysts tend to outperform. Nevertheless, research is not conclusive. On one hand, Beard and Sias (1997) find no neglected premium, and Ennis and Sebastian (2002) suggest it stems from tests that ignore management fees and a survivorship bias (Brown et al., 1992). On the other hand, Kim and Venkatachalam (2011) provide positive evidence, suggesting sin stocks neglected by investors (gaming, tobacco, etc.) experience higher expected returns, despite their higher financial reporting quality.

3.2 Critical assessment of the state of arts

Long-term return predictability tests are the main source of dispute. While behaviorists have uncovered a significant number of anomalies that contradict the EMH, rationalists have suggested alternative models to explain them. The fact that the joint hypothesis problem is particularly relevant to these tests only makes a consensus harder to achieve.

Three anomalies widely accepted are momentum, value effect and size. In cross-sectional anomalies is where rationalists have more easily digested new evidence, by simply adding new risk factors to the asset pricing. This is for instance what the three-factor model by Fama and French (1993) and, more recently, their five-factor model (Fama and French, 2016) do. In regards to time series, rationalists have observed that predictive variables of long- term return performance are often correlated with the business cycle, so return predictability would be a

consequence of changes in the discount factor (Fama and French, 1989). However, the debate continues. Campbell and Yogo (2006) suggest that classic tests may be invalid if the predictor variable is persistent and its innovations are highly correlated to returns. They introduce an efficient test to overcome this problem and find evidence of predictability. Ang and Bekaert (2007), instead, find no evidence that dividend yields predict excess returns in the long run.

Rational explanations for the success of the contrary investing strategy include Zarowin (1989, 1990), who relates it to the size effect, and a failure to correctly account for risk- adjusted returns (Chan, 1988). On the behaviorist side, Barberis and Thaler (2003) suggest that causal factors of overreaction are beliefs (representativeness, overconfidence) and preferences (loss aversion, narrow framing). The profitability of momentum strategies stands out as a major unsolved puzzle. Rationalists like Fama and French (2012) have subscribed to the evidence, but they attribute it to economic risk factors that affect investment life cycles and growth rates (Chordia and Shivakumar, 2002). Likewise, Ang et al. (2001) suggest that the profitability of momentum strategies might be a compensation for bearing asymmetric risks. However, most interpretations are behavioral (Griffin et al., 2003, for a review). Finally, herding might be rational for managers who are concerned about their reputation in the labor market (Scharfstein and Stein, 1990), while incentives may arise endogenously either because agents mimic their more skilled counterparts (Trueman, 1994), perceive it to be a safe course of action (Jegadeesh and Kim, 2010) or herd on non-informative signals (DeLong et al., 1990).

4. Event studies

These classic tests of the semi-strong form EMH deal with the rapidity with which the market incorporates new information into prices. They are known as event studies afterFama (1970): the study of how security prices adjust to “one kind of information generating event (e.g. stock splits, announcements of financial reports by firms, new security issues, etc.)” (p. 404). The list of the most common event studies is summarized in Table III.

4.1 Types of event studies

The seminal paper by Fama et al. (1969) analyzes the effect of stock splits on prices, but all event studies follow the same logic: when new information arrives, there must be an immediate price impact and some unusual behavior in the rates of return, and then prices should subsequently remain unpredictable. Four are the most common events analyzed. The first one is earnings announcements (Bernard and Thomas, 1989). The post-earnings announcement drift evidences that, when firms do not meet market expectations, prices tend to respond to earnings announcements for about a year, suggesting investors’ underreaction to news. It was first noted by Ball and Brown (1968), and confirmed, both for unexpectedly positive and negative profits, by Foster et al. (1984) and Ball (1992). Other studies analyze the effect of dividend announcements on prices. Charest (1978) obtained empirical evidence that excess returns are observable during two years after a dividend rise is announced. Recent articles, though, offer mixed reviews: Bali (2003) and Dasilas and Leventis (2011) provide evidence on the anomaly; Liu et al. (2008) in favor of market efficiency, suggesting that abnormal returns is driven only by the post-earnings-announcement drift. Other articles include Landsman et al. (2012) and La Porta et al. (1997), who relate the anomaly to the value effect. Finally, trading volume increases around earnings announcement dates. Bamber et al. (2011) provide a recent literature review on the topic.

A second category analyzes the effect on prices of trading changes, including splits, exchange listings and block trades. Grinblatt et al. (1984) show that prices, on average, react positively to split announcements. Moreover, Ikenberry et al. (1996) suggest that splits realign prices to a lower trading range, and markets underreact to the announcement. Chen et al. (2011) suggest that stock splits contain information about future operating performance. However, there is evidence against the anomaly, too (Byun and Rozeff, 2003). Regarding block trades, Kraus and Stoll (1972) and Scholes (1972), show that prices react efficiently to the information conveyed in the sale of large blocks of shares. Subsequent literature favored the efficient hypothesis (Easley and O'Hara, 1987; Fama, 1990). Finally, the study of price effects after a listing announcement – the inclusion of a security in a selective or sectoral index – was pioneered by Dharan and Ikenberry (1995). Recent literature is ample and offers mixed views. Relevant articles include Karolyi (2006), who reviews the literature that challenges conventional wisdom arguing that firms pursue overseas listings to access to global investors and benefit from a lower cost of capital, and Sarkissian and Schill (2009) who find that valuation gains due to overseas listings are not permanent.

A third category of event studies considers the effect on prices of corporate events such as M&As and stock repurchases (Cheng et al., 2015), accounting restatements (Badertscher et al., 2011) and other corporate strategic decisions. The most common is the announcement of initial public offerings (IPOs) (Ritter, 1991), which led to identifying the IPOs underpricing puzzle (Purnanandam and Swaminathan, 2004) and seasoned equity offerings (SEOs) leading to negative returns (Asquith and Mullins, 1986). Other articles include Loughran and Ritter (1995) and Booth and Chang (2011). Finally, a fourth category includes the effects that economic news may have on prices. Examples are changes in the interest rate (Rigobon and Sack, 2004), accounting changes (Nourayi, 1994), changes in normative standards (McGuire and Dilts, 2008) and major economic news (Conrad et al., 2006).

4.2 The soundness of the efficient market hypothesis in event studies: a critical assessment

Empirical results are mixed in this category. On one hand, results are favorable overall to market efficiency in instances like trading effects, or easy to rationalize, such as the effects of economic news. On the other hand, the effects of earnings and dividend announcements are well documented, and the IPOs underpricing remains as an unsolved puzzle. However, as it happens to cross-sectional evidence of abnormal returns, the joint hypothesis problem allows to digesting anomalies by rationalizing their existence or adding new risk factors to the asset pricing. Thus, as mentioned, rational explanations range from econometric problems and the existence of valuable information content, to unobserved risk factors such as liquidity, and an asymmetric appetite for risk.

Rational interpretations of the earnings anomaly suggest an incorrect measurement of corporate results (Warfield and Wild, 1992), econometric problems (Brennan, 1991), and unobserved risk factors such as liquidity risk (Sadka, 2005). However, most authors consider the cause is investors' underreaction to new information (Bernard and Thomas, 1990) when they are not aware of the serial correlation in profits (Bernard, 1993) and underestimate such correlation (Ball and Bartov, 1996). Fama (1998) considered it one of the two unsolved anomalies – the other is the profitability of momentum strategies – and recent articles (DellaVigna and Pollet, 2009) subscribe to this view. Kaniel et al. (2012) relate the anomaly to the strong-form EMH, when showing that about half of the abnormal returns can be attributed to private information. Finally, behaviorists have also succeeded in providing an interpretation for anomalies related to corporate events. Thus, Green and Huang (2012) relate the first-day IPO

returns to a preference for skewness, while Barberis and Huang (2008) explain these anomalies using prospect theory and mental accounting.

5. Tests of relative efficiency

An alternative means to test whether prices do reflect fundamentals, the tests of relative efficiency search for patterns where the law of one price – the rule that identical goods must have identical prices in different markets (Lamont and Thaler, 2003) – is violated. The law ensures relative efficiency, not absolute, but rejecting it implies irrefutable evidence that the price is biased in at least one market. This way, several anomalies of the EMH were identified: the closed-end fund puzzle, twin stocks, corporate spin-offs, and the forward premium puzzle, among others. The list is summarized in Table IV.

5.1 Relative efficiency: main anomalies

Rather than a series of tests, this section includes the anomalies observed when testing the law of one price in different contexts. The first anomaly observed was the closed-end fund puzzle, originally uncovered by Zweig (1973). Closed-end equity funds are tradable mutual funds: investors cannot redeem their fund shares for cash, but they have to sell them in the market instead. The puzzle is the empirical evidence that these funds often trade at prices not equal to the per-share market value of their underlying stock portfolio. Discounts and premia greater than 30 per cent are common (Lamont and Thaler, 2003). Lee et al. (1991) argue that fluctuations in the discounts are driven by investor sentiment and are correlated with returns on small stocks. Baker and Wurgler (2007) show that a sentiment index, which includes closed-end fund discounts, is correlated with aggregate stock returns. The puzzle is often related to the limits of arbitrage. For instance, Pontiff (1996) finds the anomaly is likely to be observed when portfolios are difficult to replicate, funds pay smaller dividends, have lower market values, or interest rates are high, consistent with noise trader models of asset pricing (DeLong et al., 1990).

Twin stocks or Siamese Twins are stocks traded in more than one location. A classic example is Royal Dutch shares traded in Amsterdam and Shell shares in London. Following the merger agreement of 1907, the ratio of their market values should be 1.5, but it has varied from discounts of 30 per cent in 1981 (Rosenthal and Young, 1990) to premiums over 15 per cent in 1996 (Lamont and Thaler, 2003). Froot and Dabora (1999) show a high correlation of the relative price of twin stocks with the indexes of the countries where the stocks trade. Another instance where the price of two stocks is bounded by a common ratio is in corporate spin-offs. Mitchell et al. (2002) and Lamont and Thaler (2003) report examples of how the valuation of the spun-off company imply that the value of the parent's remaining assets was negative. Possible explanations are short-sale constraints and risk-averse arbitrageurs (DeLong et al., 1990).

In currency markets, the forward premium – the difference between the forward and the

spot exchange rates – negatively forecasts changes in the exchange rate. This contradicts rational expectations models, an anomaly called the forward premium puzzle (Hodrick, 1987). Froot and Thaler (1990) suggest that the bias is due to expectation errors, not to time-varying rational premium for systematic risk, as Fama (1984) suggests. Burnside et al. (2011) offer an alternative explanation based on investors' overconfidence. Finally, other examples of empirical refutation of the law of one price are in order. First, the pricing of American depositary receipts (ADRs), i.e. shares of foreign securities traded in US markets like closed- end funds, may be different from the value of the underlying portfolio (Lamont and Thaler, 2003). Second, short-

sale constraints might explain the evidence that the pricing of Chinese warrants in the late 2000s traded far above their fundamental value (Xiong and Yu, 2011).

5.2 The soundness of the efficient market hypothesis in tests of relative efficiency: a critical assessment

Tests of relative efficiency provided behaviorists with a theoretical tool symmetrical to that

of the joint hypothesis for rationalists. They overcome the joint hypothesis problem, as the anomaly stands on having two different prices for a same asset. Thus, rejecting the law of one price affords irrefutable evidence of market inefficiency.

Economic theory assumes that the law of one price should hold in competitive markets with negligible transaction costs and no barriers to trade. However, this is where the counter-argument of rationalists enters the discourse: the limits of arbitrage would be the cause of any violations of relative efficiency. Being arbitrage the simultaneous buying and selling of the same security for different prices, the absence of arbitrage opportunities is a pillar in modern finance, and should ensure that relative efficiency is satisfied. Evidence in such respect is mixed. Rationalists allege they are explained by short-sale constraints and other external restrictions to free-markets. Behaviorists, instead, suggest they are due to bounded rationality.

6. Tests of insider information

Tests of the strong form EMH trace evidence of private information not fully reflected in market prices. This is the least analyzed form of efficiency, due to the difficulties for an empirical contrast: we cannot observe the private information available, nor what market prices would be that fully reflect this information (Del Brío, 2003). Thus, indirect tests are performed by studying agents who may have access to inside information, like corporate insiders and different sorts of professional investors. However, these tests are also limited because of data shortage and the fact that we cannot assert when a given piece of inside information has arrived to the market. Unlike tests of semi-strong form, tests of insider information analyze market returns before a particular announcement, to trace evidence of insiders making excess profits out of privileged information. Following the above, we distinguish two types of tests: those that focus on corporate insiders, and those that focus on groups of professional investors. The taxonomy is provided in Table V.

6.1 Types of tests of strong-form efficient market hypothesis

The seminal paper on corporate insider trading is Jaffe (1974), who analyzes the trades executives and large shareholders performed on stocks of their own companies, to conclude they earned excess profits. Since then, most empirical studies obtained evidence against the strong form of efficiency, including Beneish and Vargus (2002) and Ke et al. (2003). Conversely, results in favor include Sharpe (1981), who suggests that investment funds make insider information less valuable. Recent articles focus on the sources of insider trading gains (Aboody and Baruch, 2000), their ability to perform as contrarian investors (Lakonishok and Lee, 2001), the effects of regulation and ownership (Fidmuc et al., 2006), the credibility of voluntary disclosure (Gu and Li, 2007), legal insider trading contribution to efficiency (Aktas et al., 2008) and how to decode non-informative routine versus information- rich opportunistic insider trading (Cohen et al., 2012).

Regarding tests of professional investors, the most common are performance tests of mutual fund managers. Classic papers are Treynor (1965), Sharpe (1966) and Jensen (1969), who

obtained evidence in favor of the strong-form EMH. Subsequent literature agrees, including Sauer (1997) and Bilson et al. (2005). The main evidence is the lack of a consistent outperformance by fund managers over a series of years. For the only relevant anomaly – a hot-hands effect where mutual funds that outperformed one year continued to outperform the next year (Hendricks et al., 1993) – there is no consensus on whether it implies past fund returns help to predict future performance (Grinblatt and Titman, 1992; Pätäri, 2009). Similar tests focused on other groups of professional traders, such as stock exchange specialists (Harris and Panchapagesan, 2005) and security analysts (Shane and Stock, 2006). Finally, Ivashina and Sun (2011) show how institutional investors trade on private information acquired in the loan market and obtain excess profits in the company stock, whereas Griffin et al. (2012) see no evidence if information comes from investment bank connections.

6.2 The soundness of the strong form efficient market hypothesis

Being the most extreme view of market efficiency, the strong form EMH does not yield a strong dispute as it is hard to believe that actors having relevant inside information are never able to obtain a profit out of it. Yet, this field is the less developed, due to lack of data. We may conclude that most tests of the strong-form EMH provide unfavorable evidence of efficiency regarding corporate insider trading, and favorable evidence in what professional investors' ability to consistently beating the market is referred.

7. Concluding remarks

The formulation of the EMH was a remarkable intellectual contribution. The hypothesis provided a powerful analytical tool to a better understanding of asset price formation, and triggered a cascade of research into the topic. However, 40 years of research have redefined the EMH as a controversial proposition. Researchers have not reached yet a consensus about whether financial markets are efficient. The empirical evidence supports the EMH on some issues:

- asset price movements over short periods seem close to a random walk;
- most of new information is quickly incorporated into asset prices; and
- fund managers rarely outperform the stock market on a consistent basis. However, the debate continues in many instances.

In this paper, we offer a review of the tests of EMH that document empirical evidence in favor of and against it. This analysis allows us to obtain a number of conclusions. First, the state of arts favors short-term efficiency, but there is no consensus about how to interpret negative results on tests of serial correlation. The main source of controversy is the two definitions of EMH – i.e. that unpredictability does not imply rationality. Achieving some consensus in tests of long-term return predictability is only pipe dreams, as the joint hypothesis problem plays here a determinant role. Three anomalies widely accepted are the profitability of momentum strategies, the value effect and firm size. EMH proponents have digested the cross-sectional anomalies by simply adding new risk factors to the asset pricing models. However, there is no consensus on the sources of the profitability of momentum or on whether contrarian investing offers excess returns.

Tests of the semi-strong form EMH offer mixed results. Anomalies identified are the post-earnings-announcement drift, the IPOs underpricing puzzle, and violations of the law of one price such as twin stocks and the forward premium puzzle. Anomalies in event studies are often interpreted to be a consequence of the joint hypothesis problem. Relative inefficiencies happen

because of limits of arbitrage, but there is no consensus on whether the limits of arbitrage are due to short-sale constraints and other restrictions to free- markets, or to bounded rationality. Finally, the tests of the strong form EMH do not represent a strong dispute between rationalists and behaviorists, as they provide negative evidence for insider trading, while they support the EMH in regards to professional investors.

Note

1. Assuming a constant discount rate (Merton, 1987) and price stationarity (Marsh and Merton, 1986).

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Table I. Tests of short-term return predictability

Category	Evidence	Articles	Comments
Tests of statistical independence of prices/returns			
a) Serial correlation			
Autocorrelation	Early papers	Kendall (1953), Granger and Morgenstern (1963)	Early serial correlation tests supported the independence assumption, including Kendall (1953), Osborne (1959) or Samuelson (1965), as well as methods of spectra l analysis such as Granger and Morgenstern (1963) Evidence of serial correlation of short-term returns, but predictability small in magnitude
	Positive evidence	Lo and MacKinlay (1988), Fama and French (1988)	
	Evidence against EMH		
Non-linear stochastic	Early papers	Taylor (1982)	Taylor (1982) shows the assumption of returns generated by a linear stochastic process to be false. Non-linear stochastic process modeled as ARCH (Engle, 1982) and GARCH (Bollerslev,1986)
	Positive evidence	Hung *et al.* (2009)	Positive evidence that the weak-form EMH holds for large-cap stock indices, but not for small-caps
	Evidence against EMH	Shively (2003)	Evidence that stock prices are consistent with a regime-reverting process
b) Runs tests			
	Early papers	Fama (1965b)	These tests check whether a run of successive price changes of the same sign happens more frequently than randomly
	Positive evidence	Hassan *et al.* (2006)	Positive evidence that European emerging markets are overall unpredictable
	Evidence against EMH	Worthington and Higgs (2009)	Daily and monthly returns of the Australian stock market over decades shown to be weak-form inefficient
		Urquhart and Hudson (2013)	Runs and variance ratio tests for UK, US and Japan stock markets favor the AMH
Tests of trading rules			
c) Filter rules			
	Early papers	Alexander, 1961), Fama and Blume (1966)	Named after Fama (1965b) tested Alexander's filter rule in particular. Fama and Blume (1966) showed that any potential profits of these rules were exceeded by trading costs
	Positive evidence	Curcio *et al.* (1997)	Avoiding sample selection bias, data mining, and hindsight bias, no evidence that common technical trading strategies predict stock markets
	Evidence against EMH	Conrad and Kaul (1998), Yu *et al.* (2013)	Strong predictive power of moving average trading rules in emerging markets

Category	Evidence	Articles	Comments
Tests for seasonality of returns			
d) Calendar effects			
January effect	Early papers	Wachtel (1942)	Fama (1991) considered it the most mystifying seasonal. Officer (1975) detected that Australian stock returns, particularly on small cap stocks, were on average higher in January than in any other month
	Positive evidence	Gaunt *et al.* (2000)	The effect would be a consequence of investors selling losers in December to avoid paying higher taxes
	Evidence against EMH	Gu (2003)	These effects would be spurious and tend to disappear once identified
Monday effect	Early papers	Cross (1973), French (1980)	Early literature found that Monday returns are on average lower than on other days
	Positive evidence	Lakonishok and Smidt (1986)	Market microstructure-returns deviating by less than the bid-ask spread - would explain the Monday effect
	Evidence against EMH	Berument and Kiymaz (2001)	

Source: Own elaboration

Table II. Tests of long-term return predictability

Category	Item	Evidence	Articles	Comments
Excessive volatility and mean reversion				
a) Equity markets				
Volatility tests		Early papers	Shiller (1979, 1981)	Early volatility tests confirmed that markets fluctuate much more than they should if prices only followed fundamentals
		Positive evidence	Wachter (2013)	Large equity premia and excess volatility of stocks would be a consequence of a time-varying probability of a consumption disaster
		Evidence against EMH	Blasco *et al.* (2012)	Herding increases volatility
Mean reversion	Dividend yield PER	Early papers	Shiller (1984)	High d/P ratios forecast higher returns; hence, a contrarian strategy would be profitable
			Campbell and Shiller (1988)	A moving average of real earnings predicts future dividends and stock
		returns Positive evidence	Ang and Bekaert (2007)	No evidence that dividend yields predict
		excess returns in the long run		
		Evidence against EMH	Campbell and Yogo (2006)	Classic tests on return predictability may be invalid when the predictor variable is persistent. Campbell and Yogo (2006) introduce an efficient test to find evidence of predictability
b) Other asset markets				
	Default spread Carry trade	Early papers	Chen *et al.* (1986), Shiller *et al.* (1983)	
		Positive evidence		
		Evidence against EMH	Campbell and Shiller (1991)	A predictive power by the slope of the yield curve
			Froot and Thaler (1990)	The forward premium puzzle
Over and underreaction				
Overreaction	Contrarian	Early papers	De Bondt and Thaler (1985), Poterba and Summers (1988)	Evidence of slight negative autocorrelation in stock returns over long horizons, what leads to a contrarian investment strategy outperforming
		Positive evidence	Chan *et al.* (1996)	The profitability of contrarian strategies is related to the size effect and a failure to correctly account for risk-adjusted returns
		Evidence against EMH	Pontiff and Schall (1998), Duong *et al.* (2014)	Low dividend yields and book to market ratios predict lower returns
Underreaction	Momentum	Early papers	Jegadeesh and Titman (1993)	Markets may underreact as well, with momentum strategies working over shorter periods
		Positive evidence	Fama and French (2012)	The profitability of momentum strategies is attributed to economic risk factors that affect investment life cycles and growth rates
		Evidence against EMH	Grinblatt and Han (2005), Chui *et al.* (2010)	Models that predict both over and underreaction may coexist include Barberis *et al.* (1998)

(*continued*)

Category	Item	Evidence	Articles	Comments
	Herding	Early papers	Scharfstein and Stein (1990) Banerjee (1992)	Evidence that amateur investors and professional traders do herd
		Positive evidence	Clement and Tse (2005)	Some authors obtain evidence that low-reputation analysts are more likely to herd
		Evidence against EMH	Galariotis *et al.* (2015)	Others observe analysts tend to herd towards the market consensus
Cross section a) Size				
		Early papers	Banz (1981) Fama and French (1993)	Small-cap stocks tend to exhibit higher risk-adjusted returns than those predicted by the CAPM
		Positive evidence	Amihud (2002)	Small firms carry risk factors such as a liquidity premium due to a lower trading volume
		Evidence against EMH		
b) Financial ratios				
	PER BV/MV	Early papers	Basu (1977) Stattman (1980)	Stocks with either low PER ratios, low MV/BV ratios, or high D/E ratios tend to outperform
		Positive evidence	Fama and French (1992)	
		Evidence against EMH	Chan *et al.* (1991) Cakici *et al.* (2013)	Strong evidence of the value effect in 18 emerging stock markets
c) Neglected firms				
		Early papers	Arbel *et al.* (1983)	Stocks not followed by security analysts tend to outperform – an anomaly related to the size bias, since neglected firms are often small ones
		Positive evidence	Beard and Sias (1997), Ennis and Sebastian (2002)	Either no evidence of a neglected premium, or a consequence of using inappropriate benchmarks and exhibiting a survivorship bias
		Evidence against EMH	Barber *et al.* (1993), Kim and Venkatachalam (2011)	

Source: Own elaboration

Table III. Event studies

Type of test	Items	Antecedents	Positive evidence	Evidence against EMH
a) Announcements	Earnings reports	Ball and Brown (1968)	Liu *et al.* (2008)	Ball (1992)
	Dividend announcements	Charest (1978)		Bali (2003)
	Early research confirmed a post-earnings announcement drift both for unexpectedly positive and negative profits, and excess returns during two years after a dividend rise is announced Recent literature offers mixed evidence on excess returns after dividend announcements. In addition, there is evidence that trading volume increases around earnings announcement dates			
b) Trading effects	Splits	Fama *et al.* (1969)	Chen *et al.* (2011)	Grinblatt *et al.* (1984)
	Block trades	Scholes (1972)	Fama (1990)	
	Exchange listings	Dharan and Ikenberry (1995)		Doidge *et al.* (2004)
	Literature on block trades support the efficient hypothesis			
	Mixed interpretations on the information content of splits, and on the rationale and duration of excess returns offered by exchange listings			
c) Corporate events	IPOs, M&As Strategic decisions	Asquith and Mullins (1986)	Green and Huang (2012)	Loughran and Ritter (1995)
	The IPO underpricing puzzle is one of the most frequent results, with the behavioral interpretation of prospect theory and mental accounting explaining the anomaly (Barberis and Huang, 2008)			
d) Economic news	Changes in interest rates		French *et al.* (1987)	
	Accounting changes			
	World and economic news			Conrad *et al.*, 2006

Source: Own elaboration

Table IV. Tests of relative efficiency: main anomalies identified

Anomaly	Antecedents	Positive evidence	Evidence against EMH
Closed-end fund puzzle	Zweig (1973)	Lee *et al.* (1991) Baker and Pontiff (1996) Wurgler (2007) Empirical evidence of large discounts and premia between the price of tradable funds and the per-share market value of their underlying stock portfolio Rationalists link anomalies to the existence of limits to arbitrage	
Twin stocks	Rosenthal and Young (1990)	Froot and Dabora (1999)	
Corporate spin-offs		Lamont and Thaler (2003) Similar results and interpretation (e.g. short-sale constraints) to that of the closed-end puzzle for the price of stocks traded in more than one location, and corporate spin-offs	
Forward premium puzzle	Hodrick (1987)	Froot and Thaler (1990) Burnside *et al.* (2011) In currency markets, the forward premium negatively forecasts changes in the exchange rate The debate stands between a rationalist (time-varying risk premium for systematic risk) and a behaviorist (expectation errors) interpretation	Fama (1984)
Other puzzles			
ADRs		Lamont and Thaler (2003)	
Chinese warrants		Xiong and Yu (2011)	

Source: Own elaboration

Table V. Tests of insider information

Category	Evidence	Articles	Comments
Corporate insiders			
	Early papers	Jaffe (1974)	The least analyzed form of efficiency, due to the difficulties for an empirical contrast: we cannot observe the private information available, nor what would be the market prices that fully reflect this information
	Positive evidence	Aktas *et al.* (2008)	
	Evidence against EMH	Aboody and Baruch (2000) Cohen *et al.* (2012)	Most empirical studies provide unfavorable evidence of efficiency regarding corporate insider trading
Groups of professional investors			
Specialists and analysts	Positive evidence	Harris and Panchapagesan (2005)	The literature offers favorable evidence to strong-form EMH
	Evidence against EMH	Shane and Stock (2006)	
Institutional investors	Positive evidence	Griffin *et al.* (2012)	Most literature offers favorable evidence to strong-form EMH
	Evidence against EMH	Ivashina and Sun (2011)	
Mutual fund managers	Early papers	Treynor (1965), Sharpe (1966) Jensen (1969)	The most common tests of the strong-form EMH for professional investors
	Positive evidence	Sauer (1997)	Most researchers obtain evidence in favor of the strong-form EMH when it comes to the outperformance of mutual fund managers
	Evidence against EMH	Grinblatt and Titman (1992)	

Source: Own elaboration