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Explaining abnormal returns in stock markets: An alpha-neutral version of the CAPM

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Abstract

This paper develops a behavioural asset pricing model in which traders are not fully rational as is commonly assumed in the literature. The model derived is underpinned by the notion that agents' preferences are affected by their degree of optimism or pessimism regarding future market states. It is characterized by a representation consistent with the Capital Asset Pricing Model, augmented by a behavioural bias that yields a simple and intuitive economic explanation of the abnormal returns typically left unexplained by benchmark models. The results we provide show how the factor introduced is able to absorb the "abnormal" returns that are not captured by the traditional CAPM, thereby reducing the pricing errors in the asset pricing model to statistical insignificance.

1. Introduction

During the last 50 years, a substantial part of the research effort in both theoretical and empirical asset pricing has focused on the disclosure of patterns in average stock returns which are not described by the Sharpe (1964), Lintner (1965), and Mossin (1966) capital asset pricing model (CAPM) and are thus referred to as "anomalies" in the asset pricing literature. Within this body of work, we might note the findings of patterns between stock returns and firms' characteristics, long term reversals (De Bondt & Thaler, 1985) and momentum (Jegadeesh & Titman, 1993), the discovery of an excessively flat relationship between average returns and market beta, the scarcity of explanatory power of the latter, which sometimes even manifests itself in a negative relationship (Fama & French, 1992; Lakonishok & Shapiro, 1986), and the instability of market beta over time (Guo, Wu, & Yu, 2017; Jagannathan & Wang, 1996). Moreover, the CAPM is fully rejected from a statistical point of view, in that the model is fully rejected from a statistical point of view, in that the model is indistinguishable from zero. Despite all of the critiques cited above, the CAPM still remains a model most entrusted by both practitioners and academics (Fama & French, 1996a, 1996b). At the same time, however, such strong evidence against the CAPM, underlying the paucity of the explanatory power of a single-factor model, has driven scholars to engage in a huge effort to develop new multifactor models. In particular, developments in the asset pricing literature have given rise to two different approaches to the problem. The first, purely empirical, includes multifactor models which can be seen as different specifications of Ross' asset pricing theory (Ross, 1976), such as the most praised Fama and French (1993) – henceforth FF – three-factor model, Carhart’s 1997 four-factor model, the liquidity-adjusted CAPMs of Pástor and Stambaugh (2003) and Acharya and Pedersen (2005), and, more recently, the Fama and French (2015) five-factor model. As for the second approach, we have a stream of literature that collects all of the natural extensions of the classic CAPM through a relaxation of some of its underlying assumptions, such as Black’s 1972 zero-beta CAPM, Merton’s 1973
intertemporal (I)CAPM, Kraus and Litzenberger’s 1976 three-moment CAPM, Jagannathan and Wang’s 1996 conditional (C)CAPM, consumption/investment based CAPMs (Breened, 1979; Cochrane, 1991) and Dittmar’s 2002 four-moment CAPM. The connection between the two approaches lies in the interpretation of empirical multifactor models as different specifications of equilibrium models. For instance, Maio and Santa-Clara (2012, 2017) analyse the conditions that must be satisfied by a multifactor model in order for it to be justifiable by the ICAPM.

Whether we want to interpret multifactor models as equilibrium models or not, all these specifications have in common that they are mercilessly rejected from a statistical point of view in terms of Jensen’s alpha, as shown in many empirical applications. Fama and French (2015), for instance, argue that their five-factor model performs better than their three-factor model (FF, 1993) but still shows alphas that are jointly significantly different from zero. Similarly, Harvey and Siddique (2000), Dittmar (2002), Messis, Alexandridis, and Zapranis (2021), Lewellen and Nagel (2006), and Maio and Santa-Clara (2012), present studies respectively on the conditional three-moment CAPM, four-moment CAPM, CAPM with asymmetric and constant systemic risk, conditional consumption CAPM, CCAPM, and ICAFPM, finding similar results in terms of the significance of the intercepts.

Apart from the standard view stating that other risk factors are to be included in the evaluation, the “behaviouralist” interpretation argues that the return component left unexplained by the model should be attributed to some departure from the hypothesis of agents’ full rationality (Barberis & Thaler, 2003). Common explanations that have been advanced include investors’ over-reactions to bad economic news and market seasonality (De Bondt & Thaler, 1987), under- and over-reaction to public (Barberis, Shleifer, & Vishny, 1998) and private (Daniel, Hirshleifer, & Subrahmanyam, 2001) information, optimism/pessimism (Diether, Malet, & Scherbina, 2002), narrow framing and loss aversion (Barberis, Huang, & Santos, 2001) and, more recently, ambiguity aversion (Guidolin & Liu, 2016).

Interestingly, another common feature of both multifactor models and equilibrium models, which in particular originates from considering the former as specifications of the latter, is that most are underpinned by the hypothesis of fully rational agents, represented by the usage of a von Neumann–Morgenstern (VNM) order of preferences. As showed by Cochrane (2009), in fact, the CAPM, and thus the market component in explaining the cross section of stocks’ expected returns, can be derived directly by using different types of VNM utility functions. A serious issue, and one that in our view is still not suitably considered in the asset pricing literature, is that such preferences do not properly describe the actual behaviour of individuals. As shown in a large number of studies in decision-making under risk, in fact, VNM preferences are not able to capture a wide range of features that have been shown to characterize the behaviour of agents, including, just to name few, the under- and over-weighting of probabilities, loss aversion and narrow framing.

In the light of these considerations, in this paper we introduce a different version of the CAPM in which agents are boundedly-rational in the sense that they behave not as they theoretically should but as the empirical evidence shows that they do. In particular, we focus our attention on the inclusion of probability weights and the extent to which agents are optimistic or pessimistic in the asset pricing model. These, in our view, represent the most compelling, and somehow encompassing, departures from rationality. It is now a commonly held view that the use of the prospect theory of Kahneman and Tversky (1979) and Tversky and Kahneman (1992) is warranted. However, the employment of such preferences in asset pricing leads to a considerable loss of analytical tractability, as one can appreciate from the attempts made in this direction,5 and such an approach results in specifications that are challenging to test on actual data.

In order to avoid such issues, we make use of an order of preferences adjusted for optimism proposed by Rocciolo, Gheno, and Brooks (2019), which is both simple and characterized by high descriptive power. We justify this choice as a compromise between the representativeness of agents’ behaviour and analytical tractability in that the employment of such preferences permits the maintenance of the linearity of the asset pricing model and its expression in terms of the beta terminology of the original CAPM. This is a feature that is typically not achievable when other models such as prospect theory are employed. Moreover, the S-shaped value function typically assumed in prospect theory seems unqualified in describing agents’ behaviour when they face “mixed” prospects — i.e., prospects characterized by both gains and losses (Levy & Levy, 2002). Conversely, optimism-adjusted preferences, accounting explicitly for the possible skewness of the prospects, describe these kinds of situations well. In this sense, the model that we are going to derive is similar in spirit to the three-moment CAPM, in which investors’ attitude towards skewness is implicitly taken into account (as well as its extension to the fourth moment) in an optimism-adjustment to the utility function. The fundamental difference, however, with respect to the models cited above, is given by the fact that the latter inevitably end up as multifactor models while our specification, as we will show, preserves a single factor representation in terms of beta and consistency with the traditional CAPM.

Moreover, the CAPM derived provides a clear economic interpretation of Jensen’s alpha that is also consistent with the empirical evidence reported in Diether et al. (2002). It also provides, through the introduction of market sentiment into the specification, new evidence concerning the empirical validity of the CAPM. The results shown are strongly consistent with the underlying theory, which, as we will demonstrate, outperforms the currently most celebrated asset pricing models such as the Fama–French three- and five-factor models. More specifically, the test that we conduct on a large sample of portfolios sorted by size, book-to-market, investment, and operating profitability, shows, independently from the asset considered, pricing errors that are jointly indistinguishable from zero. We thus provide new evidence that, contrary to the common view, when the CAPM is corrected for the departure from full rationality of agents’ behaviour, it is still alive and well. The series of diagnostic tests we run for confirmation gives robustness to our findings.

The remainder of the paper is organized as follows. In the next section we outline the optimism-adjusted preferences framework used in the derivation of our behavioural capital asset pricing model. Section 3 explores the datasets and the econometric techniques employed in order to obtain the results summarized in Section 4. Finally, Section 5 concludes.

2. The model

In this section we proceed to the derivation of our asset pricing model under conditions departing from full rationality. We start by introducing the system of preferences that characterize the agents in our economy. This is necessary since the representation of how agents make choices in the market will act as the basic framework in the derivation of the model.

2.1. Optimism-adjusted preferences

Let us consider an agent characterized by a VNM utility function $u(x)$ and let $X$ be a prospect represented by a finite number of outcomes

---


us assume that one of them is an optimist ($\phi$ we have that, under such preferences and $u$ be the adjusted utility function $\phi(x, y)$, and different degrees of optimism $\gamma$. In particular, let $\phi(x, y)$, which assumes the interpretation of an optimism weighting function. It determines the weight assigned to the gains (and thus to the losses) in the overall value function based on the degree of optimism of the agent.

In order to sketch out how the model works, let us consider three agents endowed with the same utility function $u(x)$ and level of absolute risk aversion $\rho$, and different degrees of optimism $\gamma$. In this case, we will assume that one of them is an optimist ($\frac{1}{2} < \gamma_1 \leq 1$), one a pessimist ($0 < \gamma_2 \leq \frac{1}{2}$) and the last one is a pure rational expected utility maximizer ($\gamma_3 = \frac{1}{2}$). With respect to a prospect $X$ faced, the three agents, while sharing the same utility function and risk aversion, might end up with very different evaluations depending on the variance of the outcome. As shown in Fig. 1, in fact, the bigger the outcome’s variance, the more the optimistic agent will assign a greater weight $\phi(y_1, x, y_2)$ to the prospect’s gains (losses), and the steeper (flatter) will be the adjusted utility function $u(x, x, y_2)$ (s)he employs in the evaluation of the positive (negative) outcomes of the prospect. Conversely, the bigger the outcome’s variance, the more the pessimistic agent will assign a lower (greater) weight to the prospect’s gains (losses), the flatter (steeper) will be the adjusted utility function $u(x, x, y_2)$ (s)he employs in the evaluation of the positive (negative) outcomes of the prospect. Thus, we have that, under such preferences and $ceteris paribus$, $U(X, x, y_2) > U(X, x, y_3) > U(X, x, y_1)$ if the prospect is risky, i.e. $x_1 > 0$, and $U(X, x, y_2) = U(X, x, y_1) = U(X, x, y_3)$ in the case of a risk-free opportunity, i.e. $x_1 = 0$.

The strength of this representation evidently lies in being a mere adjustment applicable to a wide range of existing models in the field. At the same time, it is able to reconcile one of the most widely acknowledged features in the decision-making literature – evidence that individuals make use of weighted probabilities (Kahneman & Tversky, 1979) – with the expected utility paradigm and with the advantage of a very simple mathematical representation. In fact, since the weighting function $\phi(y, x, y_2)$ is deterministic and independent from the final outcomes of the prospect, we can rewrite Eq. (1) as

$$U(x, x, y_2) = \frac{1}{2} \sum_{j \leq 3} u(x_j) p_j [1 + \phi(y, x, y_2)] + \sum_{j > 3} u(x_j) p_j \phi(y, x, y_2)$$

where $\phi(y, x, y_2)$ can be interpreted in this representation as a function which assigns different weights to the objective probabilities according to the degree of optimism of the agent and the standard deviation of the prospect’s outcomes, $\gamma$ is the objective probability assigned to the outcome $x_1$ in the prospect $X$, and $x$ is the reference point.

In this kind of setting, the choice of a proper analytical expression for the weighting function $\phi(y, x, y_2)$ is needed in order to apply the model. We suggest the following

$$\phi(y, x, y_2) = \begin{cases} 1 - \frac{1}{2} \exp \left( -\rho \left( y - \frac{1}{2} \sigma_y^2 \right) \right) & \text{if } \frac{1}{2} \leq \gamma < 1 \\ 1 - \frac{1}{2} \exp \left( -\rho \left( y - \frac{1}{2} \sigma_y^2 \right) \right) & \text{if } 0 < \frac{1}{2} \leq \gamma < 1 \end{cases}$$

where, by defining $\sigma_y^2$ as the threshold variance beyond which a pessimistic agent will give up on the prospect faced, $1 - \exp(-\rho(y - \frac{1}{2} \sigma_y^2))$ is an indicator function which assumes the value one if the variance of the prospect’s outcomes is lower than the critical level $\sigma_y^2$ and conversely is equal to zero when $\sigma_y^2 \geq \sigma_y^2$.

Rocciolo et al. (2019) studied in detail how such preferences perform in terms of their descriptive power for many of the most acknowledged “counter-examples” of the expected utility criterion. Their tests show in particular how the adjustment for optimism, characterized through the use of an optimism weighting function such as that in Eq. (3), can adapt expected utility theory in order to allow the latter to better describe the empirical evidence collected in a wide number of empirical studies, such as Allais (1953) and Kahneman and Tversky (1979). Moreover, they showed how the latter form is convenient, especially when applied in a CARA-Normal assumptions setting, in that it allows the derivation of linear demand curves, as we will show in the next section. In this sense, our decision to make use of such an order of preferences finds justification in that improving the descriptive power of the expected utility criterion allows us to use the latter, which is still the currently preferred framework in the asset pricing literature. As shown in the next section, this preference ordering also allows us to derive an asset pricing model expressed in the usual beta language.

2.2. The alpha-neutral CAPM

As in the classic CAPM, let us consider as a basic framework an economy free of taxes and transaction costs, characterized by $n$ risk-avere utility maximizing agents, $N$ risky assets, each characterized by a normally distributed gross return $R_i$, and a risk-free asset with an exogenously determined gross risk-free return $R_f$. The market is always in equilibrium and each agent $i$ can invest any fraction of his/her capital in either the risk-free asset or any of the risky assets traded in the market, and can freely borrow and lend funds at the gross risk-free return $R_f$. All $n$ agents are assumed to be price-takers and plan to trade over the same time horizon at prices that are determined as a consequence of the equilibrium condition. In addition, let us make the following further assumptions:

Assumption 1. All $n$ agents have the same information and beliefs about the objective joint probability distribution of the returns of all individual stocks.
Assumption 2. Every agent $i$ is equipped with an optimism-adjusted negative exponential utility function of the type $u_{i}(x, \sigma_{x}, \gamma_{i}) = -2[1 - \phi(\gamma_{i} \sigma_{x})] \exp(-\rho_{i} x)$, where the function $\phi(\gamma_{i} \sigma_{x})$ takes the form in (3), and where the parameters $\sigma_{x}$, $\rho_{i}$ and $\gamma_{i}$ are respectively the standard deviation of the prospect $X$, the absolute risk aversion coefficient, and the degree of optimism of the agent $i$. Risk aversion and agents’ degree of optimism are assumed constant over time.

The second assumption represents the actual breaking point with “rational” asset pricing theory through the introduction of a behavioural element in the evaluation of the assets, represented by the agent’s degree of optimism. Being the unique difference with respect to the standard assumption set used in deriving the traditional CAPM, the asset pricing model we are going to derive makes a comparison with similar models in the literature an easy task. In particular, this greatly facilitates the study of where and how the original formulation of the asset pricing model we are going to derive makes a comparison with the standard assumption set used in deriving the traditional CAPM, the derivation of which can be split how (s)he prefers between the risk-free and risky securities. Under Assumption 2, every agent holds a portfolio characterized by different combinations, according to his/her risk aversion and degree of optimism, of the risk-free asset and the market portfolio so that, at an aggregate level and for each asset $j$ traded in the market, the following relationship holds

$$
\mathbb{E}[R_{j}] - R^{f} = (\rho + \kappa(\gamma)) \sigma_{M}^{2}
$$

where $\rho$ and $\gamma$ are aggregate measures of the agent’s absolute risk aversion and degree of optimism respectively, and where $R^{M}$ is the gross return on the market portfolio.

The first result in Eq. (7) is the optimal individual demand schedule, expressed in the usual hyperbolic form introduced in Grossman (1976), and which can be found in many other studies, generalized for the case in which $N$ risky assets are traded in the market, and adjusted for the behavioural bias implicit in the order of preferences used. As for the second result, Eq. (8) again represents the usual expression that ties the risky security excess returns to risk attitudes, adjusted through the agents’ aggregate degree of optimism.

The term $\kappa(\gamma) = 1 - 2\gamma \in [-1,1]$, contained in both equations (7) and (8), represents a quantification of the distance from rationality that characterizes typical agents who act in the economy. In particular, the term $\kappa(\gamma)$ in Eq. (7) identifies the mitigation, in the case that the agent $i$ is an optimist, or the enhancement, in the case in which (s)he is a pessimist, on the total impact that the asset’s risk has on the demand function.

Starting from the result in Eq. (8), the pricing equation can be rewritten in terms of the more commonly used beta language. Since, in fact, Eq. (8) holds for every agent $i$ and every asset $j$, it also holds for the market portfolio. In particular, we have in this case that

$$
\mathbb{E}[R^{M}] - R^{f} = (\rho + \kappa(\gamma)) \sigma_{M}^{2}
$$

and thus,

$$
\rho + \kappa(\gamma) = \frac{\mathbb{E}[R^{M}] - R^{f}}{\sigma_{M}^{2}}
$$

By plugging this last result into Eq. (8) and by defining the systematic risk component beta in a conventional way as $\beta_{j} = \frac{\text{cov}(R_{j}, R^{M})}{\sigma_{M}^{2}}$, we end up with

$$
\mathbb{E}[R_{j}] - R^{f} = (\mathbb{E}[R^{M}] - R^{f}) \beta_{j},
$$

### Proposition 1.
Under Assumption 2, the $N \times 1$ vector of individual optimal demand schedules for the risky assets traded in the market, which solves the optimization problem in (4) subject to (5), is given by

$$
x_{j} = \sum_{k} \frac{\mathbb{E}[R_{j}] - R^{f}}{(\rho_{k} + \kappa(\gamma_{k}))}
$$

where $\kappa(\gamma_{j}) = 1 - 2\gamma_{j}$, $R^{f} = 1^{R^{f}}$ and $\Sigma_{R}$ is the $N \times N$ covariance matrix of risky asset gross returns. Under Assumptions 1 and 2, every agent holds a portfolio characterized by different combinations, according to his/her risk aversion and degree of optimism, of the risk-free asset and the market portfolio so that, at an aggregate level and for each asset $j$ traded in the market, the following relationship holds:

$$
\mathbb{E}[R_{j}] - R^{f} = (\rho + \kappa(\gamma)) \sigma_{M}^{2}
$$

where $\rho$ and $\gamma$ are aggregate measures of the agent’s absolute risk aversion and degree of optimism respectively, and where $R^{M}$ is the gross return on the market portfolio.

The most recent works include Cochrane (2009), Mendel and Shleifer (2012) and Banerjee and Green (2015).
which is a pricing equation consistent with the original representation of the CAPM, with the difference that the systematic risk beta reflects, in this case, both the agents’ risk aversion and their degree of optimism.

This last expression, which is the fruit of pure algebraic manipulation, is not so innocuous as it might first appear. By recalling that in the original derivation of the CAPM only the risk aversion \( \rho \) is taken into account in determining the market price of risk, it generates a clash between the model just derived, in which the behavioural bias is taken into account as well, and the traditional CAPM. To better understand this point, let us consider two types of asset pricing model, both with representation as in Eq. (10), which focus on two different conjectures of the market risk premium.

Assume that the market is not uniquely composed of fully rational expected utility maximizers, i.e., \( \kappa(\gamma) \neq 0 \).

**Conjecture 1.** The market price of risk reflects not only the aggregate degree of risk aversion but also the aggregate degree of agents’ optimism, i.e., Eq. (9) holds

**Conjecture 2.** The market price of risk reflects only agents’ aggregate risk aversion without taking into consideration the potential presence of a behavioural bias in their decisions, resulting in the traditional version of the CAPM,

\[
\rho = \frac{\mathbb{E}[R_M] - R^F}{\sigma_M^2} \quad (11)
\]

The two conjectures are clearly not compatible simultaneously in that they give rise to different expressions for the unitary market’s risk premium. It is immediately clear that the only possible case in which the two expressions are equivalent is when \( \kappa(\gamma) = 0 \), i.e., all agents in the market are purely rational expected utility maximizers. As a result, we have that, under Conjecture 1 in which the model takes account of agents’ behavioural biases in formulating asset prices, the representation in Eq. (10) holds for every agent \( i \) and for every security \( j \) traded in the market. Thus, under Conjecture 1, prices determined by the market and the model coincide. The same is evidently not true in the case of Conjecture 2, under which there will exist a misprice \( \alpha \) between the market and the model, given by the fact that we are imposing a model which assumes rational agents (as the CAPM does) on the prices of assets which are traded by agents who are not rational. In particular, we have the following different result.

**Proposition 2.** Let \( \alpha_j \) be the misprice of asset \( j \) as a consequence of the assumption in Conjecture 2. Given the asset pricing model expressed by Eq. (8), under Conjecture 2 in which the model does not take into account agents’ behavioural biases in formulating asset prices, Eq. (10) becomes

\[
\mathbb{E}[R_j] - R^F = \alpha_j + (\mathbb{E}[R_M] - R^F)\beta_j + \kappa(\gamma)\text{COV}(R_j, R^M)
\]

(12)

which we will refer to from now on as an Alpha-Neutral CAPM, and where \( \beta_j \) is a measure of the systematic risk of asset \( j \), which, as in the traditional CAPM and according to Conjecture 2, reflects only agents’ risk aversion. Consistent with the name that we give to the model, we will refer to \( \beta_j \) as alpha-neutral betas in what follows.

A few comments are necessary on this last proposition. First, the expression in Eq. (12) has to be interpreted as a single-factor asset pricing model since, given our assumption-setting, we are still in an economy in which assets’ prices are determined only according to the systematic risk of assets. The new element \( \kappa(\gamma)\text{COV}(R_j, R^M) \) is actually a direct consequence of the fact that we are considering a mispricing of the traditional CAPM due to the non-fully rational behaviour of agents in the economy. In this sense, the factor \( \kappa(\gamma) \) merely quantifies how much of the cross-sectional pricing error produced by the traditional CAPM is explained by the behavioural component \( \kappa(\gamma)\text{COV}(R_j, R^M) \). This can be seen in the model as the portion of the covariance between the risky asset considered and the market left unexplained by the traditional market beta, and instead captured by the new factor. Notice that we have deliberately left the intercepts \( \alpha_j \) in Eq. (12) in accordance with the idea of mispricing of the traditional version of the model as assumed in Conjecture 2. If the traditional CAPM completely explains the covariance between the asset considered and the market, the intercepts \( \alpha_j \), as well as the coefficient \( \kappa(\gamma) \) should not be distinguishable from zero since the latter would constitute an unnecessary explanatory variable in the regression of the excess returns against the market risk premium, since all of the co-movement between the asset and the market would be fully captured by the alpha-neutral betas, \( \beta_j \), which would in this case be equivalent to the market beta of the traditional CAPM.

Conversely, in the case in which the model’s \( \alpha_j \) estimate is significantly distinguishable from zero, and if, as we have conjectured, the pricing errors are fully generated by behavioural biases, we should expect for every \( \alpha_j \) a model estimate \( \kappa(\gamma) \) such that the net intercepts \( \delta_j = \alpha_j + \kappa(\gamma)\text{COV}(R_j, R^M) \) are jointly indistinguishable from zero. In this sense, the model is an “alpha-neutral” version of the CAPM, in that the new factor, which exists because of the presence of a mispricing according to Conjecture 2, does not enter in the asset pricing equation as an explanatory variable for expected returns. Rather, it appears only as a counterbalance to the assumed misprice, which, if it works well, ends up “neutralizing” it. Moreover, if that is the case, such a result is consistent with the intuition behind the optimism-based order of preferences employed. According to Eq. (12) and the definition of the factor \( \kappa(\gamma) = 1 - 2\gamma \), in fact, in the presence of a positive unexplained excess return, the CAPM holds only if \( \kappa(\gamma) < 0 \) in such a way that the net intercepts are nullified, and thus if agents are on average optimistic about returns on the asset under study. The contrary evidently applies in the case of negative alphas where we will have, on average, pessimistic traders with regard to the asset under consideration. Finally, by using the definition of net intercepts \( \delta_j \) as above, the model in Eq. (12) can be rewritten as

\[
\mathbb{E}[R_j] - R^F = \delta_j + (\mathbb{E}[R_M] - R^F)\beta_j^* \]

(13)

Eq. (13) tells the same story but from a different perspective. The main difference with respect to the previous representation in Eq. (12) is in that the absorption of the intercepts by the behavioural component \( \kappa(\gamma)\text{COV}(R_j, R^M) \) is made explicit here, so that the expression recalls the traditional CAPM representation under conditions of non-full rationality and explicitly in a market where agents suffer from optimism/pessimism biases. In this sense, Eq. (13) defines a unique equilibrium characterized by an augmented security market line (SML*), which will, in general, be steeper with respect to the traditional SML defined by the traditional CAPM in Eq. (10). In fact, this change in the measurement of the intercept inevitably generates a change in the measurement of the systematic risk beta, which will result in a “purified”, behaviourally driven part of the movement in the market which at the same time impacts positively on the slope of the SML. In a comparison between the traditional CAPM in Eq. (10) and the Alpha-Neutral CAPM in Eqs. (12) and (13) we will refer to \( \beta_j \) and \( \beta_j^* \) as, respectively, traditional betas and alpha-neutral betas.

In order to outline the intuition behind the model, let us consider a simplified version of our economy in which only three assets named A, B and C are traded. Let us suppose that the cross-sectional errors from the traditional CAPM are \( \alpha_A^d > 0, \alpha_B^d > 0 \) and \( \alpha_C^d < 0 \) respectively for the three assets. Let us then imagine running the regression in Eq. (12) and finding the result that, consistent with the results previously obtained and with our Alpha-Neutral CAPM, the regressions on the assets A and C generate pricing errors \( \alpha_A > 0 \) and \( \alpha_C < 0 \) respectively and, consistent with these, the behavioural adjustments \( \kappa_A < 0 \) and \( \kappa_C > 0 \). Conversely, let us suppose that the asset B lies perfectly on the regression plane with \( \alpha_B = 0 \) and \( \kappa_B = 0 \).
and on three groups of 100 two-way sorted portfolios, which result in 18 portfolios with stocks sorted on size quantiles and 18 portfolios with stocks sorted on book-to-market (BTM) ratio quantiles.)

The covariances that will be used as explanatory variables as in Eq. (12). The latter are employed only to compute the covariance that could be used as explanatory variable as in Eq. (12). The latter are employed only to compute the covariances that will be used as explanatory variables in the estimation of the alpha-neutral CAPM (SML*). Figure 2 represents the situation for the three assets. Consistent with the situation depicted, we have that the model describes well the excess returns of the assets A and C if respectively the segment A – A* is equal to 0 – κ_A and C* – C is equal to κ_C – 0. Regarding asset B, we have instead that the model does not help in explaining the abnormal return of B predicted by the traditional CAPM in that the asset lies, in equilibrium, on the plane with a coefficient κ_B equal to zero. As we will show in the next section, this situation is quite rare, at least in the dataset that we employ.

Assuming that the latter conditions on the behavioural factors of the three assets are satisfied, Fig. 3 shows the traditional SML in Eq. (10) and the augmented SML* in Eq. (13) for the example we consider with three assets. According to the previous results, assets A and C that were showing respectively positive and negative pricing errors under the traditional CAPM, result in equilibrium on the new SML* defined by the Alpha-Neutral model. In particular, as mentioned above, the augmented SML* will, in general, be steeper than the traditional SML and the beta associated with the assets’ return reduced since, as argued above, the behavioural factor that we have included in the model also deadens the spurious component present in the betas when agents are not fully rational.

3. The playing field

3.1. Data description

Our empirical tests concern two main datasets: (a) average returns from Kenneth French’s data library on 336 portfolios typically used in the literature to describe patterns in expected stock returns, and (b) the average returns on portfolios that are considered to mimic the patterns in the portfolios in (a), plus the covariances between returns to each of the assets in (a) and the proxy for the market portfolio. For both samples, the period considered is July 1963–December 2016, and the excess returns are observed at both a monthly and a daily frequency, where the former have been used in order to perform the main tests of the model, while the latter are employed only to compute the covariances that will be used as explanatory variables as in Eq. (12).

Sample (a) has been constructed by considering excess returns with respect to the one-month U.S. Treasury Bill rate on 36 one-way sorted portfolios (18 portfolios with stocks sorted on size quantiles and 18 portfolios with stocks sorted on book-to-market (BTM) ratio quantiles) and on three groups of 100 two-way sorted portfolios, which result from the intersections of 10 portfolios of stocks sorted on size deciles and three groups of 10 portfolios in which the stocks have been independently sorted with respect to their BTM ratio, investment (INV) and operating profitability (OP) deciles. Consistent with Fama and French (1993, 1996a, 2015), the latter portfolios have been constructed at the end of each June using NYSE breakpoints and considering in the construction all NYSE, AMEX, and NASDAQ stocks for which returns and book values are available respectively on CRSP and COMPUSTAT.

Table 1 shows the monthly average excess returns for the portfolios considered in Sample (a). It is easy to recognize the typical patterns in the excess returns of the portfolios pointed out by Fama and French (1993, 1996a, 2015). The size effect, which is typically used to refer to the phenomenon characterized by a fall in the average returns from small stocks to big stocks is persistent in each panel of data analysed; exceptions are the first deciles of all three of the other firms’ characteristics involved in the sorts — i.e., the BTM-Low (panel B), OP-Low (panel C) and INV-Low (panel D).

Table 1 shows that the monthly average excess returns for the portfolios considered in Sample (a). It is easy to recognize the typical patterns in the excess returns of the portfolios pointed out by Fama and French (1993, 1996a, 2015). The size effect, which is typically used to refer to the phenomenon characterized by a fall in the average returns from small stocks to big stocks is persistent in each panel of data analysed; exceptions are the first deciles of all three of the other firms’ characteristics involved in the sorts — i.e., the BTM-Low (panel B), OP-Low (panel C) and INV-Low (panel D).

Panel B of Table 1 documents the value effect — i.e., the tendency of average returns to increase for higher values of the BTM ratio. This relationship shows up clearly in each row of the panel and, consistent with Fama and French (1993, 1996a, 2015), its effect is stronger for small size portfolios.

Panels C and Panel D of Table 1 instead provide evidence of the so-called profitability effect (Fama & French, 2015; Novy-Marx, 2013) and the investment effect (Aharoni, Grundy, & Zeng, 2013) respectively. In particular, we observe that average returns typically increase for stocks of firms with higher operating profitability (Panel C) and decrease for stocks of firms that invest more (Panel D).

For Sample (b), we have considered monthly and daily excess returns with respect to the one-month Treasury bill rate on the portfolio of all sample stocks, which can be considered a proxy for the market portfolio, and the monthly returns on the portfolios typically used in order to mimic the risk factors acknowledged in the literature, represented by (i) size, (ii) value, (iii) momentum, (iv) operating profitability and (v) investment. The manner in which the latter portfolios have been constructed is described in detail in Fama and French (1993, 1996a) for portfolios (i) and (ii), Carhart (1997) for (iii), and Fama and French (2015) for (iv) and (v). In what follows, we provide a brief summary.

Portfolios (i) and (ii), named SMB (small minus big) and HML (high minus low), are constructed as the differences between, respectively, the average returns on three small-stock value-weighted portfolios and three big-stock value-weighted portfolios in the former case and...
the average returns on two high BTM stock value-weighted portfolios and two low BTM stock value-weighted portfolios in the latter case. Portfolio (iii), named UMD (up minus down), is computed by considering the difference between the average returns on two high prior (winner) stock value-weighted portfolios and two low prior (losers) stock value-weighted portfolios.

Finally, portfolios (iv) and (v), named RMW (robust minus weak) and CMA (conservative minus aggressive), are determined as the differences, respectively, between the average returns on two high prior (winner) stock value-weighted portfolios and two low prior (losers) stock value-weighted portfolios in the latter case.

Regarding portfolios (i), (ii), (iv), and (v), Fama and French (2015) consider different methods of construction that differ from the 2 x 3 sorts used in Fama and French (1993, 1996a). Although they find interesting insights from the different ways of constructing the risk factors, in this paper we focus our attention just on the standard construction since they show in their paper that different procedures employed at this point do not affect the final result that is the principal objective of this paper.

Table 2 reports summary statistics for the monthly average returns on the portfolios that proxy for the risk factors. The extra three years of data with respect to the sample used in Fama and French (2015) do not significantly change the picture regarding the descriptive statistics of the risk factors. The only relevant change can be found with respect to SMB, which results in an average value of six basis points less and just 1.86 standard errors from zero. With respect to the remainder, we can still find a negative correlation between the value, profitability, and CMA factors, and the market and size factors. An extremely high correlation between CMA and HML is still present, as well as evidence of non-correlation between RMW and HML.

To complete Sample (b), we have determined the covariances between the daily excess returns of all the portfolios in (a) and the daily returns on the market portfolio for each month. Formally, for each m month of non-correlation between RMW and HML.

Finally, portfolios (iv) and (v), named RMW (robust minus weak) and CMA (conservative minus aggressive), are determined as the differences, respectively, between the average returns on two high prior (winner) stock value-weighted portfolios and two low prior (losers) stock value-weighted portfolios in the latter case.
will be in the specification of the model given in Eq. (13). The restricted model expressed by the definition of the model’s net intercepts \( \delta \), \( \gamma \), \( \kappa \) and \( \mu \) will in general be different on average from the behavioural component \( \delta \), \( \gamma \), \( \kappa \) and \( \mu \) given that the behavioural component is not a traded security. More specifically, the test will be structured in the following way: At the first step, for each portfolio \( j \) in Sample (a), we run the following 5-year rolling window time series regression of the type in Eq. (12), with the purpose of estimating the alpha-neutral betas and the behavioural factors \( \delta, \gamma, \kappa, \mu \), which represents the key element of our extension

\[
\begin{align*}
R_j^t - R_f^t &= a_j + b_j^M (R_M^t - R_f^t) + k_j \sigma (R_f^t, R_{M}^t) + \epsilon_{j,t} \\
R_j^t &= R_f^t + \epsilon_{j,t} 
\end{align*}
\]

where \( a_j, b_j^m, k_j \) and \( \epsilon_{j,t} \) are respectively the intercepts, the slopes for the market risk factor, the behavioural factors which quantify the portions of the covariances left unexplained by the market and explained by agents’ non-rational behaviour, and the regressions’ residuals. Then in the second step, we consider the restriction characterized by the definition of the model’s net intercepts \( \delta \), \( \gamma \), \( \kappa \) and \( \mu \) as in the specification of the model given in Eq. (13). The restricted model will be

\[
\begin{align*}
R_j^t - R_f^t &= d_j + b_j^M (R_M^t - R_f^t) + \epsilon_{j,t} \\
R_j^t &= d_t + b_j^M (R_M^t - R_f^t) + \epsilon_{j,t} 
\end{align*}
\]

which is not different from a CAPM adjusted for the hypothesis of agents’ limited rationality.

If the traditional CAPM still works after adjusting for the limited rationality of agents in the market, we should find that all net intercepts are jointly indistinguishable from zero. In order to test this hypothesis, we have made use of the GRS statistical which, when applied to the model expressed as in Eq. (13) can be used to perform a test of the null hypothesis \( H_0 : \delta = 0, \forall j \in [1, N] \) against the alternative hypothesis \( H_1 : \exists \delta_j \neq 0, j \in [1, N] \) where \( N \) is the number of portfolios considered. The test statistic is given by

\[
GRS = \frac{\sum_{i=1}^{N} \left( \frac{d_i' \Sigma^{-1} d_i}{1 + \Sigma_i' \Omega_i \Sigma_i} \right)}{N} \sim F_{N,T-N-L}
\]

where \( T \) is the number of observations, \( L \) is the number of factors included in the regressions, \( \Omega \) is the \( L \times 1 \) vector of estimated net intercepts from the time series regressions, \( \Sigma \) is the \( L \times L \) covariance matrix of time series regression residuals and the \( L \times L \) matrix of covariances between the factors \( \Omega \) employed.

In both steps, we analyse the performance of the model in describing the excess returns of the portfolios considered against the performance of the most accredited asset pricing models. In particular, we consider the following alternatives to our model:

- The traditional CAPM (Lintner, 1965; Mossin, 1966; Sharpe, 1964)
- The Fama–French three-factor model (Fama & French, 1993)
- The Carhart four-factor model (Carhart, 1997)
- The Fama–French five-factor model (Fama & French, 2015)

As a robustness check, we also run a performance test by considering the latter three models augmented for the behavioural bias measured by \( \kappa \).

3.2. Estimation method

In order to test the performance of the Alpha-Neutral CAPM in Eqs. (12) and (13), we have made use of a two-step procedure that extends the usual time series testing approach for the purpose of making the latter suitable to test our model. The employment of this kind of testing approach is unusual in this context in that the behavioural component in Eq. (15) is not a traded asset and therefore, in general, a cross-sectional approach is usually favourable. Notwithstanding this, the particular kind of setting in which the Alpha-Neutral CAPM is conceived allows us the use of the GRS test provided by Gibbons et al. (1989) as in a normal setting with traded assets, without any consequences for the test’s power or interpretation. In fact, we have the following result which we demonstrate in the paper’s appendix.

Proposition 3. Given the Alpha-Neutral CAPM, the average net cross-sectional pricing errors \( E[\delta_j] \) coincide with the average time-series net intercepts \( E[\delta_j] \). The same does not apply to the standard cross sectional pricing errors \( a_j \), which will in general be different on average from the time series intercepts \( a_j \) given that the behavioural component is not a traded security.

Panel A: Averages, standard deviations and t-statistics for risk factors

<table>
<thead>
<tr>
<th></th>
<th>SMB</th>
<th>HML</th>
<th>UMD</th>
<th>RMW</th>
<th>CMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.510</td>
<td>0.227</td>
<td>0.373</td>
<td>0.664</td>
<td>0.242</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>4.424</td>
<td>3.087</td>
<td>2.819</td>
<td>4.228</td>
<td>2.234</td>
</tr>
<tr>
<td>t-statistic</td>
<td>2.922</td>
<td>1.863</td>
<td>3.350</td>
<td>2.388</td>
<td>2.234</td>
</tr>
</tbody>
</table>

Panel B: Correlations between risk factors

<table>
<thead>
<tr>
<th></th>
<th>SMB</th>
<th>HML</th>
<th>UMD</th>
<th>RMW</th>
<th>CMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMB</td>
<td>1.000</td>
<td>0.295</td>
<td>-0.258</td>
<td>-0.132</td>
<td>-0.233</td>
</tr>
<tr>
<td>HML</td>
<td>0.295</td>
<td>1.000</td>
<td>-0.204</td>
<td>0.002</td>
<td>-0.404</td>
</tr>
<tr>
<td>UMD</td>
<td>-0.258</td>
<td>-0.204</td>
<td>1.000</td>
<td>-0.187</td>
<td>0.074</td>
</tr>
<tr>
<td>RMW</td>
<td>-0.132</td>
<td>0.002</td>
<td>-0.187</td>
<td>1.000</td>
<td>0.109</td>
</tr>
<tr>
<td>CMA</td>
<td>-0.384</td>
<td>-0.169</td>
<td>0.691</td>
<td>0.109</td>
<td>1.000</td>
</tr>
</tbody>
</table>

4. Results

4.1. Model performance summary

We now turn to the main empirical results. As widely discussed in the paper, our main target is to test the extent to which the Alpha-Neutral CAPM is able to explain the excess returns of portfolios of stocks, and to examine a comparison of the performance of our model against those of the Fama-French and Carhart multifactor models. We
test the performance of the models by looking both at the time series regression-generated intercepts and at different measures of the overall explanatory power of the models involving the cross-sectional pricing errors.

Table 3 reports the GRS statistics of Gibbons et al. (1989) and the relative p-values, which test whether the models’ net intercepts with respect to the behavioural bias, $A(d_j)$, are jointly statistically equal to zero – obviously, for models which do not consider the behavioural adjustment in the pricing equation, the net intercepts will coincide with the alphas – for the Alpha-Neutral CAPM and the seven alternative models considered. For every set of portfolios examined, the GRS test easily rejects the traditional CAPM along with all of the multifactor models that are not adjusted for the behavioural bias.

Conversely, the test never rejects the Alpha-Neutral CAPM, a result that is strongly robust across all samples as documented by the high level of the p-values (from 0.197 for the BTM portfolios to 0.995 for the Size X BTM portfolios). The conclusions from the Alpha-Neutral variations of the multifactor models are less obvious: the results from the augmented FF three-factor model are not robust for the size (Panel A) and BTM portfolios (Panel B) with GRS statistic p-values respectively equal to 0.115 and 0.125, while the augmented FF five-factor model is clearly rejected for the same portfolios with p-values equal to 0.045 and 0.005 respectively. On the contrary, with regard to the two-way sorted portfolios in panels C, D, and E, the two models cannot be rejected. In any case, it is interesting to observe that all the augmented multifactor models are, in terms of their GRS statistic, systematically outperformed by the Alpha-Neutral CAPM, except for the 100 Size X BTM portfolios (Panel C), where the best performance is achieved by the behaviourally augmented Carhart four-factor model.

Table 3 reports for each model and panel of data, along with the GRS test, the estimated average absolute intercepts $A(d_j)$, the estimated average absolute slope for the behavioural factor $A(k_j)$, the percentage of sign reversals between the latter two, and the average absolute net intercepts $A(d_j)$, along with some descriptive statistics which characterise the empirical distribution of the latter: the maximum and minimum values for the net estimated intercepts, their standard deviation $σ(d_j)$, the skewness $Sk(d_j)$ and the kurtosis $Ku(d_j)$.

The intercepts $d_j$ generated by the Alpha-Neutral variation of the models are always greater than those generated by the traditional models. However, by representing the pricing errors of the regressions’ hyperplanes that consider the behavioural biases as independent variables, their magnitude is not relevant when testing model performance in that, as discussed in the previous sections, the tests are conducted in terms of the restriction applied to the models that the net intercepts equal zero. Moreover, the finding of higher standard intercepts in this setting is not necessarily bad news in that it is simply a consequence of estimating an asset pricing model that makes use of a non-traded asset, as explained in Proposition 3.

The behavioural coefficients $k_j$ show up as always statistically significant in each sample. Consistent with the intuition of the model introduced, the behavioural adjustments generated by the products of the latter with the associated covariances display signs that are inverted with respect to the intercepts $a_j$ in almost every portfolio analysed (the figure runs from 83% for the 18 BTM portfolios in Panel B to 100% for the 18 size portfolios in Panel A).

With respect to the Alpha-Neutral CAPM, for every sample considered, the average net intercept $A(d_j)$ is always significantly reduced in magnitude by the presence of the behavioural component with respect to the traditional CAPM in which the latter is not considered. This reduction is, however, never sufficient to generate net intercepts which are on average lower than the traditional multifactor model alphas. Nevertheless, although highly emphasized in the literature, the magnitude of the absolute average intercept is definitely not, on its own, an unquestionable measure of the performance of an asset pricing model, as highlighted by, among others, Barillas and Shanken (2016). In fact, it is highly informative to also look at the higher moments of the net intercepts’ distribution. Specifically, a skewness close to zero and a low kurtosis are good news since that would imply that the pricing errors will be distributed homogeneously on the equilibrium hyperplane and with a low frequency of values far from zero.

If, in general, the information contained in the descriptive statistics of the distribution of net intercepts is helpful in the interpretation of the GRS test, it is also true that it is not sufficient to fully describe the results. The Alpha-Neutral CAPM has a distribution of pricing errors clearly improved with respect to the traditional models for the 18 Size portfolios (Panel A), the 18 BTM portfolios (Panel B) and 100 Size X BTM portfolios (Panel C), with a skewness index that goes from −0.7 to 0.4 and kurtosis from 1.7 to 3.6. The same is not true for the 100 Size X OP portfolios (Panel C) and 100 Size X INV portfolios (Panel D) in which the statistics seem to contradict the GRS test result, showing a pricing error distribution for the Alpha-Neutral CAPM which is clearly outperformed by the traditional model and, in particular, by the FF five-factor model, which is instead rejected by the formal test.

4.1.1. Size portfolios

The CAPM, along with the FF three-factor and the Carhart four-factor models, are all easily rejected by the GRS test with p-values close to zero. The Alpha-Neutral version of the latter instead easily passes the test with p-values from 0.11 for the augmented three-factor model to 0.4 for the Alpha-Neutral CAPM. The traditional and the augmented five-factor model share p-values around the threshold values and thus the asset pricing test is inconclusive in these cases.

The average net intercept $A(d_j)$ produced by the Alpha-Neutral CAPM and the behaviourally augmented models are close in magnitude to the traditional multifactor models, which also share similar values for the descriptive statistics of the intercepts. Specifically, almost all models share a slightly skewed and platykurtic distribution of pricing errors. An interesting exception is represented by the high kurtosis displayed by the five-factor model (4.196), which identifies a higher frequency of values far from zero that is coherent with a rejection of the GRS test. The best possible distribution is achieved for this sample by the Alpha-Neutral variation of the FF three-factor model with a skewness index equal to −0.265 and a kurtosis of just 1.952, a result that is in contradiction with the rejection of the GRS test.

4.1.2. BTM portfolios

For the 18 BTM portfolios, the test easily rejects the FF three-factor model, the Carhart four-factor model and the augmented five-factor model. With p-values from 0.1 and 0.2, the test is not able to reject the Alpha-Neutral variation of the CAPM, the three-factor model and the four-factor model. Again, the test is inconclusive for the five-factor asset pricing model. The average net intercept $A(d_j)$ values for the Alpha-Neutral CAPM are considerably higher than those of the traditional multifactor models and in particular show a magnitude similar to those of the traditional CAPM. The maximum value assumed by the net intercepts is equal to 0.32, which is again close to the 0.36 of the traditional CAPM and considerably greater than the maximum net intercept generated by the traditional multifactor models. However, the lower skewness (−0.2) and kurtosis (1.7) with respect to the other competing traditional models might justify the non-rejection of the GRS test. The best possible distribution is achieved this time by the traditional FF three-factor model with a skewness value tending towards a normal (0.06) and a kurtosis of just 1.861.

4.1.3. Size-BTM portfolios

The GRS test does not reject the null hypothesis that the net intercepts are jointly equal to zero for all of the Alpha-Neutral variations of the traditional models considered and conversely, it easily rejects the latter with p-values tending to zero. Again, the average absolute net intercepts for the Alpha-Neutral CAPM are lower than those of the traditional CAPM and higher than those of the traditional multifactor models. The descriptive statistics give strength to the non-rejection of
the null hypothesis that the net intercepts are jointly equal to zero.

4.1.4. Size-OP portfolios and size-INV portfolios

Competing models (Ku et al., 2015) have shown the only case of a platykurtic distribution amongst all the competing traditional multifactor models. Moreover, contradicting the results with respect to the traditional CAPM results, are again larger with respect to the traditional multifactor models. The maximum is of a lower magnitude than for the traditional traditional CAPM despite the higher magnitudes of the intercepts. The maximum is of a lower magnitude than for the traditional traditional CAPM despite the higher magnitudes of the intercepts.

Table 3
Model performance summary.

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Fama French 3 Factor</td>
<td>0.033</td>
<td>0.151</td>
<td>0.259</td>
<td>0.252</td>
<td>0.246</td>
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<tr>
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<td>0.140</td>
<td>0.406</td>
<td>0.403</td>
<td>0.402</td>
</tr>
<tr>
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<td>0.103</td>
<td>0.203</td>
<td>0.203</td>
<td>0.203</td>
</tr>
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<td>0.062</td>
<td>0.391</td>
<td>0.391</td>
<td>0.391</td>
</tr>
<tr>
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<tr>
<td>Carhart 4 Factor</td>
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<td>0.406</td>
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<tr>
<td>Fama French 5 Factor</td>
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<tr>
<td>Fama French 3 Factor</td>
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</tr>
<tr>
<td>Carhart 4 Factor</td>
<td>0.110</td>
<td>0.156</td>
<td>0.203</td>
<td>0.203</td>
<td>0.203</td>
</tr>
<tr>
<td>Fama French 5 Factor</td>
<td>0.110</td>
<td>0.156</td>
<td>0.203</td>
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<td>0.156</td>
<td>0.203</td>
<td>0.203</td>
<td>0.203</td>
</tr>
</tbody>
</table>

the Alpha-Neutral CAPM despite the higher magnitudes of the intercepts. The maximum is of a lower magnitude than for the traditional CAPM, while the minimum is lower in magnitude with respect to the FF three-factor and the Carhart four-factor models. Skewness and kurtosis are the lowest among the competing traditional multifactor models, although, surprisingly, the values are higher than for the traditional CAPM. The best performance in terms of the distribution of intercepts is this time achieved by the augmented Fama and French five-factor model with a skewness that tends towards the normal (−0.03) and showing the only case of a platykurtic distribution amongst all the competing models (Ku(d_j) = 2.115).

4.1.4. Size-OP portfolios and size-INV portfolios

As for the Size X BTM portfolios, the GRS test does not reject the null hypothesis that the net intercepts are jointly equal to zero for all of the Alpha-Neutral variations of the traditional models and conversely, it easily rejects the latter with p-values tending to zero for both samples. The results for the portfolios formed from stocks sorted on size and operating profitability and on size and investment are, however, the most controversial for the Alpha-Neutral CAPM. Despite the clear non-rejection of the GRS test, the magnitude of the net average absolute intercepts, although inferior with respect to the traditional CAPM results, are again larger with respect to the traditional multifactor models. Moreover, contradicting the results with respect to the previous samples, the distribution of net intercepts for the Alpha-Neutral CAPM is in this case highly leptokurtic (Ku(d_j) = 5.24 for Panel D and Ku(d_j) = 4.76 for Panel E) and skewed (Sk(d_j) = −1.32 for Panel D and Ku(d_j) = −1.29 for Panel E), identifying a high frequency of extreme values with respect to the competing models. Thus, the descriptive statistics regarding the distribution of net intercepts are in...
contradiction to the result of the formal test, showing the necessity to delve deeper in analysing the results obtained.

4.2. Diagnostics

The apparent clash between the information obtained from the GRS test and the net average absolute value of the estimated intercepts highlights an important question. A possible controversy that may arise by observing the latter results concerns the extent to which the non-rejection of the GRS tests is due to chance rather than to an actual contraction of the (true) magnitude of the net intercepts.

This issue can be addressed through a dissection of the GRS statistic into the unexplained ex-post squared Sharpe ratio \( \theta_j^2 = d' \Sigma^{-1} d \) and the factors’ Sharpe ratio \( \theta_j^2 = E[\Omega_j]^{1/2} \Omega_j^{-1} E[\Omega_j] \) according to the economic interpretation of the GRS statistic given in Gibbons et al. (1989), in which they show the possibility of rewriting the latter as

\[
GRS = \left( \frac{T}{N} \right) \left( \frac{T - N - 1}{T - L - 1} \right) \left( \frac{\theta^2 - \theta_j^2}{1 + \theta_j^2} \right),
\]

where \( \theta \) is the Sharpe ratio of the ex post tangency portfolio spanned by the \( N \) assets and the \( L \) factors. According to this interpretation, the less is the relative distance between the ex post tangency portfolio Sharpe ratio and the factor Sharpe ratio, the higher will be the unexplained Sharpe ratio \( \theta_j \), and thus the distance from the intercepts to zero. In a recent study, Barillas and Shanken (2016) discuss this decomposition, showing that a comparison between competing models essentially relies on the magnitude of the factor Sharpe ratio while the test assets are shown as irrelevant unless one or more factors employed in the asset pricing model are not returns.

Table 4 reports the decomposition of the GRS statistic into unexplained Sharpe ratios \( \theta_j^2 \) and Sharpe ratios of the factors \( \theta_j^2 \) along with Shanken’s 1987 efficiency ratio, \( \rho = \theta_j / \theta \).

Ideally, if the portfolio given by the combination of factors is efficient, \( \rho = 1 \). Consistent with the result in Proposition 3 and with the findings of Barillas and Shanken (2016), the unexplained Sharpe ratio is approximately the same for every model in each of the samples considered. Thus, for each of the asset pricing models that have been considered, the actual explanatory power of the latter is wholly represented by the factor Sharpe ratio \( \theta_j^2 \). The Alpha-Neutral models always display values considerably higher than those of the traditional asset pricing models (at least eight times higher than the FF five-factor model, which represents the best alternative amongst the traditional models). Notice also that the unexplained Sharpe ratios of the Alpha-Neutral models, although remaining very close to those obtained from the traditional models, benefit from a consistent reduction in three out of five of the samples.

Consistent with the findings of Fama and French (2015), the five-factor model always outperforms the three-factor model, but in terms of absolute efficiency, the combination of factors: MKT, SMB, HML, CMA and RMW, slightly exceeds 50% for the one-way sorted portfolios (panel A and B) and 30% for the two-way sorted portfolios (panel C, D and E). Conversely, the Alpha-Neutral CAPM, along with all the adjusted multifactor models, display an efficiency coefficient of around 70% for every sample, which is surprisingly robust across the samples.

Another important point that is not always well addressed in the empirical literature is represented by the fact that, more important than the magnitude of the estimated intercepts themselves, is the proportion in the estimation represented by the real unknown pricing errors and the estimation errors which naturally arise from the application of the econometric technique employed. The estimated intercepts \( d_j \) are in fact given by the true intercepts \( \delta_j \) plus the sum of the estimation errors of the \( \alpha \)s, \( \epsilon_j,\alpha \), and of the behavioural bias \( \epsilon_j,\kappa \).

\[
d_j = \delta_j + \epsilon_j,\alpha + \epsilon_j,\kappa.
\]

Following Fama and French (2016), since \( \delta_j \) is constant, the cross-sectional average over the expected value of \( d_j^2 \) is

\[
E[d_j^2] = E[\delta_j^2] + E[\epsilon_{j,\alpha}^2] + 2E[\epsilon_{j,\alpha}\epsilon_{j,\kappa}] + 2E[\epsilon_{j,\kappa}^2],
\]

where \( E[\epsilon_{j,\alpha}^2] \) is the variance of the net intercepts \( \delta_j \) due to estimation error which we estimate using the cross-sectional average standard error of \( d_j \), \( \sigma^2(d_j) \). The ratio \( A^2(d_j)/Ad^2_j \) thus measures the dispersion of net intercept estimates due to estimation error. Along with the latter ratio, Table 4 also reports some metrics, introduced in Fama and French (2015, 2016), which estimate the proportion of the cross-section of expected returns left unexplained by the models. Let \( r_j = R_j - R, R \) be the time series average excess return on the portfolio \( j \) and \( R \) is the cross-section average of \( r_j \).

\[
A(d_j)/Ad_j = \frac{\sigma^2(d_j)}{A^2(d_j)} = \frac{\sigma^2(d_j)^2}{A^2(d_j)}
\]

Thus, for each of the asset pricing models that have been considered, the actual explanatory power of the latter is wholly represented by the factor Sharpe ratio \( \theta_j^2 \). The Alpha-Neutral models always display values considerably higher than those of the traditional asset pricing models (at least eight times higher than the FF five-factor model, which represents the best alternative amongst the traditional models). Notice also that the unexplained Sharpe ratios of the Alpha-Neutral models, although remaining very close to those obtained from the traditional models, benefit from a consistent reduction in three out of five of the samples.

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\]

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\[
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Thus, for each of the asset pricing models that have been considered, the actual explanatory power of the latter is wholly represented by the factor Sharpe ratio \( \theta_j^2 \). The Alpha-Neutral models always display values considerably higher than those of the traditional asset pricing models (at least eight times higher than the FF five-factor model, which represents the best alternative amongst the traditional models). Notice also that the unexplained Sharpe ratios of the Alpha-Neutral models, although remaining very close to those obtained from the traditional models, benefit from a consistent reduction in three out of five of the samples.
4.3. Factor spanning test

A common practice in the empirical asset pricing literature is to test whether a factor can be explained through a combination of the others and thus, if it is redundant as an explanator of the test assets considered. The nature of the model that we have introduced, the strength of our results and of the evidence about the contraction of the intercepts obtained in general compared with the three-factor and five-factor models (Fama & French, 1993, 1996a, 1996b, 2015, 2016) lead us to attempt to give an answer to an old controversy which usually characterizes the latter models, i.e. whether the “better” pricing attained by these model is rationally or irrationally driven (Fama & French, 1993, 1996a, 1996b, 2015, 2016; Titman, Wei and Xie, 2013).

Table 4

<table>
<thead>
<tr>
<th>Panel A: 18 Size Portfolios</th>
<th>(\alpha_i)</th>
<th>(\beta_i)</th>
<th>(\lambda_i)</th>
<th>(\delta_i)</th>
<th>(\rho)</th>
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<tr>
<td>Fama French 3 Factor</td>
<td>0.417</td>
<td>0.192</td>
<td>0.979</td>
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<tr>
<td>Carhart 4 Factor</td>
<td>0.482</td>
<td>0.204</td>
<td>1.051</td>
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<tr>
<td>Fama French 5 Factor</td>
<td>0.288</td>
<td>0.087</td>
<td>0.977</td>
<td>0.054</td>
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<tr>
<td>a-Fama French 3 Factor</td>
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<tr>
<td>a-Carhart 4 Factor</td>
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<td>a-Fama French 5 Factor</td>
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<td>Carhart 4 Factor</td>
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<td>1.041</td>
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</tr>
<tr>
<td>Fama French 5 Factor</td>
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<td>0.997</td>
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<tr>
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<td>0.788</td>
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<tr>
<td>a-Fama French 3 Factor</td>
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<tr>
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<tr>
<td>a-Fama French 5 Factor</td>
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<td>Carhart 4 Factor</td>
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<td>a-Fama French 3 Factor</td>
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<td>1.203</td>
<td>0.756</td>
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<th>Panel E: 100 Book-to-Market Portfolios</th>
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<td>a-Fama French 3 Factor</td>
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In the table, the factor squared Sharpe ratio, Shanken’s 1987 index of efficiency. Period: July 1963–December 2016, 642 months.
the test assets if, in a time-series regression of the type
\[ f_t = a_f + b_f (R_M^t - R_F^t) + e_f, \]
the intercepts \( a_f \) are statistically different from zero.

However, if the market’s mispricing of the factor is not due to the presence of a real effect that is not caught by the market but instead because of the presence of a behavioural bias, exactly as occurred for the test assets, we will have a behavioural bias coefficient statistically different from zero and a representation of the model in Eq. (25) as
\[ f_t = a_f + b_f (R_M^t - R_F^t) + k_f \text{COV}(f_f, R_M^t) + e_f, \]
where now the condition in order for the factor to not be discarded is \( d_f \) different from zero.

In each regression, the behavioural factor \( \text{COV}(f_f, R_M^t) \) takes the form of the covariances, estimated from the daily returns, between the market and the factor that has to be explained. Panel A of Table 5 shows regressions in which six factors are used to explain the returns on the seventh. In terms of the estimated intercepts, our findings are similar to those in Fama and French (2015, 2017). Judging each of the different factors considered along with the market in terms of \( a_f \), almost all seem to play a role in the explanation of the average returns of the test assets. In particular, the size, momentum and investment factors show highly significant estimated intercepts with p-values less than 0.01. Again consistent with Fama and French (2015, 2017), we find that the value factor instead seems redundant with an estimated intercept of just 0.09 and a p-value of 0.27, while, different from them, the addition of the behavioural factor in the regression makes the profitability factor redundant as well with an intercept of 0.03 and an associated p-value of 0.06, although the result is less robust with respect to HML.

By instead judging the explanatory power of the factors under the logic introduced by the Alpha-Neutral framework, the situation is completely reversed. With the exception of the market factor, all of the remaining factors are replicable with combinations of the others within the Alpha-Neutral model, showing non-significant average net intercepts with p-values that run from 0.25 for SMB to 0.84 for CMA. These results are, however, not decisive, especially for the momentum factor, in that much of the non-rejection of the t-test is due to substantially increased standard errors obtained in the formation of the net intercepts.

The results shown in Panel B instead display more strength. In this case, we have used only the market and behavioural factors in order to explain the average monthly returns on each of the other factors. The results for the size factor are very interesting since, when all of the other factors are removed, we obtain estimated intercepts that are not significant with p-value 0.10. The behavioural bias represented by the coefficient \( k_f \) has zero explanatory power, a result which is consistent with the logic of the Alpha-Neutral CAPM in which a
behavioural bias exists in the case of mispricing of the traditional model represented by a pricing error different from zero.

Regarding the HML factor, our test clearly rejects the null hypothesis that the value factor is redundant in an Alpha-Neutral framework which considers just optimism/pessimism as a departure from rationality. The intercepts ex ante and ex post netting are statistically different from zero, showing that the market factor alone cannot correctly price the HML factor and the latter is thus a necessary variable to include in the regressions to explain the average returns on the test asset.

More controversial is the result concerning the momentum factor. The estimated intercepts are statistically different from zero with p-values around 0.00 while, as for the previous cases, the net average intercepts from the t-test are equal to zero with a p-value of 0.34. Nevertheless, it is clear from the standard error that most of the non-rejection of the test is due to the magnitude of the latter, which is approximately five times the corresponding value associated with the estimated intercept. Thus we can easily see that the spanning test is not conclusive in this case.

The CMA and RMW factors show relevant results. The estimated intercepts in this case are both statistically different from zero, showing the presence of a consistent mispricing of the latter portfolios by the market. However, different from the value factor, this mispricing seems in both cases to be behaviourally driven, given that the average net intercepts are statistically insignificant with p-values of 0.15 and 0.65 respectively. An interesting insight is that the more a firm is characterized by a high level of operating profitability, the more the market is driven by this factor, reflecting in investors being pessimistic about that stock. Thus, under this logic, profitability and investment effects have non-zero impacts on the average excess returns of the test assets not because of a real effect from these two variables on the stocks’ returns, but because of behavioural biases generated among investors regarding the firms’ investment decisions and the characteristics of their profitability.

5. Conclusions

In this paper we have derived a capital asset pricing model in an economy in which traders, consistent with recently developed theories in the decision-making literature, do not behave rationally in the sense of von Neumann–Morgenstern expected utility theory. In particular, we have focused our attention on the inclusion of the agents’ degrees of optimism in the capital asset pricing model. In our view, this represents the most compelling departure from rationality and at the same time is a crucial component in decision-making. The Alpha-Neutral CAPM that we derive provides an intuitive and analytically simple explanation of the abnormal returns left unexplained by the Sharpe (1964), Lintner (1965) and Mossin (1966) traditional CAPM and by many of the currently most accredited multifactor models by attributing the presence of these “anomalies” to the limited rationality of traders.

The results we present, both on the performances of competing models in Table 3 and on the spanning tests in Table 5, are consistent with the idea that the SMB, CMA and RMW factors are not necessary in order to explain the average returns of the test assets. Conversely, the parsimonious representation of the Alpha-Neutral CAPM, comprising just one risk factor augmented by the behavioural bias, seems sufficient to explain the variation in average returns.

Does this mean that all factors considered in the literature are just imperfect proxies for an effect that is purely behavioural and are thus not necessary? The answer to this question is not straightforward. First, from the spanning tests, not all of the factors are perfectly explicable in terms of just the behavioural bias characterized in terms of the degree of optimism that we introduce in this paper. A combination of the market factor and the degree of optimism is in fact able to explain the cross-section of the size, profitability and investment effects but not the value or momentum effects, which seem instead to have a real impact on the average returns of the securities in the market. At the same time, it is also true that our representation of irrationality is limited in that we are considering just one, albeit somehow encompassing, departure from rationality. Moreover, the results we have obtained do not render the other factors studied in the literature outdated. We also have to deal with the problem that the behavioural factor is not a return. In this sense, the SMB, HML, UMD, RMW and CMA factors might remain essential in order to construct a traded portfolio whose returns mimic the behavioural factor.\footnote{Such a portfolio could be constructed by taking the (normalized) weight of the slope coefficients of the Fama–French and Carhart factors in a regression where the dependent variable is the behavioural factor.}

CRediT authorship contribution statement

Francesco Rocciolo: Conceptualization, Methodology, Software, Formal analysis, Writing – original draft. Andrea Genho: Conceptualization, Supervision, Writing – review & editing. Chris Brooks: Project administration, Conceptualization, Supervision, Writing – review & editing.

Appendix. Proofs of propositions

Proof of Proposition 1

Let us start by considering the variable $W_i(t)$ in Eq. (6). If the vector of risky asset gross returns is distributed as a multivariate normal with mean $\mathbb{E}[\mathbf{R}]$ and covariance matrix $\Sigma_{\mathbf{R}}$, we have that the final level of wealth $W_i(t)$ will be normally distributed as well with moments:

$$\mathbb{E}[W_i(t)] = \chi'(\mathbb{E}[\mathbf{R}] - \mathbf{R}^F) + W_i(t-1)\mathbf{R}^F$$  
(A)

$$\text{VAR}[W_i(t)] = \chi'\Sigma_{\mathbf{R}}\chi$$  
(B)

For a normally distributed variable $W_i(t)$ and a constant $a$, the following property holds

$$\mathbb{E}[aW_i(t)] = \mathbb{E}[aW_i(t)] + \frac{1}{2}\text{VAR}[aW_i(t)]$$  
(C)

Applying this last expansion to Eq. (4) and by plugging in the results into Eqs. (A) and (B), we end up with the following objective function

$$-2[1 - \phi(\gamma, \Sigma_{\mathbf{R}})]\left[\exp\left(-\rho_1(\chi'(\mathbb{E}[\mathbf{R}] - \mathbf{R}^F) + W_i(t-1)\mathbf{R}^F) + \frac{\rho_1^2}{2}\chi'\Sigma_{\mathbf{R}}\chi\right)\right]$$  
(D)

where, according to Eq. (3),

$$\phi(\gamma, \Sigma_{\mathbf{R}}) = \begin{cases} 1 - \frac{1}{2}\exp\left(-\rho_1(\gamma - \frac{1}{2})\chi'\Sigma_{\mathbf{R}}\chi\right) & \text{if } \frac{1}{2} \leq \gamma < 1 \\ 0 & \text{if } 0 < \gamma < \frac{1}{2}, \Sigma_{\mathbf{R}} \geq \Sigma_x \\ 1 - \frac{1}{2}\exp\left(-\rho_1(\gamma - \frac{1}{2})\chi'\Sigma_{\mathbf{R}}\chi\right) & \text{if } 0 < \gamma < \frac{1}{2}, \Sigma_{\mathbf{R}} < \Sigma_x \end{cases}$$  
(E)

As demonstrated by Rocciolo et al. (2019), the optimal demand function $x_i$ is a solution to the optimization problem in Eq. (D), which will be the same for all three possible functional forms assumed by $\phi(\gamma, \Sigma_{\mathbf{R}})$ as in (E). Thus, we can solve the problem just for the case in which $\frac{1}{2} \leq \gamma < 1$. By plugging the explicit form of $\phi(\gamma, \Sigma_{\mathbf{R}})$ in Eq. (D), we can rewrite the latter as

$$-2\left[\exp\left(-\rho_1(\chi'(\mathbb{E}[\mathbf{R}] - \mathbf{R}^F) + W_i(t-1)\mathbf{R}^F) + \rho_1 - 2\rho_1 + \frac{1}{2}\right)\chi'\Sigma_{\mathbf{R}}\chi\right]$$  
(F)

This has a first order condition with respect to the demand $x_i$ of:
\[ \rho_i[(\mathbb{E}[R] - R^F) - (\rho_i - 2\gamma_i + 1)\Sigma_R x_i] \]
\[ \times \exp \left( -\rho_i (x_i' (\mathbb{E}[R] - R^F) + W_i (t-1) R^F) + \rho_i \left( \frac{\rho_i - 2\gamma_i + 1}{2} \right) x_i' \Sigma_R x_i \right) = 0 \]  

In Eq. (G), the exponential term is always positive so that the latter reduces to a concave programming problem which is solved by
\[ x_i = \Sigma_R^{-1} (\mathbb{E}[R] - R^F) (\rho_i + \kappa_i(y_i)) \]  

which is the first result of Proposition 1 embodied in Eq. (7).

### Table 5
Factor spanning test.
Factor spanning test summary: MKT is the return on the market portfolio in excess of the one-month Treasury bill rate, SMB (small minus big) is the size factor, HML (high minus low) is the value factor, UMD (up minus down) is the momentum factor, CMA (conservative minus aggressive) is the investment factor and RMW (robust minus weak) is the profitability factor. \( a_i \) and \( \alpha_i \) are respectively the time series regressions’ intercepts and the Alpha-Neutral net average net intercepts. Finally, \( \text{Cov}(f, \text{MKT}) \) is the covariance between the market and the dependent variable. Panel A shows the slopes of the regressions which use six factors to explain the return of the seventh. Panel B shows the slopes of the regressions which use just the market and the behavioural factor to explain the returns on SMB, HML, UMD, CMA and RMW.

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With regard to the result in Eq. (8), we start by computing the aggregate demand for risky assets as

$$x = \sum_{i=1}^{n} x_i = \sum_{i=1}^{n} \left( x_i \left[ \sum_{j=1}^{N} \frac{E[R_i] - R_F}{\sigma_i^2} \right] \right) = \sum_{i=1}^{n} (E[R_i] - R_F) \sum_{j=1}^{N} (\rho_i + \kappa_j)^{-1} \tag{I}$$

By defining $\rho_i = (\rho + \kappa_i)^{-1}$, where $\rho$ and $\kappa_i$ might be interpreted as aggregate measures of the absolute risk aversion and of the distance from rationality respectively, we have that, by inverting the first order condition in (1)

$$E[R_i] - R_F = \rho_i \Sigma_R x$$

where $\Sigma_R$ is the $N \times 1$ vector of covariances between each asset’s return $R_i$ and the return on the “comprehensive” portfolio obtained through the aggregation of all the individual portfolios held by the $n$ agents.

In fact, $\Sigma_R x$ is given by

$$\begin{bmatrix} \sigma_1^2 & \ldots & \sigma_1N \\ \sigma_{21} & \ldots & \sigma_{2N} \\ \vdots & \ddots & \vdots \\ \sigma_{n1} & \ldots & \sigma_{nN} \end{bmatrix} \begin{bmatrix} \sum_{i=1}^{n} x_i, \Sigma_{ij} \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^{n} x_i, \sigma_1^2 + \sum_{i=1}^{n} x_i, \sigma_{12}^2 + \cdots + \sum_{i=1}^{n} x_i, \sigma_{1N}^2 \\ \sum_{i=1}^{n} x_i, \sigma_{21}^2 + \sum_{i=1}^{n} x_i, \sigma_{22}^2 + \cdots + \sum_{i=1}^{n} x_i, \sigma_{2N}^2 \\ \vdots & \ddots & \vdots \\ \sum_{i=1}^{n} x_i, \sigma_{n1}^2 + \sum_{i=1}^{n} x_i, \sigma_{n2}^2 + \cdots + \sum_{i=1}^{n} x_i, \sigma_{nN}^2 \end{bmatrix}$$

while the return on the market portfolio is,

$$R^W = x'R + \sum_{i=1}^{n} x_i^T R^F$$

Considering for instance a single asset $j = 1$, we have

$$\text{COV}(R_1, R^W) = \text{COV}(R_1, \sum_{i=1}^{n} x_i, R_j) + \sum_{i=1}^{n} x_i^T R^F$$

and eventually, by defining beta in the usual way as $\beta_j = \frac{\text{COV}(R_j, R^M)}{\sigma^2_j}$, we end up with

$$E[R_j] - R^F = \beta_j + (E[R^M] - R^F) \beta_j + \kappa_j \text{COV}(R_j, R^M)$$

which is the result in Proposition 2.

**Proof of Proposition 3**

For the Alpha-Neutral CAPM in Eq. (12), the time series regression is:

$$R_i^t - R_F = \beta_i^t + \delta_i^t \text{MKT} + \epsilon_{i,t}$$

where $\text{MKT} = (R^M - R_F)$.

The correct asset pricing model is

$$E_t[R_i] - R^F = \delta_i^t + b_i^t \text{MKT}$$

where $\delta_i$ are the pricing errors, theoretically equal to zero, and $\lambda_{\text{MKT}}$ is the market factor premium.

Contrasting the correct model (P) with the expected value of the time series regression in (O) we have

$$E_t[\delta_i] = \delta_i^t + b_i^t E_t[\text{MKT}] - \lambda_{\text{MKT}}$$

The market factor is represented by the excess returns on the market portfolio so that $E_t[\text{MKT}] = \lambda_{\text{MKT}}$. Thus, by definition, $E_t[\delta_i] + b_i^t E_t[\text{MKT}] = E_t[\delta_i]$. Thus, we end up with

$$E_t[\delta_i] = E_t[\delta_i]$$

which is the result in Proposition 3.

**References**


