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Interfaces with Other Disciplines

On the strategic behavior of large investors: A mean-variance portfolio approach☆

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ABSTRACT

One key assumption of Markowitz's model is that all traders act as price takers. In this paper, we extend this mean-variance approach in a setting where large investors can move prices. Instead of having an individual optimization problem, we find the investors' Nash equilibrium and redefine the efficient frontier in this new framework.

We also develop a simplified application of the general model, with two assets and two investors to shed light on the potential strategic behavior of large and atomic investors. Our findings validate the claim that large investors enhance their portfolio performance in relation to perfect market conditions. Besides, we show under which conditions atomic investors can benefit in relation to the standard setting, even if they have not total influence on their eventual performance. The 'two investors-two assets' setting allows us to quantify performance and do sensitivity analysis regarding investors' market power, risk tolerance and price elasticity of demand.

Finally, for a group of well known ETFs, we empirically show how price variations change depending on the volume traded. We also explain how to set up and use our model with real market data.

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1. Introduction

The main economic assumptions in financial markets are perfect competition and symmetric information. Even though, financial markets generally approach perfect competition, in some cases these two assumptions do not hold, especially for powerful investors. Indeed, the investment decisions of institutional investors, who usually run a key part of total assets in the market and cover an even greater portion of the trading volume, can have an important impact on market prices, see Campbell, Grossman, and Wang (1993), Chan and Lakonishok (1995), Llorente, Michaely, Saar, and Wang (2002) and Huang and Heian (2010). Moreover, their private information about the market and their individual trading plans can equally affect the level of competition, see Wang (1994), Foster and Viswanathan (1996), Wang (1998), Dasgupta, Prat, and Verardo (2011).

Clearly, if done via single sell-order a trade of 10,000 shares impacts differently than a 100-share trade. Undoubtedly, the price will be negatively affected and some relevant information could be disclosed. Lo and Wang (2009) point out the theoretical consequences of this important empirical regularity: "That the demand curves of even the most liquid financial securities are downward-sloping for institutional investors, and that the price-discovery process often reveals information, implies that quantities are as fundamental as prices, and equally worthy of investigation". Lo and Wang (2006) built an inter-temporal capital asset pricing model around this empirical fact about investors with some market power.

Thus, the potential existence of market power in financial markets raises important questions about the strategic behavior of big players, and their role in the definition of portfolio allocation.

The literature contains different hypotheses regarding the assumption that prices depend upon trading strategies, giving rise to distinct methodological approaches. For example, in practice, investors may face different trading constraints, such as liquidity, that eventually could explain such deviations from the equilibrium price. Note that transaction costs can influence liquidity and hence market power, since transaction costs influence trading strategies and the bid/ask spread on the asset price, see Davis and Norman (1990) and Jouini and Kallal (1995). Regarding methodologies, Cuoco and Cvitanić (1998) for example considers a price model

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with coefficients depending on large-invest or strategy. In the same line, Ronnie Sircar and Papanicolaou (1998), Bank and Baum (2004) and Cetin, Jarrow, and Protter (2004) develop models where prices depend on strategies using reaction functions.

Nonetheless, examples of strategic models based on game theory in finance are very rare. Kannai and Rosenmüller (2010) developed a financial non-cooperative game in strategic form, where a finite number of players may borrow or deposit money at a central bank and use the cash available to purchase a commodity for immediate consumption. The bank can print money to balance its books and fix interest rates. For this game a pure-strategy Nash equilibrium is found under various assumptions. An extension of this model with multiple periods is presented by Mangoubi (2012).

Regarding portfolio theory, one key assumption of Markowitz's model is that all traders act as price takers, and hence no single one can exercise market power. According to Kolm, Tütüncü, and Fabozzi (2014), the main extensions of the model have been the inclusion of: (i) transaction costs, e.g. Brown and Smith (2011), (ii) different types of specific and institutional constraints, (see Clarke, De Silva, & Thorley, 2002), (iii) modeling and quantification of the impact of estimation errors in risk and return forecasts (via Bayesian techniques, stochastic optimization and robust optimization), (see Ledoit and Wolf, 2004 and Black and Litterman, 1992), and (iv) multi-period modeling, e.g. Merton (1969) and Campbell and Viceira (2002). Thus, despite Markowitz's portfolio selection model for a single period (Markowitz, 1952) having been one of the cornerstones of modern finance – inspiring numerous extensions and applications as those enumerated above – the price taker assumption has not yet been relaxed.

In sum, the financial literature has not directly addressed the issue of strategic behavior of large players in the context of portfolio management. Consequently, possible strategies for atomic players have remained neglected as well.

In this paper, we analyze the strategic behavior of large and atomic investors, using a portfolio optimization model in presence of an oligopolistic financial market. Thus, the ability of large investors to move prices in the traditional single period mean-variance portfolio model is introduced, relaxing one of the key assumptions of Markowitz's model. Under this framework, the Nash equilibrium of both investor types emerges and is compared with standard portfolio results.

This paper is organized as follows. Section 2 describes the general portfolio model considering oligopolistic financial markets. We derived its equilibrium and show how to construct an efficient frontier under this new framework. Section 3 constructs an example of the equilibrium for two risky assets and two types of investors: large and atomic. We analyze and compare performance results between both players and also with respect to results obtained in a perfect market setting. Section 4 shows how the model can be calibrated and applied to real financial data. Finally, some conclusions and potential for further research is presented.

2. The model and its equilibrium

Let us assume a market composed of m investors and n assets. The portfolio return for investor i is defined as:

$$r_p^i := \sum_{j=1}^{n} x_j^i r_j = r' x^i \tag{1}$$

where x_j^i is the fraction allocated in asset j by investor i and r_j is the return of the asset j. From (1), the portfolio mean return and its volatility emerges easily from having each asset's expected return, volatility and correlation between assets:

$$\mu_p^i := E(r_p^i) = \sum_{j=1}^{n} E(r_j x_j^i) = \mu' x^i$$

$$(\sigma_p^i)^2 := Var(r_p^i) := \sum_{j=1}^{n}\sum_{k=1}^{n} x_j^i x_k^i C_{jk} = (x^i)' C x^i$$

with $C_{jk} := \mathrm{cov}(r_j, r_k)$.

In the classical Markowitz problem, each investor determines x_j^i by taking the best compromise between the variance and the expected return of the portfolio, considering the budget constraint $1' x^i = 1$.

Markowitz model assumes a perfect market setting. Investors are price takers, and therefore returns are exogenous to them. In these expressions, returns do not depend on investors' allocations and their wealth is irrelevant when determining optimal allocation.

Now, let us assume participants can individually affect the prevailing market price by modifying the quantity demanded of assets. Following Vath, Mnif, and Pham (2007) and Lo and Wang (2006), a large investor could affect the price of the asset. The stock price rises when a trader buys and falls when s/he sells, and the impact is increasing relative to the size of the order. Specifically, we will assume a positive relationship between the volume of the demand for the asset in the market and its price, i.e., a price mechanism of the form

$$P(Q_j) := P_j^{PM} + \theta_j Q_j \tag{2}$$

where $P(Q_j)$ is the market price of asset j, P_j^{PM} is the price of asset j in a perfect market setting, $\theta_j \geq 0$ is an elasticity measure, or how the price is affected by the volume of assets demanded, and Q_j represents the quantity of asset j demanded in the market. Thus, $\theta_j Q_j$ represents the degree of market power.

If P_j^0 stands for the current price and w^i represents the wealth of investor i, then $Q_j = \frac{\sum_{i=1}^m w^i x_j^i}{P_j^0}$. Hence, the price in (2) becomes

$$P(Q_j) = P_j^{PM} + \theta_j \frac{\sum_{i=1}^m w^i x_j^i}{P_j^0}$$

In this context, the return of asset j is

$$r_j := \frac{P(Q_j)}{P_j^0} - 1 = \frac{P_j^{PM}}{P_j^0} + \frac{\theta_j}{(P_j^0)^2}\sum_{i=1}^{m}\left(w^i x_j^i\right) - 1 = r_j^{PM} + \theta_j' \sum_{i=1}^{m} w^i x_j^i$$

where r_j^{PM} represents the return of the asset in a perfectly competitive market and $\theta_j' = \frac{\theta_j}{(P_j^0)^2}$. Then the expected return of asset j is

$$\mu_j := \bar{r}_j^{PM} + \theta_j' \sum_{i=1}^{m} w^i x_j^i \tag{3}$$

where μ_j^{PM} is the expected return when solving the traditional Markowitz model. Note that r_j can stand above or below $\bar{r}_j^{PM}$ because we allow long and short positions. From now on we denote $\bar{r}_j^{PM}$ as $\bar{r}_j$.

2.1. Optimal allocations in the oligopolistic setting

Following previous definitions, and writing D for the diagonal matrix with $D_{jj} = \theta_j'$, the investor's mean-variance problem becomes

$$\min \left(x^i\right)^T C x^i - \lambda^i \left(\bar{r} + \sum_{k=1}^{m} w^k D x^k\right)^T x^i$$

$$s.t\ 1' x^i = 1$$

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