Factor Selection and Factor Strength

An Application to U.S. Stock Market Return

Research Plan

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1 Introduction and Motivation

Capital Asset Pricing Model (CAPM) (Sharpe (1964), Lintner (1965), and Black (1972)) introduces a risk pricing paradigm. The model divided risk of certain asset into two parts: systematic risk and asset specified idiosyncratic risk. By extending the CAPM into the multi-factor form through adding new factors, the systematic risk can be more accurately and consistently priced. Some famous examples of multi-factor CAPM include the Fama-French (FF) three-factor model (Fama & French, 1992), and the Momentum model (Carhart, 1997). Researchers after them are trying to find new risk factors to included into the multi-factor CAPM model. Harvey and Liu (2019) had collected over 500 factors from paper published in the top financial and economic journals, and they found the growth of new factors speed up since 2008. In his 2011 presidential address, J. H. Cochrane coined the term "factor zoo" to describe the situation factor modelling is facing: researchers and practitioners have too many options when pricing the risk

In those famous multi-factor model like FF three-factor model (Fama & French, 1992), the loadings of risk factors pass the significant test comfortably, but this is not always the case. Kan and Zhang (1999) found that the test-statistic of FM two-stage regression (Fama & MacBeth, 1973) will inflate when incorporating factors which is independent with the cross-section return. Provides spurious factors the chance to pass the significant test. Harvey, Liu, and Zhu (2015) argue that the current threshold for a test of parameter significant is too low for newly proposed factors, and this allowed some newly discovered factor become significant purely by chance.

These discoveries cast doubt on the reliability of significant test for factors' loading. J. H. Cochrane (2011) post the question: "Which characteristics really provide independent information about average return. Which are subsumed by others ?"

To answer this question, a number of scholars had applied various methods. Such as the bootstrap method introduced by (Harvey & Liu, 2017) to estimate test power and therefore adjust the test-statistic to solve the multiple-test problem when testing factors, trying to identified the factors has truly significant pricing power. Some other scholars use machine learning methods to reduce the potential candidates of useful factors, more precisely, a stream of them have used a shrinkage and subset selection method called Lasso (Tibshirani, 1996) and other variation to find suitable factors. One example is Rapach, Strauss, and Zhou (2013). They applied the Lasso regression, trying to find some characteristics from a large group to predict the global stock market's return. But an addition challenge is that factors, especially in the high-dimension, are commonly correlated. J. Cochrane (2005) argues that the correlation between factors will reduce the ability of using risk premium to infer factors. But one main drawback of Lasso,however, is that it fails to handle the correlated factor appropriately. Kozak, Nagel, and Santosh (2020) points out that when facing a group of correlated factors, Lasso will only pick several highly correlated factors, and then ignore the other and shrink them to zero.

The main empirical problem in this project is that: how to select useful factors from a large group of highly correlated candidates. To solve this problem, we first adopt the idea of "factor strength" from Bailey, Kapetanios, and Pesaran (2020) and then applied another variable selection method called Elastic Net (Zou & Hastie, 2005)

Bailey et al. (2020) defines the factor strength as the pervasiveness of a factor. They suggest that if a factor can generate loading significantly different from zero for all assets, then we call such factor a strong factor. And the less significant loading a factor can generate, the weaker the strength it has. By examining the strength of each factors, we can filter out those spurious factors therefore reduce the dimension of the number of potential factors. Base on the decision of the strength of potential factors, given the correlation between factors, we use the method of elastic net to make a selection from a subset of these factors.

2 Related Literature

This project combines three literatures: CAPM, factor strength, and factor selection under high dimensioned setting for the number of potential factors.

Beside the work by Kan and Zhang (1999) mentioned before, Kleibergen (2009) pointed out how a factor with small loading would deliver a spurious FM two-pass risk premia estimation. Kleibergen and Zhan (2015) found out even if some factor-return relationship does not exist, the r-square and the t-statistic of FM regression would in favour of the conclusion of such structure presence. Gospodinov, Kan, and Robotti (2017) show how the involving of a spurious factor will distort statistical inference of parameters. And, Anatolyev and Mikusheva (2018) studied the behaviours of the model with the presence of weak factors under asymptotic settings, find the regression will lead to a inconsistent risk premia result.

This project also relates to some researches effort to identify useful factors from a group of potential factors. Harvey et al. (2015) exam over 300 factors published on journals, presents that the traditional threshold for a significant test is too low for newly proposed factor, and they suggest to adjust the p-value threshold to around 3. Method like a Bayesian procedure introduced by Barillas and Shanken (2018) were tried to compare different factor models. Pukthuanthong, Roll, and Subrahmanyam (2019) defined several criteria for ”genuine risk factor”, and base on those criteria introduced a protocol to exam does a factor associated with the risk premium.

This project will attempt to address the factor selection problem by using machine learning techniques. Gu, Kelly, and Xiu (2020) elaborate the advantages of using emerging machine learning algorithms in asset pricing such as more accurate predict result, and superior efficiency. Various machine learning algorithms have been adopted on selecting factors for the factor model, especially in recent years. Lettau and Pelger (2020) applying Principle Components Analysis on investigating the latent factor of model. Lasso method, since it’s ability to select features, is popular in the field of the factor selection. Feng, Giglio, and Xiu (2019) used the double-selected Lasso method (Belloni, Chernozhukov, & Hansen, 2014),and a grouped lasso method (Huang, Horowitz, & Wei, 2010) is used by Freyberger, Neuhierl, and Weber (2020) on picking factors from a group of candidates. Kozak et al. (2020) used a Bayesian-based method, combing with both Ridge and Lasso regression, argues that the factor sparse model is ultimately futile.

3 Methodology

3.1 Factor Strength

Capital Asset Pricing Model (CAPM) is the benchmark for pricing the systematic risk of a portfolio. Consider the following multi-factor models for n different assets and T observations with stochastic error term ε_{it}:

$$r_{it} - r_{ft} = a_i + \beta_{im}(r_{mt} - t_{ft}) + \sum_{j=1}^{k} \beta_{ij} f_{jt} + \varepsilon_{it} \tag{1}$$

In the left-hand side, we have r_{it} denotes the return of security i at time t, where $i = 1,2,3,\cdots,N$ and $t = 1,2,3,\cdots T$. r_{ft} denotes the risk free rate at time t. In the other hand, a_i is the constant term. r_{mt} is the market average return and therefore, $(r_{mt} - r_{ft})$ is the excess return of the market. Corresponding β_{im} is the lading of market excess return or market factor. f_{jt} of $j = 1, 2, 3 \cdots k$ is potential risk factor under consideration. b_{ij} represents the factor loading for each k risk factors.

The factor strength of factor f_{jt} as α_j from Pesaran and Smith (2019), and Bailey et al. (2020) is defined as the pervasiveness of a factor.

If we run the OLS regression for equation (1) with only one facto f_{jt}, we will obtain n different factor loading $\hat{\beta}_{it}$. For each of the factor loading $\hat{\beta}_{ij}$, we can construct a t-test to test does the loading equals to zero. The test statistic will be $t_{jt} = \frac{\hat{\beta}_{ij} - 0}{\hat{\sigma}_{jt}}$ where $\hat{\sigma}_i$ is the standard error of $\hat{\beta}_{ij}$. Then we defined π_{nT} as the proportion of significant factor's amount to the total factor loadings amount:

$$\hat{\pi}_{nT} = \frac{\sum_{i=1}^{n} \hat{\ell}_{i,nT}}{n} \tag{2}$$

$\ell_{i,nT}$ is an indicator function as: $\ell_{i,nT} := \mathbf{1}[|t_{jt}| > c(n)]$. If the t-statistic t_{jt} is greater than the critical value $c_p(n)$, $\hat{\ell}_{i,nT} = 1$. In other word, we will count one if the factor loading $\hat{\beta}_{ij}$ is significant. $c_p(n)$ represent the critical value of a test with test size p. The critical value is calculated by:

$$c_p(n) = \Phi^{-1}(1 - \frac{p}{2n^{\delta}}) \tag{3}$$

Here, $\Phi^{-1}(\cdot)$ is the inverse cumulative distribution function of a standard normal distribution, and δ is a non-negative value represent the critical value exponent. The traditional method to calculate critical value has not fixed the multiple testing problem. One of the most commonly used adjustment for multiple testing problem is Bonferroni correction. When n as sample size goes to infinity, however, the Bonferroni correction can not yield satisfying results since the $\frac{p}{2n^{\delta}} \to 0$ when $n \to \infty$. Therefore, Bailey, Kapetanios, and Pesaran (2016) provides another adjustment with additional exponent δ to constrain the behaviour of n.

After obtain the $\hat{\pi}_{nT}$, we can use the following formula to estimate our strength indicator α_j:

$$\hat{\alpha} = \begin{cases} 1 + \frac{\ln(\hat{\pi}_{nT})}{\ln n} & \text{if } \hat{\pi}_{nT} > 0, \\ 0, & \text{if } \hat{\pi}_{nT} = 0. \end{cases}$$

From the estimation, we can find out that $\hat{\alpha} \in [0, 1]$

$\hat{\alpha}$ represent the pervasiveness of a factor. Here we denote $[n^{\alpha}]$, $[\cdot]$ will take the integer part of number inside. For factor f_{jt}:

$$|f_{jt}| > c_p(n) \quad i = 1, 2, \ldots, [n^{\alpha_j}]$$

$$|f_{jt}| = 0 \quad i = [n^{\alpha_j}] + 1, [n^{\alpha_j}] + 2, \ldots, n$$

For a factor has strength $\alpha = 1$, factor loading will be significant for every assets at every time. The more observation the factor can significantly influence, the stronger the factor is, and vice versa. Therefore, we can use the factor strength to exclude those factor has only very limited pricing power, in other word, those factor can only generate significant loading on very small portion of assets.

3.2 Elastic Net

Elastic net is variable selection model that can be used for factor selection, introduced by Zou and Hastie (2005). Applying elastic net method to estimate the factor loading β_{ij} requires:

$$\hat{\beta}_{ij} = \underset{\beta_{ij}}{\arg\min} \{ \sum_{i=1}^{n} [(r_{it} - r_{ft}) - \beta_{ij} f_{jt}]^2 + \lambda_2 \sum_{i=1}^{n} \beta_{ij}^2 + \lambda_1 \sum_{i=1}^{n} |\beta_{ij}| \} \tag{4}$$

Because the Lasso regression only contains L_1 penalty term $\sum_{i=1}^{n} |\beta_{ij}|$, it will treat every potential variable in the same manner when they are correlated. So when using Lasso regression to select factors, it will either randomly choose factors from highly correlated candidates, or eliminate them as a whole. Elastic Net, however, by containing L_2 penalty term $\sum_{i=1}^{n} \beta_{ij}^2$, solves this problem. The L_2 penalty term tend to shrink the potential parameters when they does not provide enough explanatory power, but it will not remove redundant factors. Therefore, the elastic net method will shrink those parameters associated with the correlated factors and keep them, or drop them if they are redundant at pricing risk.

4 Preliminary Result

In current stage, we have studied the property of estimator of factor strength α under finite sample scenario. In purpose of this, we have designed and applied a Monte Carlo Simulation. The design details and result table can be find at the Appendix A and Appendix B

To measure the goodness of simulation, we calculate the difference between the estimated factor strength and assigned true factor strength and refer the difference as bias. Base on the bias, we also calculated the Mean Squared Error (MSE) for each setting.

The table shows that both the bias and MSE of $\hat{\alpha}$ for different value of the α, N and T.

From the table 1 and table 2 we can see that when the α is at a relatively low level, the estimator tends to overestimate the strength. For instance, under the setting of $T = 120, N = 500$ and $\alpha = 0.5$, the bias is over 0,2, indicates that the estimated strength $\hat{\alpha}$ is around 0.7. The overestimation, however decreased with the increase of the α. Under the same setting as above, if the strength is assigned to 0.9, the bias significantly reduced to only 0.023. When the α touched it's upper bound as $\alpha = 1$, the bias disappears. Therefore we can conclude that the error converge to zero when the strength α increases. Precision of this estimator improves as α increases toward unity for given T and N increases as well.

5 Further Plan

For the next step of this project, we will start the empirical analyse.

Considering the variations of companies included, we will use companies return from Standard & Poors (S&P) 500 index as assets, and examine the strength of potential factors (150 in total) to be included in the final factor model specification. The time span will be 10 years, and since we consider monthly return, so the time observation for each stock will be t = 120

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A Monte Carlo Design

In this section, I will introduce the baseline design setting of the Monte Carlo Simulation and provides a preliminary result of the simulation.

A.1 Monte Carlo Design

Before start using the real data, we want to study the property of α by running Monte Carlo simulation and in this section, I will introduce the basic simulation design.

Consider the following model with stochastic error:

$$r_{it} = f_1(\bar{r}_t - r_f) + f_2(\theta_i x_t) + \varepsilon_{it} \tag{2}$$

In this Monte Carlo simulation, we consider a dataset has $i = 1, 2, \ldots, n$ different assets, with $t = 1, 2, \ldots, T$ different observations. $j = 1, 2, \ldots, k$ different factors and one market factors are included in the simulation.

$f_1(\cdot)$ and $f_2(\cdot)$ are two different functions represent the unknown mechanism of market factor and other factors in pricing asset risk. $(\bar{r}_t - r_f)$ is the market return, calculated from market or index return $\bar{r}_t$ minus risk free return r_f. r_{it} is the stock return, θ_{jt} denotes factors other than market factors and $\beta_{ij}$is the corresponding factor loading. ε_{it} is random error with structure can be defined in different designs. Notice that the β_{ij} will be influenced by each factor's strength α_j, where we have α as defined in section 3.1. And for each factor, we assume they follow a multinomial distribution with mean zero and a $k \times k$ variance-covariance matrix Σ. The diagonal of matrix Σ indicates the variance of each factor, and the rest represent the correlation among all k factors. In this model, we can control several parts to investigates different scenarios of the simulation:

A.2 Baseline Design

Follow the model (2), we assume both $f_1(a)$ and $f_2(a)$ are linear function:

$$f_1(a) = c_i + \beta a$$

$$f_2(a) = a$$

Therefore, the model with single factor can be write as:

$$r_{it} = c_i + \theta_i x_t + \varepsilon_{it}$$

The constantc_i is generated from a uniform distribution $U[-0.5, 0.5]$. θ_i is the factor loading, and x_t is factor with strength α_x. To generate factors loading, we employed a two steps strategy. First we generate a whole factor loadings vector $\theta_{\mathbf{i}} = (\theta_{i1}, \theta_{i2} \cdots, \theta_{in})$, All elements of the vector follows $IIDU(\mu_\theta - 0.2, \mu_\theta + 0.2)$. The μ_θ has been equalled to 0.71 to ensure all values apart from zero. After generating the vector, we randomly selected $[n^{\alpha_x}]$ elements from $\theta_{\mathbf{i}}$ to keep their value and set the other elements to zero. This step ensures the loading reflects the strength of each factor. For the stochastic error term, in this baseline design, we assume it follows a Standard Gaussian distribution, but we can easily extend it into a more complex form.

Follow the same idea, we also construct a two factor model:

$$r_{it} = c_i + \lambda x_m + \theta_i x_t + \varepsilon_{it}$$

Here the x_m is the market factor which assumably has strength $\alpha_m = 1$. λ is the market factor loading as a vector with all elements different from zero.

For each of the those different models, we consider the $T = \{120, 240, 360\}$, $n = \{100, 300, 500\}$. The market factor will have strength $\alpha_m = 1$ all the time, and the strength of the other factor in two factor model will be $\alpha_x = \{0.5, 0.7, 0.9, 1\}$. For every setting, we will replicate 500 times independently, all the constant c_i and loading θ_i will be re-generated for each replication.

B Simulation Result Table

Table 1: Simulation result of single factor model

	Single Factor					
	Biass			MSE		
$\alpha = 0.5$						
n \ T	120	240	360	120	240	360
100	0.194	0.188	0.199	0.050	0.047	0.053
300	0.224	0.224	0.226	0.062	0.062	0.062
500	0.229	0.237	0.225	0.064	0.067	0.062
$\alpha = 0.7$						
100	0.093	0.090	0.092	0.013	0.012	0.013
300	0.101	0.098	0.101	0.014	0.008	0.014
500	0.101	0.107	0.100	0.015	0.015	0.014
$\alpha = 0.9$						
100	0.023	0.022	0.023	0.001	0.001	0.001
300	0.023	0.023	0.024	0.001	0.001	0.001
500	0.023	0.023	0.024	0.001	0.001	0.001
$\alpha = 1.0$						
100	0.000	0.000	0.000	0.000	0.000	0.000
300	0.000	0.000	0.000	0.000	0.000	0.000
500	0.000	0.000	0.000	0.000	0.000	0.000

Table 2: Simulation result of two factor model

	Two Factor					
	Biass			MSE		
$\alpha_x = 0.5$, $\alpha_m = 1.0$						
n \ T	120	240	360	120	240	360
100	0.221	0.219	0.221	0.050	0.049	0.050
300	0.253	0.253	0.253	0.042	0.064	0.065
500	0.268	0.266	0.269	0.072	0.071	0.071
$\alpha_x = 0.7$, $\alpha_m = 1.0$						
100	0.100	0.101	0.100	0.010	0.010	0.010
300	0.113	0.113	0.112	0.013	0.013	0.013
500	0.118	0.118	0.119	0.014	0.014	0.014
$\alpha_x = 0.9$, $\alpha_m = 1.0$						
100	0.024	0.023	0.024	0.001	0.001	0.001
300	0.025	0.025	0.025	0.001	0.001	0.001
500	0.026	0.025	0.025	0.001	0.001	0.001
$\alpha_= 1.0$, $\alpha_m = 1.0$						
100	0.000	0.000	0.000	0.000	0.000	0.000
300	0.000	0.000	0.000	0.000	0.000	0.000
500	0.000	0.000	0.000	0.000	0.000	0.000