Factor Selection and Factor Strength

An Application to U.S. Stock Market Return

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Contents

List of Figures

List of Tables

1 Introduction and Motivation

Capital Asset Pricing Model (CAPM) (Sharpe, 1964; Lintner, 1965; Black, 1972) introduces a risk pricing paradigm. By incorporating factors, the model divides an asset's risk into two parts: systematic risk and asset specified idiosyncratic risk. In general, the market factor proxies for the systematic risk, and different risk factors price the idiosyncratic risk. Researches (see Fama and French (1992), Carhart (1997), Kelly, Pruitt, and Su (2019)) have shown that adding different risk factors into the CAPM model can enhance the ability of pricing risk. Because of this, identifying risk factors has become an important topic in finance. Numerous researchers have contributed to this field, and the direct result is an explosive growth of factors. Harvey and Liu (2019) have documented and categorised over 500 factors from papers published in the top financial and economic journals, and they find the growth of new factors has sped up since 2008.

But we should notice that for a factor, it may not able to capture the risk-return relationship for every asset. Therefore, Pesaran and Smith (2019) introduced a new criterion for assessing the significance of each factor, which they call it factor strength. In general, if a factor can generate coefficients, or refer it as loadings in financial literatures, significantly different from zero for all assets, then we call such a factor strong factor. And the less amounts of significant loadings a factor can generate, the weaker the strength the factor has.

In his 2011 president address Cochrane emphasized the importance of finding factors which can provide independent information about average return and risk. With regard to this, many scholars applied various methods to find such factors. For instance, Harvey and Liu (2017) provided a bootstrap method to adjust the threshold of factor loading's significant test, trying to exclude some falsely significant factor caused by multiple-test problem. Some other scholars are using machine learning methods to reduce the potential candidates. One stream of them has used a shrinkage and subset selection method called Lasso (Tibshirani, 1996) and it's variations to find suitable factors. One example of such an application is made by 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 additional challenge is that factors, especially in the high-dimension, are correlated. Kozak, Nagel, and Santosh (2020) point out that when facing a group of correlated factors, Lasso

will only pick several highly correlated factors, seemly at random, and then ignore the other and shrink them to zero. In other words, Lasso fails to handle the issue of correlated factors appropriately.

Therefore, the main empirical question in this project is: how to select useful factors from a large group of possibly highly correlated candidates. We address this question from two different prospects.

From one side, we employ the idea of factor strength discuss above, trying to use this criterion to select those strong factors. On the other hand, we use another variable selection method called Elastic Net (Zou & Hastie, 2005) to select factors. With regard of the first approach, Bailey, Kapetanios, and Pesaran (2020) provide a consistent estimator for the factor strength, and we will use this method to examine the strength of each candidate factor and filter out any spurious factors. Under the second approach, unlike Lasso, elastic net adds an extra penalty term into the loss function, which makes it suitable to handle the potential correlation variables. This trait makes it suitable for our purpose. We will assess and compare the methods in their selection of risk factors. Additionally, we can also use the factor strength as a standard to reduce the dimension of our candidates factors and then applied the elastic net to conduct further selection.

The rest of the thesis is organized as follows. In section 2, we go through some literatures relate with the CAPM model and methods about factor selection. Then in section 3, we will provide a detailed description of the concept of factor strength and the estimation method. In section 4, we set up a simple Monte Carlo simulation experiment to examine the finite sample properties of the factor strength estimator. We introduce the elastic net in section 5. Section 6 includes the empirical application, where we estimate the strength of potential risk factors to be included in a CAPM model, as well as apply elastic net as a method to select factors.

2 Related Literature

This project is built on contributions to the field of asset pricing. First formulated by Sharpe (1964), Lintner (1965), and Black (1972), the original CAPM model only contains the market factor, which is denoted by the difference between average market return and risk-free return. Fama and French (1992) extend the model into three-factors, which it then extend into four (Carhart, 1997), and five

(Fama & French, 2015). Recent research created a six-factors model and claim it outperforms all other sparse factor models. (Kelly et al., 2019).

In terms of assessing the strength of risk factors, this thesis also relates to papers discussing factors that have no or weak correlation with assets' return under the paradigm of the CAPM model. Kan and Zhang (1999) found that the test-statistic of FM two-stage regression (Fama & MacBeth, 1973) will inflate when incorporating factors which are independent of the cross-section return. Therefore, when factors with no pricing power were added into the model, those factors may have the chance to pass the significant test falsely. Kleibergen and Zhan (2015) found out that even when some factor-return relationship does not exist, the r-square and the t-statistic of the FM two-stage regression would become in favour of the conclusion of such structure presence. Gospodinov, Kan, and Robotti (2017) show how the addition of a spurious factor will distort the statistical inference of parameters. Besides, Anatolyev and Mikusheva (2018) studied the behaviours of the model with the presence of weak factors under asymptotic settings, and they find the regression will lead to an inconsistent risk premia estimation result.

Finally, of interest in this thesis is the large dimension of potential factors. For these reasons, it borrows from researchers that identify useful factors from a group of potential factors. Harvey, Liu, and Zhu (2015) examine over 300 factors published in journals, presents a new multi testing framework to exam the significance of factors. And they claim that a higher hurdle for the t-statistic is necessary when examining the significance of newly proposed factors. Methods like a Bayesian procedure introduced by Barillas and Shanken (2018) were used to compare different factor models. Pukthuanthong, Roll, and Subrahmanyam (2019) defined several criteria for "genuine risk factor", and based on those criteria introduced a protocol to examine whether a factor is associated with the risk premium.

Once the factor strength is identified, the thesis will attempt to reconcile empirically the factor selection under machine learning techniques and the factor strength implied by the selection.

Gu, Kelly, and Xiu (2020) elaborate on the advantages of using emerging machine learning algorithms in measuring the equity risk premiums. They obtained a higher predictive accuracy in measuring risk premium, and demonstrated large economics gains using investment strategy base on the machine learning forecast. Various machine learning algorithms have been adopted when selecting factors for the factor model, especially in recent years. Lettau and Pelger (2020)

apply Principle Components Analysis when investigating the latent factor of the model. Lasso is a popular algorithms for factor selections, because of its ability of selecting features. 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) when picking factors from a group of candidates. Kozak et al. (2020) arguing that the sparse factor model is ultimately futile by using a Bayesian-based method. They constructed their estimator similar to the ridge regressor, but instead of putting the penalty on the sum of squared of factor coefficients, they impose the penalty base on the maximum squared Sharpe ration implied by the factor model. They also augmented their Bayesian based estimator with extra L^1, created a method, similar but different to the elastic net algorithm which will be employed by our project. (**Still not very good**)

3   Factor Strength

The concept of factor strength employed in this project comes from Bailey et al. (2020), and it was first introduced by Bailey, Kapetanios, and Pesaran (2016). They defined the strength of factor from the prospect of the cross-section dependences of a large panel and connect it to the pervasiveness of the factor, which is captured by the factor loadings. In a separate paper, Bailey, Pesaran, and Smith (2019) extended the method by loosening some restrictions and proved that their estimation can also be applied on the residuals of regression result. Here, we focus on the case of observed factor, and use the method of Bailey et al. (2020) in this project.

3.1   Definition

Consider the following multi-factor model for n different cross-section units and T observations with k factors.

$$x_{it} = a_i + \sum_{j=1}^{k} \beta_{ij} f_{jt} + \varepsilon_{it} \tag{1}$$

In the left-hand side, we have x_{it} denotes the cross-section unit i at time t, where $i = 1,2,3,\cdots,n$ and $t = 1,2,3,\cdots T$. In the other hand, a_i is the constant term. f_{jt} of $j = 1,2,3\cdots k$ is factors included

6

in the model, and β_{ij} is the corresponding factor loading. ε_{it} is the stochastic error term.

The factor strength relates to how many non-zero loadings correspond to a factor. More precisely, for a factor f_{jt} with n different factor loading β_{ij}, we assume that:

$$|\beta_{ij}| > 0 \quad i = 1, 2, \ldots, [n^{\alpha_j}]$$

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

The α_j represents the strength of factor f_{jt} and $\alpha_j \in [0, 1]$. If a factor has strength α_j, we will assume that the first $[n^{\alpha_j}]$ loadings are all different from zero, and here $[\cdot]$ is defined as the integral operator, which will only take the integral part of the inside value. The rest $n - [n^{\alpha_j}]$ terms are all equal to zero. Assume for a factor which has strength $\alpha = 1$, the factor's loadings will be non-zero for all cross-section units. We will refer such factor as a strong factor. And if we have factor strength $\alpha = 0$, it means that the factor has all factor loadings equal to zero, and we will describe such factor as a weak factor (Bailey et al., 2016). For any factor with strength in [0.5, 1], we will refer such factor as semi-strong factor. In general term, the more non-zero loading a factor has, the stronger the factor's strength is.

3.2 Estimation Under single factor setting

To estimate the strength α_j, Bailey et al. (2020) provides the following estimation.

To begin with, we consider a single-factor model with the only factor named f_t. β_i is the factor loading of unit i. v_{it} is the stochastic error term.

$$x_{it} = a_i + \beta_i f_t + v_{it} \tag{2}$$

Assume we have n different units and T observations for each unit: $i = 1, 2, 3, \cdots, n$ and $t = 1, 2, 3, \cdots T$. Running the OLS time-regression for each $i = 1, 2, 3 \cdots, n$, we obtain:

$$x_{it} = \hat{a}_{iT} + \hat{\beta}_{iT} f_t + \hat{v}_{it}$$

For every estimated factor loading of the unit i: $\hat{\beta}_{iT}$, we can construct a t-test to examine its

7

significance under the null hypothesis of the loading is zero. The t-test statistic will be $t_{iT} = \frac{\hat{\beta}_{iT} - 0}{\hat{\sigma}_{iT}}$.
Empirically, we calculate the t-statistic of $\hat{\beta}_i$ using:

$$t_{iT} = \frac{(\mathbf{f}'\mathbf{M}_\tau\mathbf{f})^{1/2}\hat{\beta}_{iT}}{\hat{\sigma}_{iT}} = \frac{(\mathbf{f}'\mathbf{M}_\tau\mathbf{f})^{-1/2}(\mathbf{f}'\mathbf{M}_\tau\mathbf{x}_i)}{\hat{\sigma}_{iT}} \tag{3}$$

Here, the $\mathbf{M}_\tau = \mathbf{I}_T - T^{-1}\tau\tau'$, and the τ is a $T \times 1$ vector with every elements equals to 1. $\mathbf{f}$ and $\mathbf{x_i}$ are two vectors with: $\mathbf{f} = (f_1, f_2 \cdots, f_T)'$ $\mathbf{x_i} = (x_{i1}, x_{i2}, \cdots, x_{iT})$. The denominator $\hat{\sigma}_{iT} = \frac{\sum_{i=1}^{T} \hat{v}_{it}^2}{T}$.

Using this test statistic, we can then define an indicator function as: $\ell_{i,n} := \mathbf{1}[\|\beta_i\| > 0]$. If the factor loading is non-zero, $\ell_{i,n} = 1$. In practice, we use the $\hat{\ell}_{i,nT} := \mathbf{1}[\|t_{it}\| > c_p(n)]$. Here, if the t-statistic t_{iT} is greater than critical value $c_p(n)$, $\hat{\ell}_{i,n} = 1$, otherwise $\hat{\ell}_{i,n} = 0$. In other words, we are counting how many $\hat{\beta}_{iT}$ is significant. With the indicator function, we then define $\hat{\pi}_{nT}$ as the fraction of significant factor loading amount to the total factor loadings:

$$\hat{\pi}_{nT} = \frac{\sum_{i=1}^{n} \hat{\ell}_{i,nT}}{n} \tag{4}$$

In term of the critical value $c_p(n)$, rather than use the traditional critical value from student-t distribution $\Phi^{-1}(1 - \frac{P}{2})$, we use:

$$c_p(n) = \Phi^{-1}(1 - \frac{p}{2n^\delta}) \tag{5}$$

Suggested by Bailey et al. (2019), here, $\Phi^{-1}(\cdot)$ is the inverse cumulative distribution function of a standard normal distribution, p is the size of the test, and δ is a non-negative value represent the critical value exponent. Adopting this adjusted value helps to tackle the problem of multiple-testing.

After obtaining the $\hat{\pi}_{nT}$, we can use the following formula provided by Bailey et al. (2020) to estimate our strength indicator α_j:

$$\hat{\alpha} = \begin{cases} 1 + \frac{\ln(\hat{\pi}_{nT})}{\ln n} & \text{if } \hat{\pi}_{nT} > 0, \\ 0, & \text{if } \hat{\pi}_{nT} = 0. \end{cases} \tag{6}$$

When we have the $\hat{\pi}_{nT} = 0$, it means that none of the factor loadings are significantly different from zero, therefore the estimated $\hat{\alpha}$ will be equal to zero. From the estimation, we can find out that $\hat{\alpha} \in [0, 1]$.

3.3 Estimation Under Multi-Factor Setting

This estimation can also be extended into a multi-factor set up. Consider the following multi-factor model:

$$x_{it} = a_i + \sum_{j=1}^{k} \beta_{ij} f_{jt} + v_{it} = a_i + \beta_{\mathbf{i}}' \mathbf{f_t} + v_{it}$$

In this set up, we have $i = 1, 2, \cdots, n$ units, $t = 1, 2, \cdots, T$ time observations, and specially, $j = 1, 2, \cdots, k$ different factors. Here $\beta_i = (\beta_{i1}, \beta_{i2}, \cdots, \beta_{ij})'$ and $\mathbf{f}_t = (f_{1t}, f_{2t} \cdots, f_{jt})$. We employed the same strategy as above, after running OLS and obtain the:

$$x_{it} = \hat{a}_{iT} + \hat{\beta}_{\mathbf{i}}' \mathbf{f}_t + \hat{v}_{it}$$

To conduct the significance test, we calculate the t-statistic: $t_{ijT} = \frac{\hat{\beta}_{ijT} - 0}{\hat{\sigma}_{ijT}}$. Empirically, the test statistic can be calculated using:

$$t_{ijT} = \frac{\left(\mathbf{f}_{j\circ}' \mathbf{M}_{F_{-j}} \mathbf{f}_{j\circ} \right)^{-1/2} \left(\mathbf{f}_{j\circ}' \mathbf{M}_{F_{-j}} \mathbf{x}_i \right)}{\hat{\sigma}_{iT}}$$

Here, $\mathbf{f}_{j\circ} = (f_{j1}, f_{j2}, \ldots, f_{jT})'$, $\mathbf{x}_i = (x_{i1}, x_{i2}, \ldots, x_{iT})'$, $\mathbf{M}_{F_{-j}} = \mathbf{I} - \mathbf{F}_{-j} \left(\mathbf{F}_{-j}' \mathbf{F}_{-j} \right)^{-1} \mathbf{F}_{-j}'$, and $\mathbf{F}_{-j} = (\mathbf{f}_{1\circ}, \ldots, \mathbf{f}_{j-1\circ}, \mathbf{f}_{j+1\circ}, \ldots, \mathbf{f}_{m\circ})'$ For the denominator's $\hat{\sigma}_{iT}$, it was from $\hat{\sigma}_{iT}^2 = T^{-1} \sum_{t=1}^{T} \hat{u}_{it}^2$, the $\hat{u}_{it}$ is the residuals of the model. Then, we can use the same critical value from (5). Obtaining the corresponding ratio $\hat{\pi}_{nTj}$ from (4), and use the function:

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

to estimate the factor strength.

4 Monte Carlo Design

4.1 Design

In order to study the finite sample properties of factor strength $\hat{\alpha}_j$, we conduct a Monte Carlo study. Through the simulation, we compare the property of the factor strength in different settings. We set up the experiments to reflect the CAPM model and its extension. For simplicity, we first define $x_{it} := r_{it} - r_{ft}$. r_{it} is the unit's return, and r_{ft} represent the risk-free rate at time t, therefore, the x_{it} is the excess return of unit i at time t. We use $f_{mt} := r_{mt} - r_{ft}$ to denote the market factor. Here r_{mt} is the average market return of hypothetically all assets in the universe. Additionally, we set $q_1(\cdot)$ and $q_2(\cdot)$ as two different functions that represent the unknown mechanism of market factor and other risk factors in pricing asset risk. In the classical CAPM model and it's multi-factor extensions, for example, the three-factor model introduced by Fama and French (1992), both q_1 and q_2 are linear. Now consider the following data generating process (DGP):

$$x_{it} = q_1(f_{mt}) + q_2(\sum_{j=1}^{k} \beta_{ij} f_{jt}) + \varepsilon_{it}$$

In the simulation, we consider a dataset has $i = 1, 2, \ldots, n$ different cross-section units, with $t = 1, 2, \ldots, T$ different observations. f_{jt} represents different risk factors, and the corresponding β_{ij} are the factor loadings. We expect the market factor will have strength equal to one all the time, so we consider the market factor has strength $\alpha_m = 1$. ε_{it} is the stochastic error term.

For each factor, we assume they follow a multivariate normal distribution with mean zero and a $k \times k$ variance-covariance matrix Σ.

$$\mathbf{f_t} = \begin{pmatrix} f_{i,t} \\ f_{2,t} \\ \vdots \\ f_{k,t} \end{pmatrix} \sim MVN(\mathbf{0}, \Sigma) \quad \Sigma := \begin{pmatrix} \sigma_{f_1}^2, & \rho_{12}\sigma_{f1}\sigma_{f2} & \cdots & \rho_{1k}\sigma_{f1}\sigma_{fk} \\ \rho_{12}\sigma_{f2}\sigma_{f1}, & \sigma_{f2}^2 & \cdots & \rho_{2k}\sigma_{f2}\sigma_{fk} \\ \vdots & \vdots & \ddots & \vdots \\ \rho_{1k}\sigma_{fk}\sigma_{f1}, & \rho_{k2}\sigma_{fk}\sigma_{f2} & \cdots & \sigma_{fk}^2 \end{pmatrix}$$

The diagonal of matrix Σ indicates the variance of each factor, and the rest represent the covariance among all k factors.

4.2 Experiment Setting

Follow the general model above, we assume both $q_1(\cdot)$ and $q_2(\cdot)$ are linear function:

$$q_1(f_{mt}) = a_i + \beta_{im} f_{mt}$$

$$q_2\left(\sum_{j=1}^{k} \beta_{ij} f_{jt}\right) = \sum_{j=1}^{k} \beta_{ij} f_{jt}$$

To start the simulation, we consider a two-factor model:

$$x_{it} = a_i + \beta_{i1} f_{1t} + \beta_{i2} f_{2t} + \varepsilon_{it} \tag{7}$$

The constant term a_i is generated from a uniform distribution, $a_{it} \sim U[-0.5, 0.5]$. For the factor loading β_{i1} and β_{i2}, we first use a uniform distribution $IIDU(\mu_\beta - 0.2, \mu_\beta + 0.2)$ to produce the values. Here we set $\mu_\beta = 0.71$ to make sure every generated loading value is sufficiently larger than 0. Then we randomly assign $n - [n^{\alpha_1}]$ and $n - [n^{\alpha_2}]$ factor loadings as zero. α_1 and α_2 are the true factor strength of f_1 and f_2. In this simulation, we will start the factor strength from 0.7 and increase it gradually till unity with pace 0.05, say $(\alpha_1, \alpha_2) = \{0.7, 0.75, 0.8, \cdots, 1\}$. $[\cdot]$ is the integer operator defined at section (3.2). This step reflects the fact that only $[n_1^\alpha]$ or $[n_2^\alpha]$ factor loadings are non-zero. In terms of the factors, they come from a multinomial distribution $MVN(\mathbf{0}, \Sigma)$, as we discuss before.

Currently, we consider three different experiments set up:

Experiment 1 (single factor, normal error, no correlation) *Set β_{i2} from (7) as 0, the error term ε_{it} and the factor f_{1t} are both standard normal.*

Experiment 2 (two factors, normal error, no correlation) *Both β_{i1} and β_{i2} are non-zero. Error term and both factors are standard normal. The correlation ρ_{12} between f_{1t} and f_{2t} is zero. The factor strength for the first factor $\alpha_1 = 1$ all the time, and α_2 varies.*

Experiment 3 (two factors, normal error, weak correlation) *Both β_{i1} and β_{i2} are non-zero. Error term and both factors are standard normal. The correlation ρ_{12} between f_{1t} and f_{2t} is 0.3. The factor strength for the first factor $\alpha_1 = 1$ all the time, and α_2 varies.*

The factor strength in each experiment is estimated using the method discussed in section (3.2), the size of the significance test is $p = 0.05$, and the critical value exponent σ has been set as 0.5. For each experiment, we calculate the bias, the RMSE and the size of the test to assess the estimation performances. The bias is calculated as the difference between the true factor strength α and the estimated factor strength $\hat{\alpha}$.

$$bias = \alpha - \hat{\alpha}$$

The Root Square Mean Error (RMSE) comes from:

$$RMSE = [\frac{1}{R} \sum_{r=1}^{R} (bias_r)^2]^{1/2}$$

Where the R represents the total number of replication. The size of the test is under the hypothesis that $H_0 : \hat{\alpha}_j = \alpha_j, \ j = 1, 2$ against the alternative hypothesis $H_1 : \hat{\alpha}_j \neq \alpha_j, \ j = 1, 2$. Here we employed the following test statistic from Bailey et al. (2020).

$$z_{\hat{\alpha}_j : \alpha_j} = \frac{(\ln n) (\hat{\alpha}_j - \alpha_j) - p (n - n^{\hat{\alpha}_j}) n^{-\delta - \hat{\alpha}_j}}{\left[p (n - n^{\hat{\alpha}_j}) n^{-\delta - 2\hat{\alpha}_j} \left(1 - \frac{p}{n^\delta} \right) \right]^{1/2}} \quad j = 1, 2 \tag{8}$$

Define a indicator function $\mathbf{1}(|z_{\hat{\alpha}_j : \alpha_j}| > c|H_0)$. For each replication, if this test statistic is greater than the critical value of standard normal distribution: $c = 1.96$, the indicator function will return value 1, and 0 otherwise. Therefore, we calculate the size of the test base on:

$$size = \frac{\sum_{r=1}^{R} \mathbf{1}(|z_{\hat{\alpha}_j : \alpha_j}| > 1.96|H_0)}{R} \quad j = 1, 2, \tag{9}$$

In purpose of Monte Carlo Simulation, we consider the different combinations of T and n with $T = \{120, 240, 360\}, n = \{100, 300, 500\}$. The market factor will have strength $\alpha_m = 1$ all the time, and the strength of the other factor will be $\alpha_x = \{0.7, 0.75, 0.8, 0.85, 0.9, 0.95, 1\}$. For every setting, we will replicate 2000 times independently, all the constant and variables will be re-generated for each replication.

4.3   Monte Carlo Results

We report the results in Table (5), (6) and (7) in Appendix A.

Table (5) provides the results under the experiment 1. The estimation method we applied tends to over-estimate the strength slightly most of the time when the true strength is relatively weak under the single factor set up. With the strength increasing, the bias will turn to negative, represents an under-estimated results. Such bias, however, vanishes quickly while observation t, unit amount n, and true strength α increase. When we increase the time spam by including more data from the time dimensions, the bias, as well as the RMSE decrease significantly. Also, when including more cross-section unit n into the simulation, the performance of the estimation improves, as shown by the decreased bias and RMSE values. An impressive result is that the gap between estimation and true strength will go to zero when we have $\alpha = 1$, the strongest strength we can have. With the strength approaching unity, both bias and RMSE will converge to zero. We also present the size of the test in the table. The size of the test will not vary too much when the strength increases, so as the unit increases, But we can observe that when observations for each unit increase, in other words, when t increases, the size will shrink dramatically. The size will become smaller than the 0.05 threshold after we extend the t to 240, or empirically speaking, when we included 20 years monthly return data into the estimation. Notice that, from the equation (8), when $\hat{\alpha} = \alpha = 1$, the nominator becomes zero. Therefore, the size will collapse to zero in all settings, so we do not report the size for $\hat{\alpha} = \alpha = 1$

For the two factors scenarios, we obtain similar conclusions in both the no correlation setting and weak correlation setting. The result of no correlation settings is shown in the table (6), and the table (7) shows the result when the correlation between two factors is 0.3. The estimation results improve when increasing either the observations amount t, or the cross-section units amount n. We also have the same unbiased estimation when true factor strength is unity under all unit-time combinations. In some cases, even when the factor strength is relatively weak, we can have unbiased estimation if the n and t are big enough. (see table (7)). However, we should also notice that when t > n, the results of the size of the test in two factors setting are performing similar to the single factor result. The size will shrink with the observation amount t increasing, and when we have t greater than 240, the size will be smaller than 0.05 threshold in all situations.

5   Elastic Net

Elastic net is variable selection model that can be used for factor selection, introduced by Zou and Hastie (2005). Applying the 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 shows no preference when selecting variables when they are highly correlated. So when Lasso regression will either randomly choose factors from highly correlated candidates, or eliminate them together 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.

To be complete

6   Empirical Application

Researchers and practitioners have been using the CAPM model (Sharpe, 1964; Lintner, 1965; Black, 1972) and its multi-factor extension (For example, the three-factor model by Fama and French (1992)) when they are trying to capture the uncertainty of asset's return. The surging of new factors (Harvey & Liu, 2019) provides numerous option to construct the CAPM model, but it also requires users to pick the factors wisely. In this section, we will use two different methods to identify appropriate factors from a group of 146 candidates. First, we utilise the method introduced in section 3 to estimates the strength of each factor from the factor group. Then, we use the strength as a criterion to select factors including in the CAPM model. In the second part of this section, we apply the elastic net method, ask the algorithm to pick factors for us. We will compare the factors selected by those two approaches, expected a consistent selection outcome. Through the empirical application, we also found that under certain conditions, we will obtain a generous CAPM model with too many factors, when using factor strength as the criterion. Therefore, additionally, we apply

the elastic net method to further shrinkage down factor selection.

6.1 Data

In the empirical application part, we use the monthly returns on U.S. securities as the assets. The companies are selected from Standard Poor (S&P) 500 index component companies.[1] We prepared three data sets for different time spans: 10 years (January 2008 to December 2017, T = 120), 20 years (January 1998 to December 2017, T = 240), and 30 years (January 1989 to December 2017, T = 360). The initial data set contains 505 companies, but because of the components companies of the index are constantly changing, bankrupt companies will be moved out, and new companies will be added in. Also, some companies do not have enough observations. Therefore, for each of the datasets, the number of companies (n) is different, the dimensions of the data set are showing in the table (1) below.

Table 1: Data Set Dimensions

	Time Span	Number of Companies (n)	Observations Amount (T)
10 Years	January 2008 - December 2017	419	120
20 Years	January 1998 - December 2017	342	240
30 Years	January 1988 - December 2017	242	360

For the risk-free rate, we use the one-month U.S. treasury bill return.[2] For company i, we calculate the companies return at month t (r_{it}) using the following formula:

$$r_{it} = \frac{p_{it} - p_{it-1}}{p_{it-1}} \times 100$$

and calculate the excess return $x_{it} = r_{it} - r_{ft}$. Here the p_{it} and p_{it-1} are the company's close stock price on the first trading day of month t and t-1. The price is adjusted for the dividends and splits.[3]

Concerning the factors, we use 145 different risk factors from Feng, Giglio, and Xiu (2020). The factor set also includes the market factor, represented by the difference between the average market return and risk-free return. The average market return is a weighted average return of all

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[1]The companies return data was obtained from the Global Finance Data: http://www.globalfinancialdata.com/, Osiris: https://www.bvdinfo.com/en-gb/our-products/data/international/osiris, and Yahoo Finance: https://finance.yahoo.com/.

[2]The risk free rate was from the Kenneth R. French website: http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/

[3]The data is adjusted base on the Central for Research in Security Price (CRSP) method.

stocks in the U.S. market, incorporated by CSRP. Each factor contains observations from January 1988 to December 2017.

6.2 Factor Strength Analysis

6.2.1 Regression model setting

For the first part of the empirical application, we estimate the factor strength using the method discussed in section 3. More precisely, we set the regression models based on section 3.3.

$$x_{it} = a_i + \beta_{im}(r_{mt} - r_{ft}) + v_{it}$$

$$x_{it} = a_i + \beta_{im}(r_{mt} - r_{ft}) + \beta_{ij}f_{jt} + v_{it}$$

Here x_{it} is the excess return of asset i at time t, which is pre-defined in section 6.1. $r_{mt} - r_{ft}$ represents the market factor, calculated by the difference between average market return and risk-free return at the same time t. f_{jt} is the value of jth risk factor at time t. Here $j = 1, 2, 3, \cdots 145$. β_{mt} and β_{ij} are the factor loadings for market factor and risk factor, respectively.

We use two different regressions in the purpose of estimating the strength under the single factor setting and the two factors setting. However, due to the potential correlations among factors, we will only focus the market factor strength when using the first single factor regression.

6.2.2 Factor Strength Findings

The complete set of results of factor strength estimation is presented in the appendix B.1 and B.2. We estimated the factors' strength using three different data sets discussed in the 6.1, and rank those strength from strong to weak, alongside the market factor strength, in the table (8).

We first look at the market factor strength under the single-factor CAPM setting. (see table 2)

As we expected, the estimated strength of market factor under all three scenarios shows consistently strong results. All three market factor strengths are close to unity, which indicates that the market factor can generate significant factor loading almost all time for every asset. Although the value is close to one, we still notice that the strength will increase slightly with the time span extended. This might indicate that for the security returns, from the long run, it will more closely

Table 2: Market factor strength estimation

	Ten Year Data	Twenty Year Data	Thirty Year Data
Market Factor Strength (Single Factor Setting)	0.988	0.990	0.995
Average Market Factor Strength (Double Factors Setting)	0.987	0.991	0.996

mimic the behaviours of the market than the short run. Then, we turn to the double factor CAPM setting. Under the double factor setting, we estimates every companies' stock return using market facto plus another risk factors. Therefore we will obtain the market factor strength for each single risk factors. So, we calculate the average market factor here:

$$\bar{\alpha}_m = \frac{1}{145} \sum_{i=1}^{145} \alpha_{im}$$

α_{im} is the estimated market factor strength for the ith risk factor setting. Table2 shows that the estimated strength is consistent with the single factor settings. All three data sets provides extremely strong results, strengths are close to one. Overall, the market factor results indicates that the market factor can generate significant loadings for almost every companies' return at any time. Such conclusion fits with the financial theory states that individual stocks will in general move with the market. When looking at other factors, the ten-year data set in general provides a significantly weaker result, compares with the other two data sets results. Except for the market factor, no other factors from the ten-years result show strength above 0.8. The strongest factor besides the market factor is the beta factor which has strength around 0.75. In contrast, the strongest risk factor (factor other than market factor) in the twenty-year data set is the ndp (net debt-to-price), which has strength 0.937. In the thirty-year scenario, the salecash (sales to cash) is the strongest with strength 0.948.

When comparing the proportion of factors with strengths falling in different intervals between 0 and 1 (see table (3)), we can find that when using 0.8 as a threshold, there are over forty-five per cent factors in the twenty-year and thirty-year result exceeds this threshold. In ten year results, the number is zero. We also find that nearly 40% of factors from the ten-year dataset show strength less than 0.5, which is almost four times higher than the twenty and thirty years proportion.

When look at the ranking, we found that there are three factors: ndq (Net debt-to-price), salecash

17

Table 3: Proportion of Strength (Excluded Market Factor)

Strength Level	10 Year Data Proportion	20 Year Data Proportion	30 Year Data Proportion
[0.9, 1]	0%	21.4%	23.4%
[0.85, 0.9)	0%	17.9%	17.9%
[0.8, 0.85)	0%	7.59%	6.21%
[0.75, 0.8)	0%	11.7%	17.9%
[0.7, 0.75)	7.59%	8.28%	7.59%
[0.65, 07)	15.9%	8.28%	2.76%
[0.6, 0.65)	17.9%	5.52%	8.97%
[0.55, 0.6)	13.1%	6.21%	2.76%
[0.5, 0.55)	8.97%	4.83%	4.14%
[0, 0.5)	36.6%	8.28%	8.28%

(sales to cash), and quick (quick ratio) who are ranking top three in both twenty year data set result and thirty year data set result. We would expect when applying the elastic net method with the twenty-year and thirty-year data set, those three factors with the market factors would be selected.

Another interesting finding is that the roavol (Earnings volatility, 10th of ten-year result, 7th of twenty-year result, 5th of thirty-year result), age (Years since first Compustat coverage, 11th of ten-year result, 9th of twenty-year result, 4th of thirty-year result), and ndp (net debt-to-price, 14th of ten-year result, 1st of twenty-year result, 2nd of thirty-year result). This might indicates a persistent risk pricing ability of these three factors exist, even with the changes of the data set's dimensions.

We also focus on some well-known factors, namely the Fama-French size factor (Small Minus Big SMB), Fama-French Value factor (High Minus Low: HML) (Fama & French, 1992) and the Momentum factor (UMD) (Carhart, 1997). It is surprising that none of these three factors enters the top fifteen list for each data sets. Except for the HML factor from the twenty and thirty-year data set has strength closely around 0.9, none of the other factors in any data set shows strength higher than 0.85. When using the ten-year data, both UMD and HML has strength around 0.67, and the SMB only has strength 0.512. Results from the twenty-year data set show that HML has strength 0.905, for SMB and UMD the strength are 0.770 and 0.733 respectively. Comparing with the twenty-year results, the thirty-year estimated strength change slightly, HML decreases to 0.894, SMB is 0.804 and UMD has strength 0.745. Therefore, when using the strength as a criterion, we may only select the value factor to incorporate in the CAPM model when having twenty and thirty-year data.

Table 4: Selected Risk Factor with Strength: top 15 factors from each data set and three well know factors.

	Ten Year			Twenty Yera			Thirty Year	
Rank	Factor	Strength	Rank	Factor	Strength	Rank	Factor	Strength
1	beta	0.749	1	ndp	0.937	1	salecash	0.948
2	baspread	0.730	2	quick	0.934	2	ndp	0.941
3	turn	0.728	3	salecash	0.933	3	quick	0.940
4	zerotrade	0.725	4	lev	0.931	4	age	0.940
5	idiovol	0.723	5	cash	0.931	5	roavol	0.938
6	retvol	0.721	6	dy	0.929	6	ep	0.937
7	std_turn	0.719	7	roavol	0.929	7	depr	0.935
8	HML_Devil	0.719	8	zs	0.927	8	cash	0.934
9	maret	0.715	9	age	0.927	9	rds	0.931
10	roavol	0.713	10	cp	0.926	10	dy	0.927
11	age	0.703	11	ebp	0.926	11	currat	0.927
12	sp	0.699	12	op	0.925	12	chcsho	0.927
13	ala	0.699	13	cfp	0.924	13	lev	0.926
14	ndp	0.686	14	nop	0.924	14	stdacc	0.926
15	orgcap	0.686	15	ep	0.923	15	cfp	0.925
20	UMD	0.678	29	HML	0.905	39	HML	0.894
24	HML	0.672	76	SMB	0.770	68	SMB	0.804
87	SMB	0.512	89	UMD	0.733	96	UMD	0.745

In general, we found that the twenty-year and thirty-year data sets provides similar estimated strength, while, in contrast, the estimated strengths from ten-year data set are significantly weaker. Therefore, as a second step, in order to see how factor strengths evolve through the time, we decompose the thirty yea-data set into three small subsample. For each subsamples, it contains 242 companies (n = 242). And for each company, we obtained 120 observations (t = 120). The results are present in the table (9) and figure (2).

In general, we can conclude that about 80% factors, their strength gradually increased from the first decade (January 1988 to December 1997) to the second decade (January 1998 to December 2007), and then decreased in the third decade (January 2008 to December 2017). This pattern can also be seen in the figure (2). The drop of factor strength in the third decades can be reconciled with the ten-year data results shows a significantly weaker strength than the results from twenty and thirty years data set.

Overall from the factor strength prospect, we would expect that for different time periods, we will have different candidate factors for the CAPM model. For the ten-year data set, we would

expect that only the market factor be useful, and therefore the elastic net method applied latter may only select the market factor. If we use the twenty and thirty-year data, we will have a longer list for potential factors, 62 factors from the twenty-year estimation and 45 from the thirty years has strength greater than 0.8. Hence, we would expect the elastic net to select a less parsimonious model.

In terms of the findings we have above, there are several potential explanations. First, if we consider the structure of our data set, we will find that the longer the time span, the fewer companies are included. This is because the S&P index will adjust the component, remove companies with inadequate behaviours, and add in new companies to reflect the market situation. Hence, those 242 companies in the thirty-year data set can be viewed as survivals after a series of financial and economic crisis. We would expect those companies will have above average performances, such as better profitability and administration, compared with other companies.

Another possible explanation the happening of a series of political and financial unease from the time of late 20 century to 2008. Crisis like the Russia financial crisis in 1998, the bankruptcy of Long Term Capital Management (LTCM) in 2000, the dot com bubble crisis in early 21st century and the Global Financial Crisis (GFC) in 2008 creates market disturbances. Such disturbances, however, provides extra correlations among factors. The extra correlations enable some factors provides additional pricing power risk. But we should also notice that the financial market has been disturbed by those crises so, therefore, some mechanism may no longer working properly during that period. Which means that those crises will also have negative influences on factor when they are capturing the risk-return relationship.

We also need to notice that for some factors, their strength will decrease with time. For instance, the gma (gross profitability) factor and dwc (change in net non-cash working capital) factor (see figure 2) has consecutive strength decrease from the 1987-1997 period to 2007-2017 period. And for most of the factors, their strength will decrease significantly from the 1997-2007 period to 2007-2017 period. Therefore, disqualify some factors as the candidate of the CAPM model when using recent year data is inevitable.

6.3 Elastic Net Application

to be added

7 Conclusion

to be added

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A Simulation Result

Table 5: Simulation result for single factor setting

	Bias × 100			RMSE × 100			Size × 100		
				$\alpha_1 = 0.7$					
n\T	120	240	360	120	240	360	120	240	360
100	0.256	0.265	0.227	0.612	0.623	0.560	7.85	7.7	5.55
300	0.185	0.184	0.184	0.363	0.338	0.335	8.9	4.45	4.5
500	0.107	0.124	0.109	0.259	0.248	0.234	6.9	2.5	1.6
				$\alpha_1 = 0.75$					
100	-0.178	-0.159	-0.168	0.490	0.465	0.450	2.5	0.85	0.4
300	0.154	0.156	0.143	0.281	0.258	0.234	9.4	3.7	3.35
500	0.024	0.033	0.263	0.171	0.155	0.148	7.8	2	1.25
				$\alpha_1 = 0.8$					
100	-0.270	-0.265	-0.258	0.434	0.409	0.411	71.4	72.05	71.45
300	-0.052	-0.044	-0.043	0.183	0.149	0.150	10.15	2.45	2.9
500	0.045	0.068	0.067	0.136	0.126	0.121	16.6	6.4	5.9
				$\alpha_1 = 0.85$					
100	0.053	0.062	0.058	0.253	0.228	0.221	6.05	2.95	2.5
300	-0.012	0.009	-0.001	0.124	0.104	0.095	10.55	1.8	1.15
500	-0.026	-0.007	-0.011	0.096	0.073	0.069	13.25	0.9	0.7
				$\alpha_1 = 0.9$					
100	0.025	0.038	0.360	0.191	0.163	0.157	6.85	2	1.65
300	-0.034	-0.018	-0.020	0.099	0.069	0.068	13.2	0.8	0.9
500	-0.025	-0.001	-0.001	0.072	0.044	0.044	22.3	1.95	1.8
				$\alpha_1 = 0.95$					
100	-0.099	-0.088	-0.090	0.156	0.125	0.126	5.6	0.3	0.55
300	-0.046	-0.025	-0.026	0.083	0.045	0.045	22.5	2.2	2.25
500	-0.030	-0.006	-0.006	0.061	0.026	0.025	33.1	4.4	3.8
				$\alpha_1 = 1$					
100	0	0	0	0	0	0	-	-	-
300	0	0	0	0	0	0	-	-	-
500	0	0	0	0	0	0	-	-	-

Notes: This table shows the result of experiment 1. Factors and error are generate from standard normal distribution. Factor loadings come form uniform distribution $IIDU(\mu_\beta - 0.2, \mu_\beta + 0.2)$, and $\mu_\beta = 0.71$. We keep $[n^{\alpha_j}]$ amount of loadings and assign the rest as zero. For each different time-unit combinations, we replicate 2000 times. For the size of the test, we use a two-tail test, under the hypothesis of $H_0, \hat{\alpha}_j = \alpha_j \ j = 1, 2$. Cause under the scenarios of $\alpha = 1$, the size of the test will collapse, therefore the table does not report the sizes for $\alpha_1 = 1$.

Table 6: Simulation result for double factors setting (no correlation)

	Bias $\times$ 100			RMSE $\times$ 100			Size $\times$ 100		
	Double Factor with correlation $\rho_{12} = 0$
	$\alpha_1 = 1, \alpha_2 = 0.7$
n\T	120	240	360	120	240	360	120	240	360
100	0.567	0.737	0.628	4.062	3.819	3.799	2.95	1.45	1.85
300	0.512	0.611	0.518	2.398	2.103	1.979	6.25	0.55	0.5
500	-0.149	0.08	-0.019	1.796	1.498	1.443	8	0.2	0.1
	$\alpha_1 = 1, \alpha_2 = 0.75$
100	-3.051	-3.02	-3.092	4.582	4.245	4.248	2.45	0.1	0.10
300	0.491	-1.035	0.640	1.843	1.460	1.576	7.6	0.8	0.55
500	-0.611	-0.372	-0.393	1.520	1.136	1.125	11.35	0.15	0.1
	$\alpha_1 = 1, \alpha_2 = 0.8$
100	-3.752	-3.630	-3.581	4.557	4.213	4.210	84.65	85.9	85.25
300	-1.218	-0.331	-1.021	1.812	0.792	1.438	9.35	0.2	0.3
500	-0.022	0.192	0.147	1.047	0.782	0.742	15.35	1.1	1.1
	$\alpha_1 = 1, \alpha_2 = 0.85$
100	-0.075	0.127	0.088	1.996	1.697	1.606	5.4	1.15	0.95
300	-0.531	-0.406	-0.351	1.097	0.613	0.777	10.8	0.15	0.2
500	-0.647	-0.391	-0.391	1.020	0.643	0.630	19.1	0.15	0
	$\alpha_1 = 1, \alpha_2 = 0.9$
100	-0.128	0.043	0.025	1.428	1.143	1.118	4.9	0.65	0.7
300	-0.651	-0.334	-0.394	1.002	0.435	0.617	17.1	0.6	0.2
500	-0.434	-0.168	-0.171	0.7435	0.367	0.368	25.2	0.4	0.3
	$\alpha_1 = 1, \alpha_2 = 0.95$
100	-1.218	-1.043	-1.036	1.603	1.222	1.212	6.65	0.25	0.05
300	-0.611	-0.344	-0.356	0.881	0.435	0.434	23.35	0.6	0.45
500	-0.415	-0.123	-0.134	0.661	0.220	0.216	36.75	1.35	1.1
	$\alpha_1 = 1, \alpha_2 = 1$
100	0	0	0	0	0	0	-	-	-
300	0	0	0	0	0	0	-	-	-
500	0	0	0	0	0	0	-	-	-

Notes: This table shows the result of experiment 2. Factors and errors are generate from standard normal distribution. Between two factors, we assume they have no correlation. Factor loadings come form uniform distribution $IIDU(\mu_\beta - 0.2, \mu_\beta + 0.2)$, and μ_β is set to 0.71. We keep $[n^{\alpha_j}]$ amount of loadings and assign the rest as zero. For each different time-unit combinations, we replicate 2000 times. For the size of the test, we use a two-tail test, under the hypothesis of $H_0, \hat{\alpha}_j = \alpha_j \; j = 1, 2$. Cause under the scenarios of $\alpha = 1$, the size of the test will collapse, therefore the table does not report the sizes for $\alpha_1 = \alpha_2 = 1$

Table 7: Simulation result for double factors setting (weak correlation)

	Bias × 100			RMSE × 100			Size × 100		
	Double Factor with correlation $\rho_{12} = 0.3$

	Bias × 100			RMSE × 100			Size × 100		
$\alpha_1 = 1, \alpha_2 = 0.7$
n\T	120	240	360	120	240	360	120	240	360
100	0.038	0.064	0.072	0.421	0.382	0.389	4.6	1.75	1.95
300	0.021	0.058	0.056	0.253	0.206	0.198	9.95	0.9	0.25
500	-0.032	0.006	0	0.201	0.153	0	12.20	0.1	0.05
$\alpha_1 = 1, \alpha_2 = 0.75$
100	-0.325	-0.313	-0.310	0.488	0.419	0.420	4.75	0.1	0
300	0.028	0.063	0.065	0.253	0.157	0.159	9.95	0.55	0.5
500	-0.082	-0.037	-0.039	0.175	0.114	0.112	19.25	0.25	0.3
$\alpha_1 = 1, \alpha_2 = 0.8$
100	-0.393	-0.361	-0.368	0.477	0.418	0.421	85.45	85.2	86.4
300	0.029	-0.099	-0.100	0.192	0.145	0.145	12.2	0.65	0.5
500	-0.037	-0.016	0.016	0.129	0.074	0.074	27.8	0.25	1.2
$\alpha_1 = 1, \alpha_2 = 0.85$
100	-0.027	0.008	0.007	0.234	0.160	0.155	9.3	0.9	0.65
300	-0.147	-0.031	-0.037	0.219	0.079	0.077	16.75	0.3	0.2
500	-0.088	-0.039	-0.039	0.136	0.063	0.062	30.6	0.15	0
$\alpha_1 = 1, \alpha_2 = 0.9$
100	-0.033	0.003	0.002	0.173	0.111	0.110	9.4	0.6	0.55
300	-0.087	-0.040	-0.041	0.131	0.061	0.061	27.8	0.1	0.05
500	-0.070	-0.017	-0.018	0.111	0.037	0.037	41.15	0.6	0.35
$\alpha_1 = 1, \alpha_2 = 0.95$
100	-0.134	-0.101	-0.104	0.185	0.122	0.122	10.15	0.1	0.15
300	-0.083	-0.034	-0.034	0.118	0.043	0.044	39.35	0.6	0.6
500	-0.062	-0.013	-0.012	0.937	0.022	0.023	51.8	1.25	2.0
$\alpha_1 = 1, \alpha_2 = 1$
100	0	0	0	0	0	0	-	-	-
300	0	0	0	0	0	0	-	-	-
500	0	0	0	0	0	0	-	-	-

Notes: This table shows the result of experiment 2. Factors and errors are generate from standard normal distribution. Between two factors, we assume they have correlation $\rho_{12} = 0.3$ Factor loadings come form uniform distribution $IIDU(\mu_\beta - 0.2, \mu_\beta + 0.2)$, and μ_β is set to 0.71. We keep $[n^{\alpha_j}]$ amount of loadings and assign the rest as zero. For each different time-unit combinations, we replicate 2000 times. For the size of the test, we use a two-tail test, under the hypothesis of $H_0, \hat{\alpha}_j = \alpha_j \ j = 1, 2$. Cause under the scenarios of $\alpha = 1$, the size of the test will collapse, therefore the table does not report the sizes when $\alpha_1 = \alpha_2 = 1$

B Empirical Application Result

B.1 Factor Strength Estimation Table

Table 8: Comparison table of estimated factor strength on three different data sets, from strong to weak

	Ten Year Data			Twenty Year Data			Thirty Year Data		
	Factor	Market Factor Strength	Risk Factor Strength	Factor	Market Factor Strength	Risk Factor Strength	Factor	Market Factor Strength	Risk Factor Strength
1	beta	0.976	0.749	ndp	0.995	0.937	salecash	0.998	0.948
2	baspread	0.980	0.730	quick	0.992	0.934	ndp	0.998	0.941
3	turn	0.983	0.728	salecash	0.993	0.933	quick	0.997	0.940
4	zerotrade	0.983	0.725	lev	0.994	0.931	age	0.997	0.940
5	idiovol	0.981	0.723	cash	0.993	0.931	roavol	0.997	0.938
6	retvol	0.978	0.721	dy	0.992	0.929	ep	0.998	0.937
7	std_turn	0.983	0.719	roavol	0.992	0.929	depr	0.998	0.935
8	HML_Devil	0.989	0.719	zs	0.994	0.927	cash	0.997	0.934
9	maxret	0.981	0.715	age	0.994	0.927	rds	0.998	0.931
10	roavol	0.986	0.713	cp	0.995	0.926	dy	0.997	0.927
11	age	0.989	0.703	ebp	0.994	0.926	currat	0.998	0.927
12	sp	0.986	0.699	op	0.993	0.925	chcsho	0.997	0.927
13	ala	0.986	0.699	cfp	0.995	0.924	lev	0.996	0.926
14	ndp	0.988	0.686	nop	0.993	0.924	stdacc	0.997	0.926
15	orgcap	0.990	0.686	ep	0.994	0.923	cfp	0.998	0.925
16	tang	0.991	0.683	depr	0.993	0.922	nop	0.997	0.925
17	ebp	0.989	0.683	rds	0.993	0.922	zs	0.996	0.924
18	invest	0.986	0.683	kz	0.993	0.919	stdcf	0.997	0.924
19	dpia	0.987	0.681	sp	0.993	0.918	cp	0.998	0.919
20	UMD	0.990	0.678	currat	0.992	0.918	op	0.997	0.919
21	zs	0.987	0.675	ato	0.993	0.918	ato	0.996	0.919
22	grltnoa	0.989	0.675	chcsho	0.992	0.916	kz	0.996	0.918
23	dy	0.989	0.672	tang	0.995	0.915	ebp	0.997	0.918
24	HML	0.989	0.672	stdacc	0.992	0.913	tang	0.997	0.917
25	kz	0.987	0.669	adm	0.993	0.913	adm	0.997	0.913
26	ob_a	0.989	0.669	stdcf	0.991	0.910	ww	0.997	0.911
27	BAB	0.989	0.666	cashpr	0.994	0.909	maxret	0.995	0.911

Table 8: Comparison table of estimated factor strength on three different
data sets, from strong to weak (Cont.)

		Ten Year Data			Twenty Year Data			Thirty Year Data	
	Factor	Market Factor Strength	Risk Factor Strength	Factor	Market Factor Strength	Risk Factor Strength	Factor	Market Factor Strength	Risk Factor Strength
28	op	0.991	0.663	nef	0.990	0.906	std_turn	0.995	0.908
29	realestate_hxz	0.988	0.663	HML	0.993	0.905	idiovol	0.994	0.908
30	ol	0.988	0.663	std_turn	0.991	0.901	nef	0.995	0.908
31	adm	0.989	0.660	idiovol	0.990	0.901	baspread	0.995	0.906
32	lev	0.987	0.657	zerotrade	0.988	0.897	IPO	0.997	0.902
33	nxf	0.990	0.651	ww	0.994	0.896	retvol	0.995	0.902
34	nop	0.990	0.651	turn	0.989	0.895	sp	0.995	0.901
35	pm	0.986	0.648	maxret	0.990	0.893	turn	0.994	0.900
36	pchcapx3	0.989	0.644	absacc	0.995	0.889	absacc	0.998	0.898
37	nef	0.989	0.644	baspread	0.990	0.885	lgr	0.997	0.897
38	cash	0.990	0.637	hire	0.994	0.883	zerotrade	0.992	0.896
39	QMJ	0.978	0.637	lgr	0.994	0.882	HML	0.995	0.894
40	rds	0.989	0.634	IPO	0.994	0.881	cashpr	0.995	0.892
41	LIQ_PS	0.989	0.634	retvol	0.990	0.879	salerec	0.997	0.890
42	ato	0.989	0.634	nxf	0.990	0.879	dcol	0.997	0.890
43	salerec	0.992	0.630	RMW	0.992	0.879	hire	0.997	0.890
44	currat	0.989	0.626	beta	0.988	0.878	RMW	0.997	0.890
45	acc	0.990	0.619	salerec	0.992	0.877	beta	0.993	0.889
46	stdcf	0.990	0.619	acc	0.995	0.875	nxf	0.996	0.886
47	HXZ_ROE	0.989	0.619	bm_ia	0.995	0.875	acc	0.997	0.882
48	depr	0.989	0.615	sin	0.994	0.874	dfin	0.996	0.875
49	noa	0.989	0.615	dcol	0.994	0.872	nincr	0.996	0.872
50	cashpr	0.988	0.615	dfin	0.993	0.870	noa	0.995	0.868
51	absacc	0.990	0.615	HML_Devil	0.988	0.870	HXZ_IA	0.997	0.868
52	gma	0.988	0.615	HXZ_IA	0.994	0.869	rdm	0.996	0.867
53	dncl	0.987	0.611	nincr	0.994	0.864	HML_Devil	0.995	0.867
54	ms	0.981	0.611	rdm	0.993	0.855	rna	0.997	0.865
55	rna	0.990	0.611	noa	0.992	0.855	ps	0.996	0.857
56	STR	0.988	0.607	rna	0.994	0.855	bm_ia	0.997	0.856
57	rdm	0.989	0.607	herf	0.991	0.854	sgr	0.997	0.854
58	chcsho	0.987	0.607	sgr	0.993	0.849	rd	0.996	0.852
59	sin	0.988	0.607	dnco	0.993	0.845	sin	0.997	0.852
60	salecash	0.989	0.602	ps	0.992	0.836	realestate_hxz	0.997	0.851

Table 8: Comparison table of estimated factor strength on three different data sets, from strong to weak (Cont.)

	Ten Year Data			Twenty Year Data			Thirty Year Data		
	Factor	Market Factor Strength	Risk Factor Strength	Factor	Market Factor Strength	Risk Factor Strength	Factor	Market Factor Strength	Risk Factor Strength
61	dnco	0.989	0.598	CMA	0.994	0.836	herf	0.995	0.846
62	quick	0.990	0.593	egr_hxz	0.992	0.832	dnco	0.996	0.844
63	stdacc	0.990	0.593	realestate_hxz	0.991	0.830	CMA	0.997	0.838
64	poa	0.989	0.593	rd	0.993	0.820	egr_hxz	0.996	0.831
65	cp	0.989	0.589	cinvest_a	0.994	0.817	ol	0.995	0.829
66	tb	0.989	0.589	ol	0.989	0.816	ob_a	0.996	0.823
67	HXZ_IA	0.988	0.584	gad	0.992	0.816	cinvest_a	0.996	0.823
68	saleinv	0.987	0.579	dolvol	0.995	0.804	SMB	0.995	0.804
69	cfp	0.989	0.579	ob_a	0.990	0.797	gad	0.995	0.804
70	egr	0.988	0.579	pchdepr	0.994	0.791	dolvol	0.997	0.798
71	dnca	0.987	0.579	ala	0.993	0.791	gma	0.995	0.798
72	egr_hxz	0.989	0.579	BAB	0.995	0.785	ala	0.996	0.798
73	os	0.985	0.569	pchcapx3	0.991	0.782	QMJ	0.996	0.795
74	pps	0.983	0.563	gma	0.990	0.782	convind	0.997	0.793
75	cto	0.988	0.563	dnca	0.992	0.780	tb	0.995	0.791
76	grltnoa_hxz	0.987	0.563	SMB	0.992	0.771	aeavol	0.998	0.791
77	cei	0.989	0.563	poa	0.991	0.769	BAB	0.998	0.788
78	CMA	0.989	0.563	aeavol	0.996	0.767	dcoa	0.995	0.784
79	em	0.989	0.552	tb	0.988	0.763	cto	0.995	0.781
80	ww	0.991	0.546	grltnoa_hxz	0.992	0.761	egr	0.996	0.781
81	std_dolvol	0.988	0.539	cei	0.988	0.761	roic	0.995	0.781
82	grcapx	0.987	0.539	dsti	0.991	0.757	indmom	0.995	0.779
83	pctacc	0.989	0.539	indmom	0.990	0.755	pm	0.995	0.779
84	ep	0.989	0.533	egr	0.992	0.753	pchdepr	0.996	0.773
85	pricedelay	0.989	0.533	moms12m	0.992	0.753	cei	0.995	0.773
86	hire	0.989	0.519	orgcap	0.990	0.744	orgcap	0.995	0.771
87	SMB	0.988	0.512	dcoa	0.993	0.737	pricedelay	0.996	0.768
88	pchcapx_ia	0.989	0.512	pchcurrat	0.993	0.735	dnca	0.995	0.768
89	aeavol	0.989	0.512	UMD	0.986	0.733	moms12m	0.995	0.768
90	moms12m	0.988	0.512	cinvest	0.993	0.733	pchcapx3	0.995	0.765
91	cashdebt	0.985	0.504	HXZ_ROE	0.992	0.733	saleinv	0.995	0.763
92	lgr	0.988	0.504	roic	0.986	0.730	pctacc	0.995	0.763
93	cinvest	0.989	0.496	QMJ	0.985	0.730	grltnoa_hxz	0.996	0.760

Table 8: Comparison table of estimated factor strength on three different data sets, from strong to weak (Cont.)

| | | Ten Year Data | | | Twenty Year Data | | | Thirty Year Data | |
	Factor	Market Factor Strength	Risk Factor Strength	Factor	Market Factor Strength	Risk Factor Strength	Factor	Market Factor Strength	Risk Factor Strength
94	herf	0.988	0.496	pctacc	0.989	0.723	poa	0.995	0.757
95	bm_ia	0.989	0.487	cto	0.990	0.718	HXZ_ROE	0.997	0.757
96	cfp_ia	0.988	0.479	pricedelay	0.993	0.715	UMD	0.995	0.745
97	cinvest_a	0.989	0.479	pchcapx_ia	0.992	0.707	dsti	0.995	0.742
98	chmom	0.990	0.469	convind	0.990	0.698	cinvest	0.995	0.733
99	RMW	0.988	0.469	cdi	0.993	0.677	em	0.995	0.733
100	sue	0.988	0.459	invest	0.991	0.677	pchcurrat	0.995	0.730
101	mom36m	0.987	0.459	chtx	0.992	0.674	ms	0.995	0.716
102	indmom	0.988	0.459	rsup	0.991	0.670	pchcapx_ia	0.995	0.708
103	dcoa	0.989	0.459	em	0.987	0.670	invest	0.995	0.708
104	etr	0.987	0.448	pm	0.992	0.667	dpia	0.995	0.705
105	chinv	0.989	0.448	ta	0.992	0.663	os	0.992	0.701
106	ill	0.989	0.448	dpia	0.991	0.663	cdi	0.995	0.701
107	roic	0.987	0.448	saleinv	0.991	0.660	chtx	0.995	0.689
108	convind	0.989	0.448	pchquick	0.991	0.652	pps	0.995	0.680
109	sgr	0.989	0.437	os	0.983	0.652	rs	0.995	0.680
110	IPO	0.990	0.437	ms	0.985	0.640	roaq	0.995	0.680
111	dolvol	0.990	0.437	roaq	0.988	0.628	rsup	0.995	0.642
112	dcol	0.988	0.425	pps	0.986	0.623	cfp_ia	0.995	0.637
113	nincr	0.989	0.411	cfp_ia	0.991	0.623	chinv	0.995	0.637
114	chempia	0.988	0.411	grcapx	0.990	0.619	ta	0.995	0.631
115	rs	0.989	0.411	ndf	0.991	0.614	cashdebt	0.993	0.625
116	pchcapx	0.989	0.411	mom6m	0.992	0.604	STR	0.995	0.619
117	chtx	0.989	0.397	dncl	0.991	0.604	ndf	0.995	0.619
118	ivg	0.989	0.381	pchsale_pchrect	0.990	0.599	grltnoa	0.995	0.613
119	LTR	0.986	0.364	pchcapx	0.992	0.599	pchcapx	0.995	0.613
120	mom6m	0.988	0.364	pchsaleinv	0.990	0.594	pchquick	0.995	0.607
121	cdi	0.988	0.364	LIQ_PS	0.990	0.588	mom6m	0.995	0.607
122	chatoia	0.988	0.364	rs	0.990	0.588	grcapx	0.995	0.607
123	gad	0.986	0.364	cashdebt	0.986	0.583	dncl	0.995	0.600
124	pchcurrat	0.989	0.297	chempia	0.992	0.583	ivg	0.995	0.586
125	pchgm_pchsale	0.989	0.297	dwc	0.990	0.565	pchsaleinv	0.995	0.579
126	rd	0.987	0.297	grltnoa	0.990	0.551	LIQ_PS	0.995	0.579

Table 8: Comparison table of estimated factor strength on three different data sets, from strong to weak (Cont.)

| | Ten Year Data | | | Twenty Year Data | | | Thirty Year Data | | |
	Factor	Market Factor Strength	Risk Factor Strength	Factor	Market Factor Strength	Risk Factor Strength	Factor	Market Factor Strength	Risk Factor Strength
127	dsti	0.990	0.297	dfnl	0.990	0.544	chempia	0.995	0.554
128	dfnl	0.988	0.297	STR	0.990	0.537	mom36m	0.995	0.545
129	roaq	0.986	0.297	std_dolvol	0.990	0.537	pchsale_pchxsga	0.995	0.526
130	pchdepr	0.989	0.266	mom36m	0.991	0.513	std_dolvol	0.995	0.526
131	dnoa	0.989	0.230	sue	0.990	0.504	pchsale_pchinvt	0.995	0.516
132	ta	0.989	0.230	LTR	0.989	0.504	dwc	0.995	0.516
133	chpmia	0.988	0.230	chmom	0.988	0.504	chmom	0.994	0.505
134	pchquick	0.988	0.182	pchsale_pchxsga	0.991	0.475	sue	0.995	0.493
135	dwc	0.990	0.182	pchsale_pchinvt	0.990	0.464	dfnl	0.995	0.480
136	dfin	0.989	0.182	lfe	0.990	0.452	LTR	0.995	0.467
137	rsup	0.989	0.182	chinv	0.991	0.439	pchsale_pchrect	0.995	0.467
138	pchsaleinv	0.989	0.115	chatoia	0.991	0.439	pchgm_pchsale	0.995	0.379
139	pchsale_pchinvt	0.989	0.115	ivg	0.991	0.426	lfe	0.995	0.379
140	pchsale_pchrect	0.989	0.115	pchgm_pchsale	0.991	0.394	ill	0.995	0.326
141	pchsale_pchxsga	0.990	0.115	etr	0.990	0.356	dnoa	0.995	0.293
142	ps	0.991	0.115	chpmia	0.991	0.356	ear	0.995	0.252
143	lfe	0.989	0.000	ill	0.990	0.276	etr	0.995	0.200
144	ndf	0.987	0.000	dnoa	0.990	0.276	chatoia	0.995	0.200
145	ear	0.989	0.000	ear	0.992	0.276	chpmia	0.995	0.200

Notes: This table presents the estimation results of factors' strength, ordered decreasingly by risk factor strength. For the estimation, we use the method from Section 3.3, with one market factor and one risk factor. The three data set is describe in the section 6.1

Table 9: Decompose the thirty year data into three ten year subset, estimated the factor strength base on those three data set separately. Rank the result base on the factor strength, from strong to weak.

Rank	January 1988 to December 1997		January 1998 to December 2007		January 2008 to December 2017	
	Factor	Strength	Factor	Strength	Factor	Strength
1	herf	0.763	ndp	0.937	salecash	0.948
2	saleinv	0.736	quick	0.934	ndp	0.941
3	cto	0.733	salecash	0.933	quick	0.940
4	turn	0.733	lev	0.931	age	0.940
5	beta	0.730	cash	0.931	roavol	0.938
6	ala	0.730	dy	0.929	ep	0.937
7	nef	0.726	roavol	0.929	depr	0.935
8	zerotrade	0.719	zs	0.927	cash	0.934
9	dy	0.716	age	0.927	rds	0.931
10	idiovol	0.716	cp	0.926	dy	0.927
11	ol	0.712	ebp	0.926	currat	0.927
12	gma	0.712	op	0.925	chcsho	0.927
13	std_turn	0.708	cfp	0.924	lev	0.926
14	depr	0.705	nop	0.924	stdacc	0.926
15	baspread	0.701	ep	0.923	cfp	0.925
16	retvol	0.701	depr	0.922	nop	0.925
17	nxf	0.701	rds	0.922	zs	0.924
18	currat	0.697	kz	0.919	stdcf	0.924
19	maxret	0.697	sp	0.918	cp	0.919
20	op	0.693	currat	0.918	op	0.919
21	SMB	0.689	ato	0.918	ato	0.919
22	orgcap	0.685	chcsho	0.916	kz	0.918
23	nop	0.680	tang	0.915	ebp	0.918
24	pm	0.680	stdacc	0.913	tang	0.917
25	tang	0.676	adm	0.913	adm	0.913
26	quick	0.672	stdcf	0.910	ww	0.911
27	roavol	0.667	cashpr	0.909	maxret	0.911
28	pricedelay	0.667	nef	0.906	std_turn	0.908
29	sp	0.657	HML	0.905	idiovol	0.908
30	aeavol	0.657	std_turn	0.901	nef	0.908
31	bm_ia	0.652	idiovol	0.901	baspread	0.906
32	cash	0.652	zerotrade	0.897	IPO	0.902
33	convind	0.652	ww	0.896	retvol	0.902
34	dcoa	0.642	turn	0.895	sp	0.901
35	ebp	0.642	maxret	0.893	turn	0.900
36	ivg	0.642	absacc	0.889	absacc	0.898
37	cp	0.637	baspread	0.885	lgr	0.897
38	chinv	0.637	hire	0.883	zerotrade	0.896
39	ndp	0.637	lgr	0.882	HML	0.894
40	hire	0.637	IPO	0.881	cashpr	0.892
41	roic	0.631	retvol	0.879	salerec	0.890
42	cashpr	0.625	nxf	0.879	dcol	0.890
43	HML_Devil	0.625	RMW	0.879	hire	0.890
44	HXZ_IA	0.625	beta	0.878	RMW	0.890
45	HML	0.619	salerec	0.877	beta	0.889
46	age	0.619	acc	0.875	nxf	0.886
47	egr_hxz	0.619	bm_ia	0.875	acc	0.882

Table 9: Decompose the thirty year data into three ten year subset, estimated the factor strength base on those three data set separately(cont.)

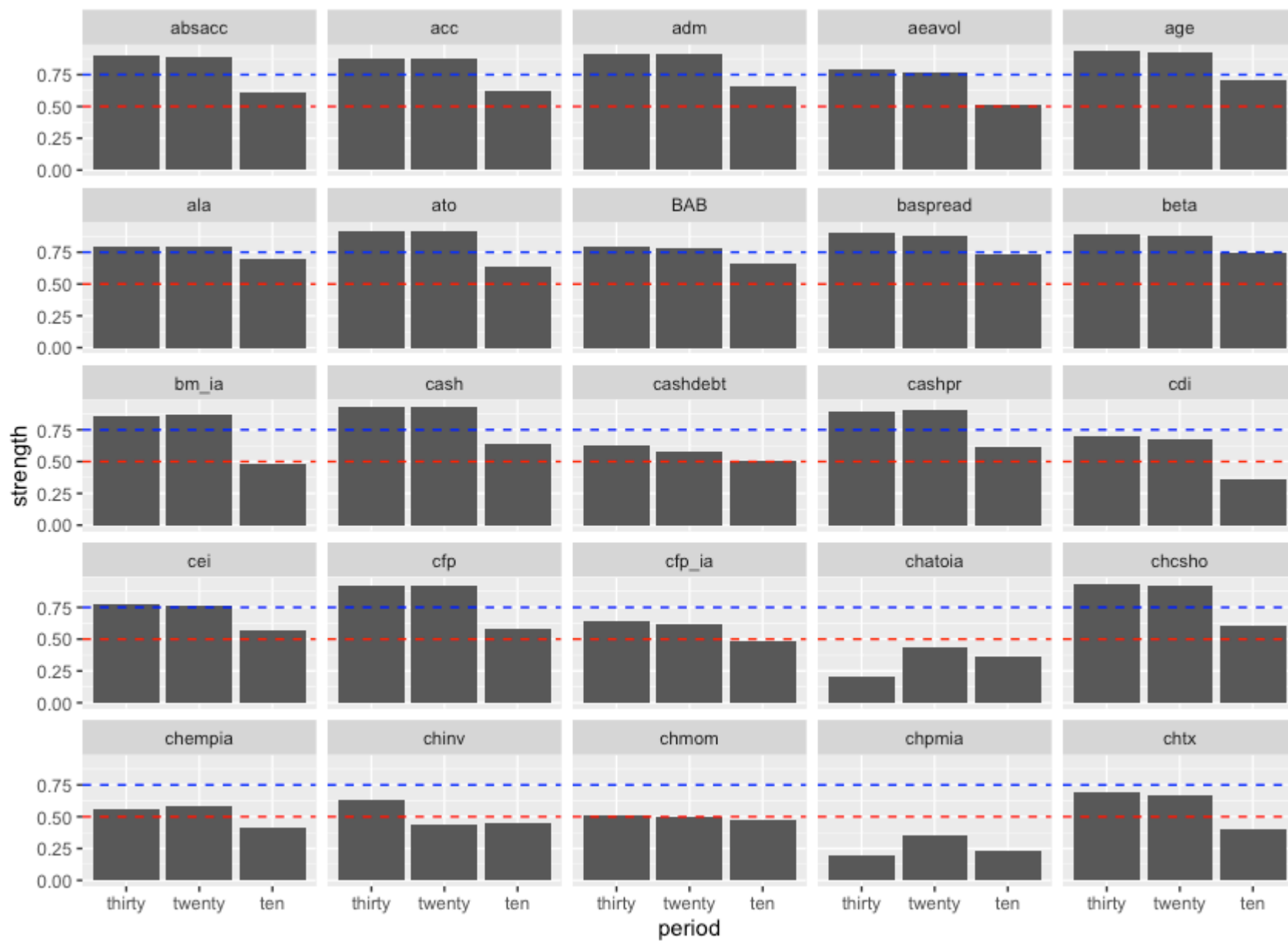|	January 1988 to December 1997		January 1998 to December 2007		January 2008 to December 2017	
Rank	Factor	Strength	Factor	Strength	Factor	Strength
48	dpia	0.619	sin	0.874	dfin	0.875
49	invest	0.619	dcol	0.872	nincr	0.872
50	poa	0.619	dfin	0.870	noa	0.868
51	QMJ	0.619	HML_Devil	0.870	HXZ_IA	0.868
52	salerec	0.613	HXZ_IA	0.869	rdm	0.867
53	dnco	0.613	nincr	0.864	HML_Devil	0.867
54	cdi	0.613	rdm	0.855	rna	0.865
55	em	0.613	noa	0.855	ps	0.857
56	salecash	0.607	rna	0.855	bm_ia	0.856
57	sgr	0.607	herf	0.854	sgr	0.854
58	egr	0.607	sgr	0.849	rd	0.852
59	dcol	0.607	dnco	0.845	sin	0.852
60	pchcapx3	0.600	ps	0.836	realestate_hxz	0.851
61	kz	0.593	CMA	0.836	herf	0.846
62	lev	0.586	egr_hxz	0.832	dnco	0.844
63	acc	0.586	realestate_hxz	0.830	CMA	0.838
64	zs	0.586	rd	0.820	egr_hxz	0.831
65	rsup	0.586	cinvest_a	0.817	ol	0.829
66	pps	0.579	ol	0.816	ob_a	0.823
67	nincr	0.579	gad	0.816	cinvest_a	0.823
68	rdm	0.579	dolvol	0.804	SMB	0.804
69	grltnoa_hxz	0.579	ob_a	0.797	gad	0.804
70	cfp	0.579	pchdepr	0.791	dolvol	0.798
71	chcsho	0.579	ala	0.791	gma	0.798
72	pctacc	0.571	BAB	0.785	ala	0.798
73	CMA	0.571	pchcapx3	0.782	QMJ	0.795
74	ep	0.563	gma	0.782	convind	0.793
75	UMD	0.563	dnca	0.780	tb	0.791
76	indmom	0.563	SMB	0.771	aeavol	0.791
77	dwc	0.563	poa	0.769	BAB	0.788
78	dnca	0.563	aeavol	0.767	dcoa	0.784
79	chmom	0.563	tb	0.763	cto	0.781
80	cei	0.563	grltnoa_hxz	0.761	egr	0.781
81	lgr	0.545	cei	0.761	roic	0.781
82	STR	0.536	dsti	0.757	indmom	0.779
83	absacc	0.536	indmom	0.755	pm	0.779
84	realestate_hxz	0.536	egr	0.753	pchdepr	0.773
85	chempia	0.505	moms12m	0.753	cei	0.773
86	rds	0.505	orgcap	0.744	orgcap	0.771
87	ps	0.493	dcoa	0.737	pricedelay	0.768
88	grltnoa	0.493	pchcurrat	0.735	dnca	0.768
89	ms	0.493	UMD	0.733	moms12m	0.768
90	rs	0.493	cinvest	0.733	pchcapx3	0.765
91	RMW	0.493	HXZ_ROE	0.733	saleinv	0.763
92	os	0.480	roic	0.730	pctacc	0.763
93	ob_a	0.480	QMJ	0.730	grltnoa_hxz	0.760
94	roaq	0.480	pctacc	0.723	poa	0.757
95	cinvest	0.467	cto	0.718	HXZ_ROE	0.757
96	ww	0.467	pricedelay	0.715	UMD	0.745

Table 9: Decompose the thirty year data into three ten year subset, estimated the factor strength base on those three data set separately(cont.)
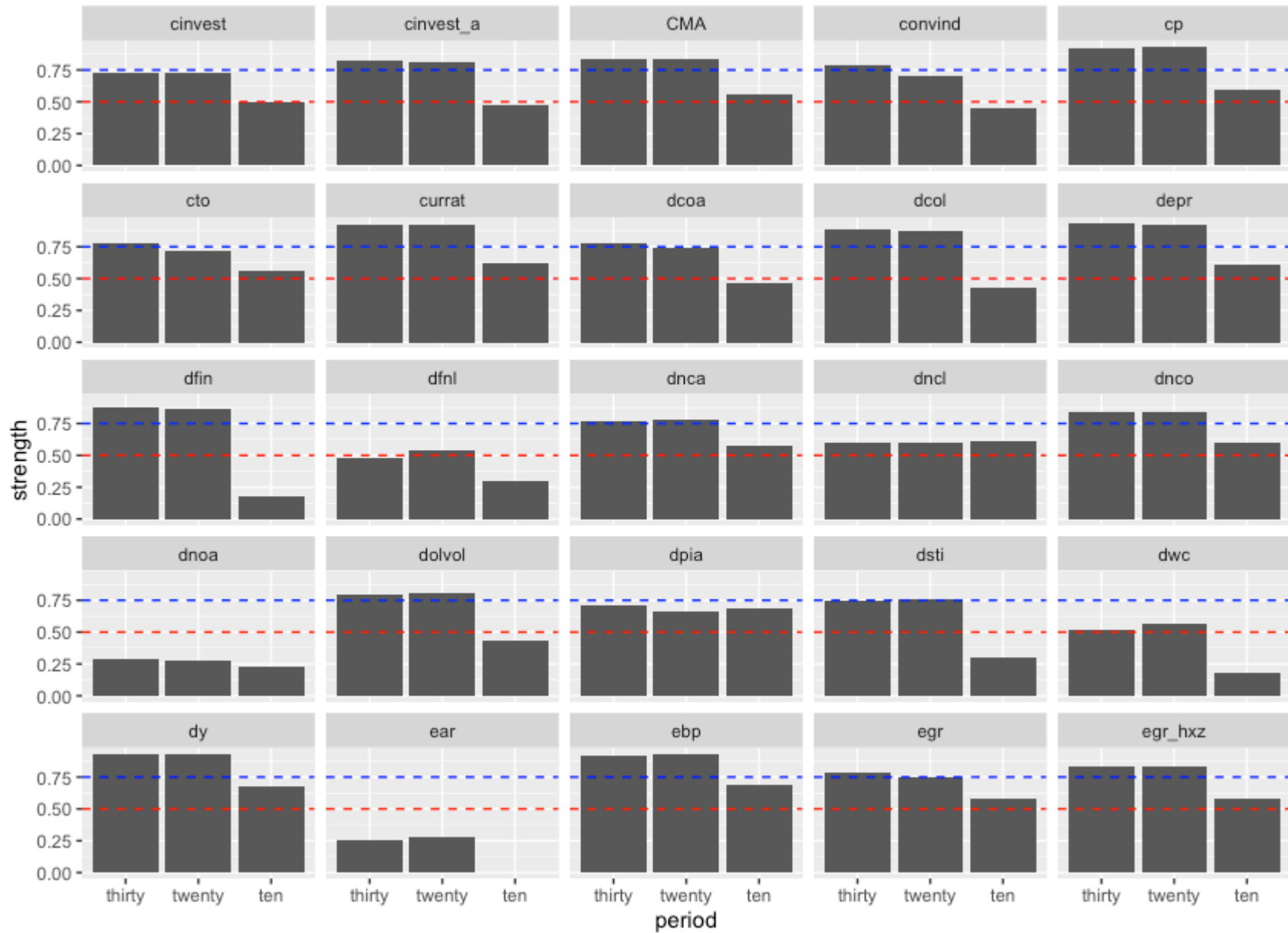
	January 1988 to December 1997		January 1998 to December 2007		January 2008 to December 2017	
Rank	Factor	Strength	Factor	Strength	Factor	Strength
97	BAB	0.467	pchcapx_ia	0.707	dsti	0.742
98	dolvol	0.452	convind	0.698	cinvest	0.733
99	std_dolvol	0.452	cdi	0.677	em	0.733
100	rd	0.452	invest	0.677	pchcurrat	0.730
101	grcapx	0.452	chtx	0.674	ms	0.716
102	moms12m	0.452	rsup	0.670	pchcapx_ia	0.708
103	chatoia	0.452	em	0.670	invest	0.708
104	mom36m	0.437	pm	0.667	dpia	0.705
105	chtx	0.419	ta	0.663	os	0.701
106	ato	0.419	dpia	0.663	cdi	0.701
107	stdcf	0.419	saleinv	0.660	chtx	0.689
108	cashdebt	0.400	pchquick	0.652	pps	0.680
109	ta	0.400	os	0.652	rs	0.680
110	stdacc	0.400	ms	0.640	roaq	0.680
111	HXZ_ROE	0.400	roaq	0.628	rsup	0.642
112	IPO	0.379	pps	0.623	cfp_ia	0.637
113	cfp_ia	0.379	cfp_ia	0.623	chinv	0.637
114	dfin	0.379	grcapx	0.619	ta	0.631
115	dfnl	0.379	ndf	0.614	cashdebt	0.625
116	pchcapx	0.379	mom6m	0.604	STR	0.619
117	adm	0.354	dncl	0.604	ndf	0.619
118	noa	0.354	pchsale_pchrect	0.599	grltnoa	0.613
119	rna	0.326	pchcapx	0.599	pchcapx	0.613
120	pchsale_pchinvt	0.293	pchsaleinv	0.594	pchquick	0.607
121	pchsale_pchxsga	0.293	LIQ_PS	0.588	mom6m	0.607
122	etr	0.293	rs	0.588	grcapx	0.607
123	lfe	0.293	cashdebt	0.583	dncl	0.600
124	cinvest_a	0.293	chempia	0.583	ivg	0.586
125	ndf	0.293	dwc	0.565	pchsaleinv	0.579
126	sue	0.252	grltnoa	0.551	LIQ_PS	0.579
127	gad	0.252	dfnl	0.544	chempia	0.554
128	LTR	0.200	STR	0.537	mom36m	0.545
129	pchsaleinv	0.200	std_dolvol	0.537	pchsale_pchxsga	0.526
130	mom6m	0.200	mom36m	0.513	std_dolvol	0.526
131	ill	0.200	sue	0.504	pchsale_pchinvt	0.516
132	LIQ_PS	0.200	LTR	0.504	dwc	0.516
133	tb	0.200	chmom	0.504	chmom	0.505
134	sin	0.200	pchsale_pchxsga	0.475	sue	0.493
135	pchcurrat	0.126	pchsale_pchinvt	0.464	dfnl	0.480
136	pchsale_pchrect	0.126	lfe	0.452	LTR	0.467
137	pchcapx_ia	0.126	chinv	0.439	pchsale_pchrect	0.467
138	dncl	0.126	chatoia	0.439	pchgm_pchsale	0.379
139	dsti	0.126	ivg	0.426	lfe	0.379
140	ear	0.126	pchgm_pchsale	0.394	ill	0.326
141	pchquick	0.000	etr	0.356	dnoa	0.293
142	pchdepr	0.000	chpmia	0.356	ear	0.252
143	pchgm_pchsale	0.000	ill	0.276	etr	0.200
144	dnoa	0.000	dnoa	0.276	chatoia	0.200

Table 9: Decompose the thirty year data into three ten year subset, estimated the factor strength base on those three data set separately(cont.)

Rank	January 1988 to December 1997		January 1998 to December 2007		January 2008 to December 2017	
	Factor	Strength	Factor	Strength	Factor	Strength
145	chpmia	0.000	ear	0.276	chpmia	0.200

Notes: This table presents the estimated factor strength, using the decomposed thirty years data. The thirty year data set is decomposed into three subsets: January 1988 to December 1997, January 1998 to December 2007, and January 2008 to December 2017. For each data set, it contains 120 observations (t = 120), and 242 units (n = 242) The table also contains the full sample estimation results of factor strength, and the standard deviation among the three sub samples results. The table is ordered decreasingly base on the full sample factor strength.

## B.2 Strength Comparison Figures

Figure 1: Strength Comparison
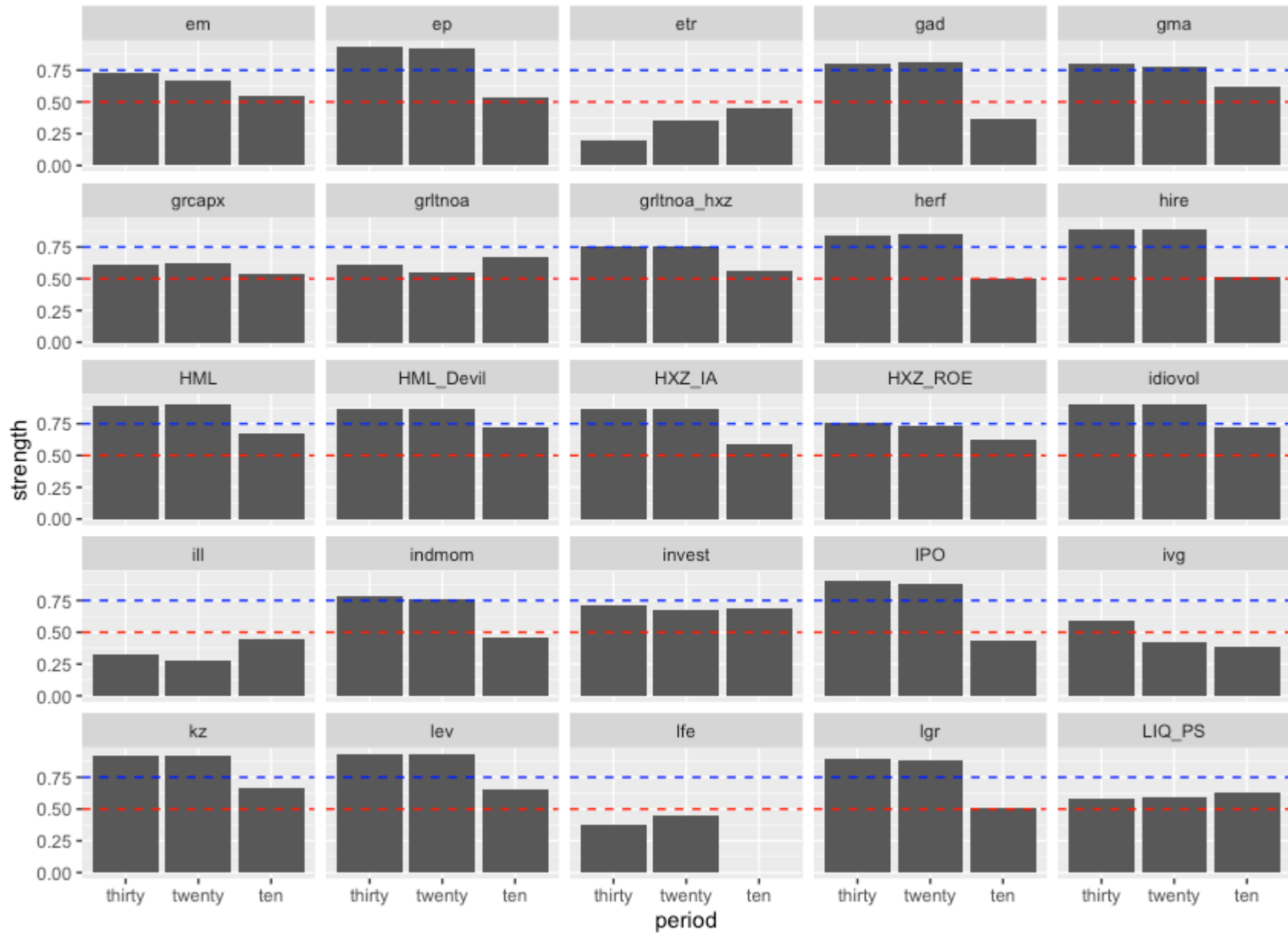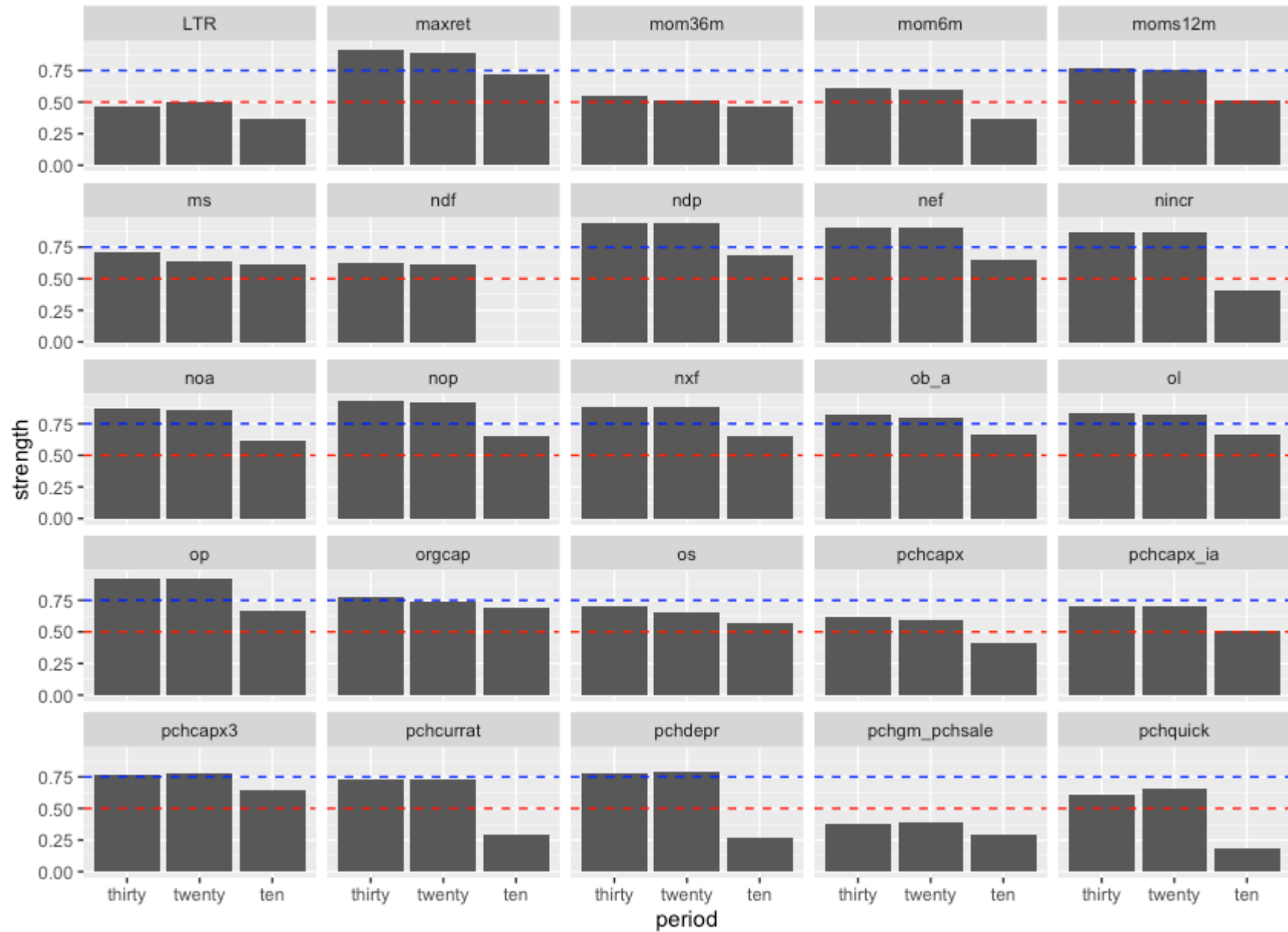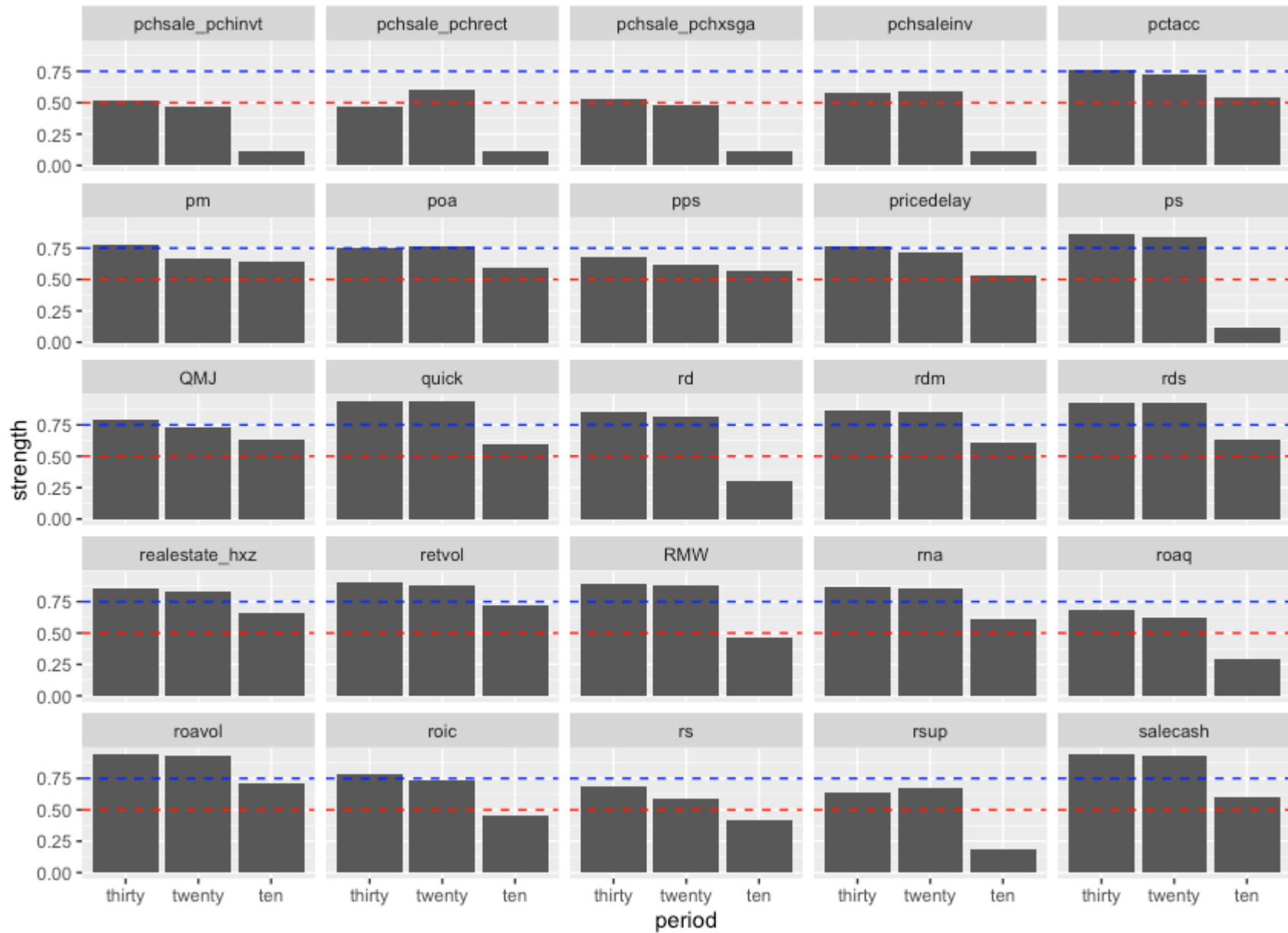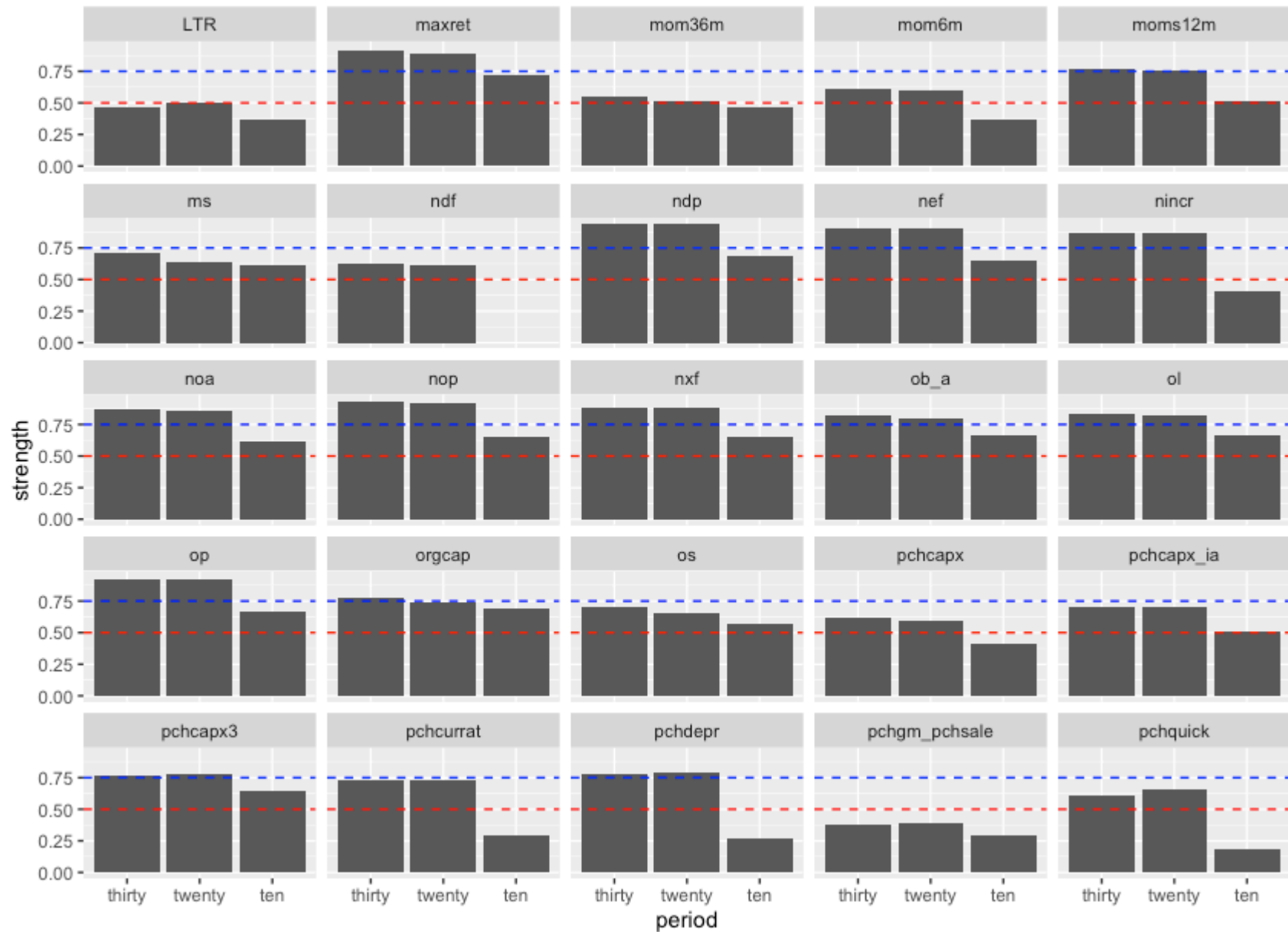
Notes: The figure compare the strength of every factor's strength in different data set. The x-axis indicates the data set: thirty is thirty years data set (January 1987 to December 2017), twenty is twenty year data set (January 1997 to December 2017), and ten is ten year data set (January 2007 to December 2017). The red dash line and blue dash line represent 0.5 and 0.75 threshold value respectively.
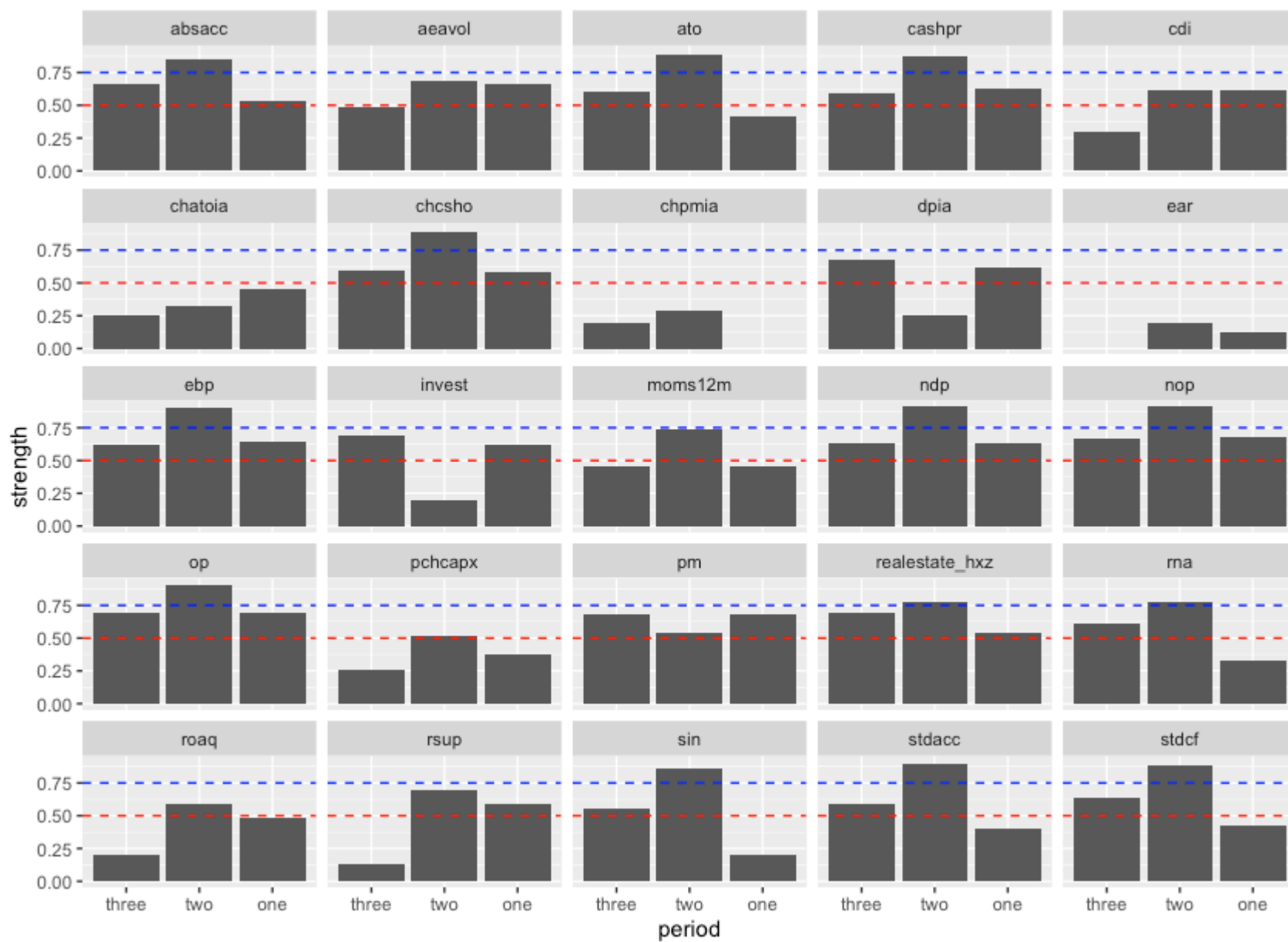
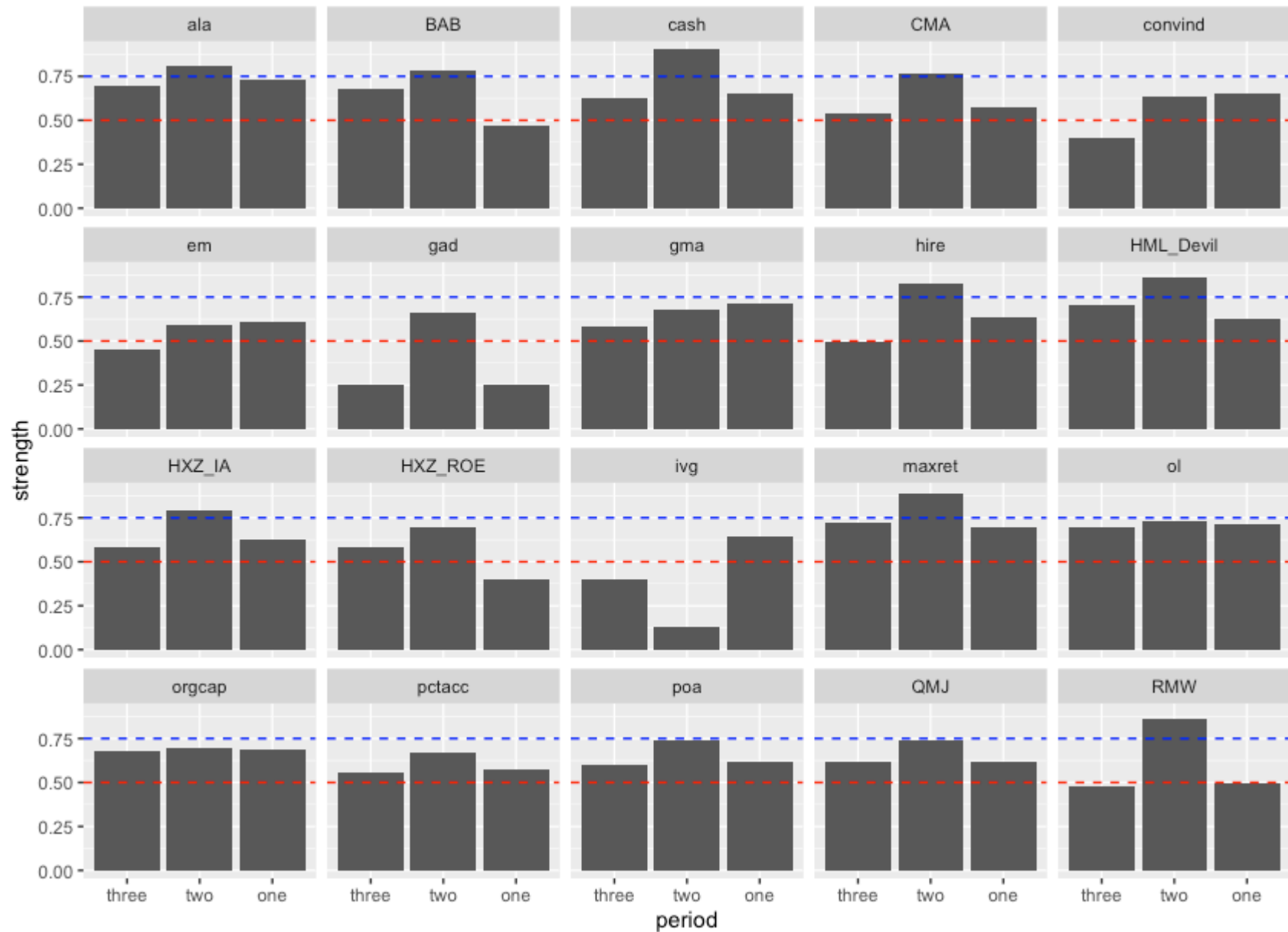Figure 2: Thirty Year Decompose Comparison
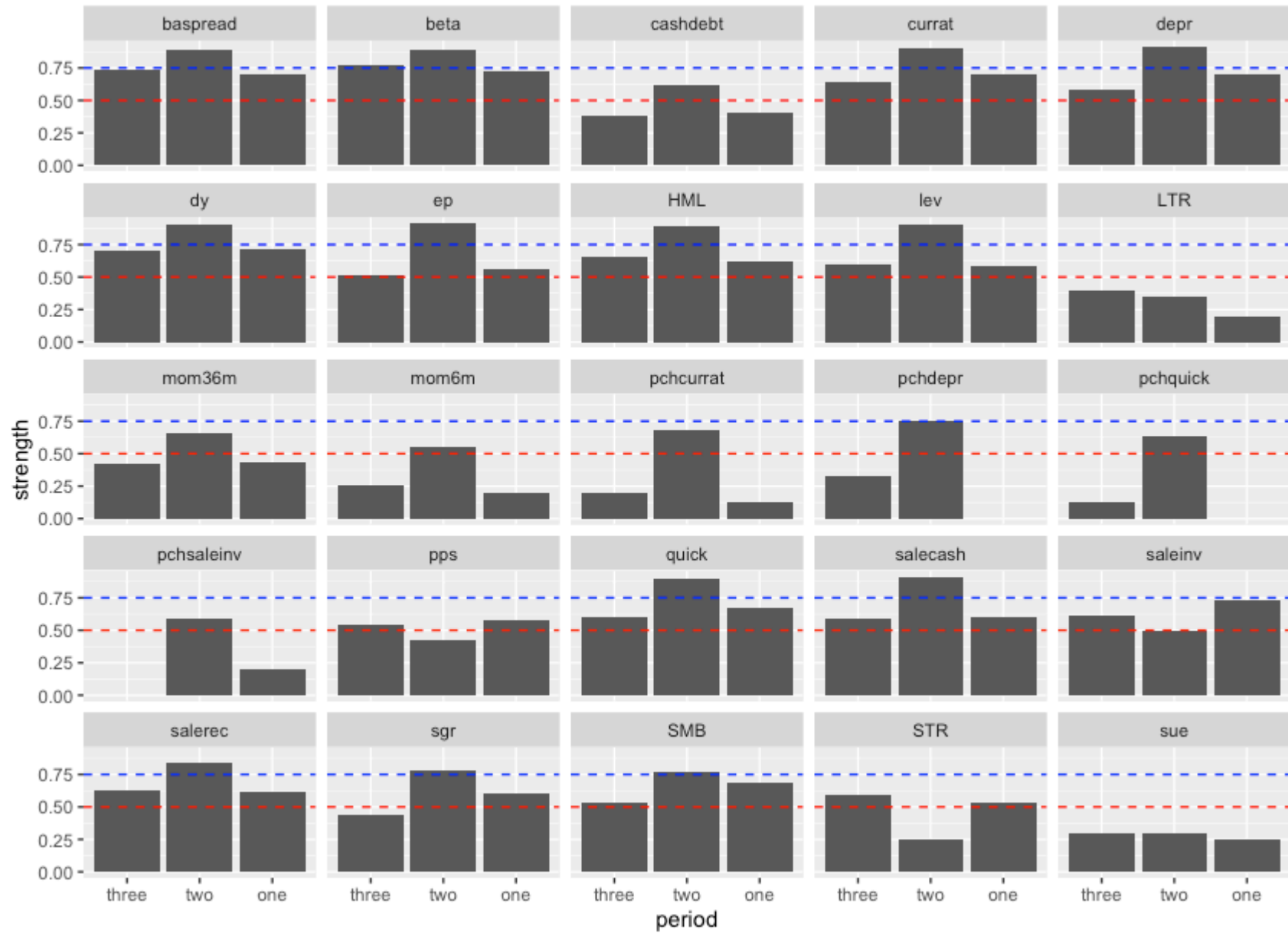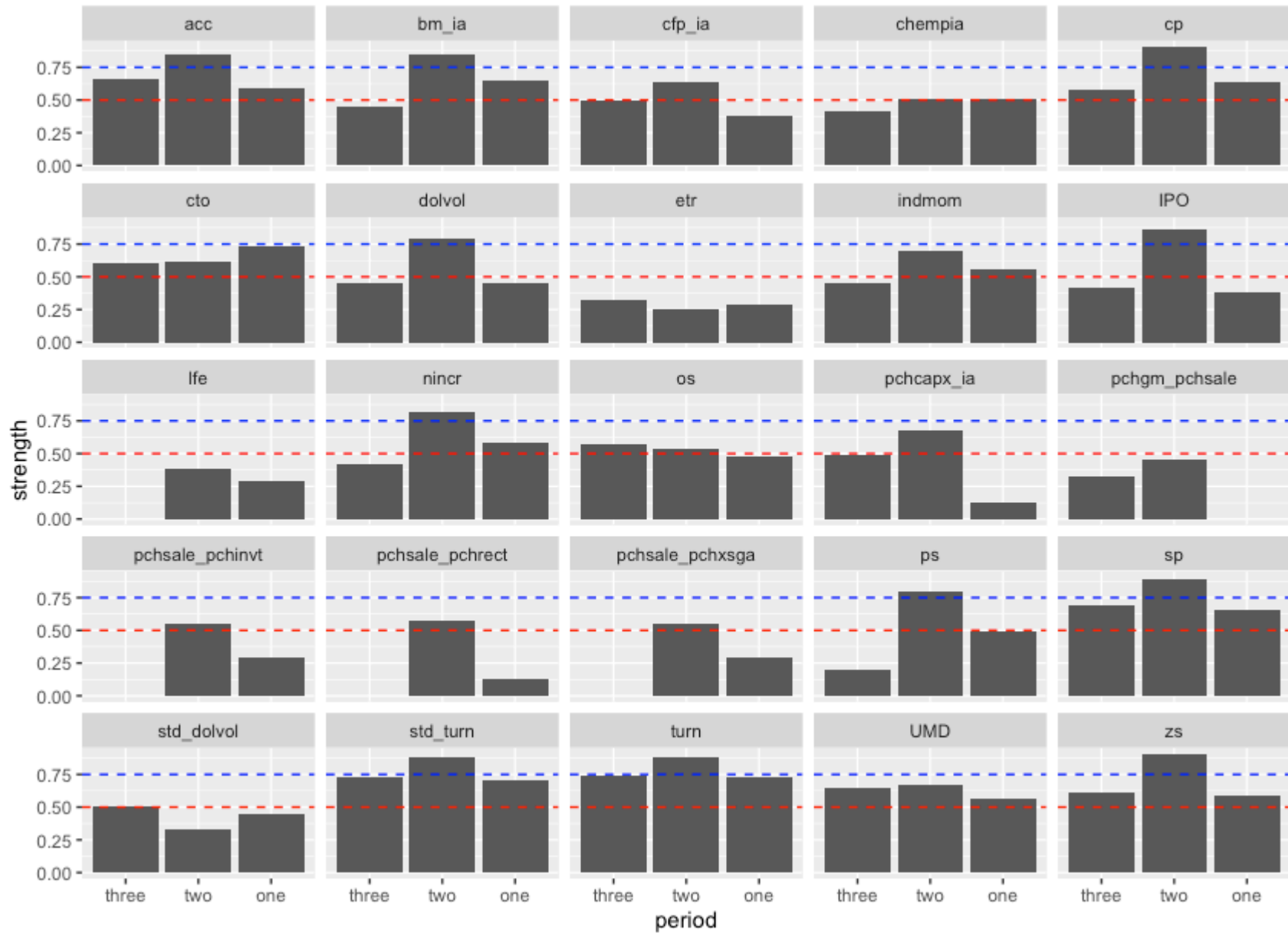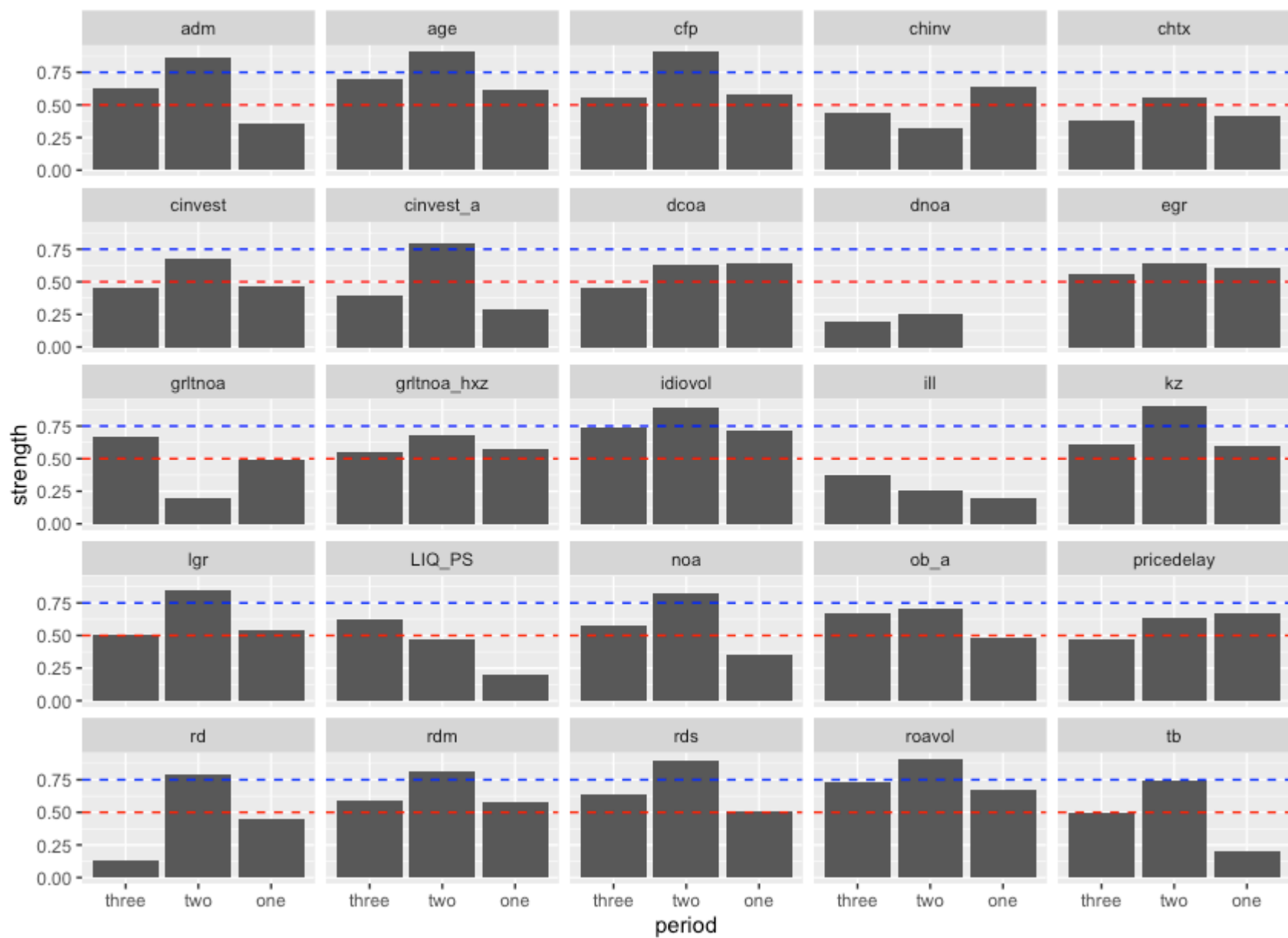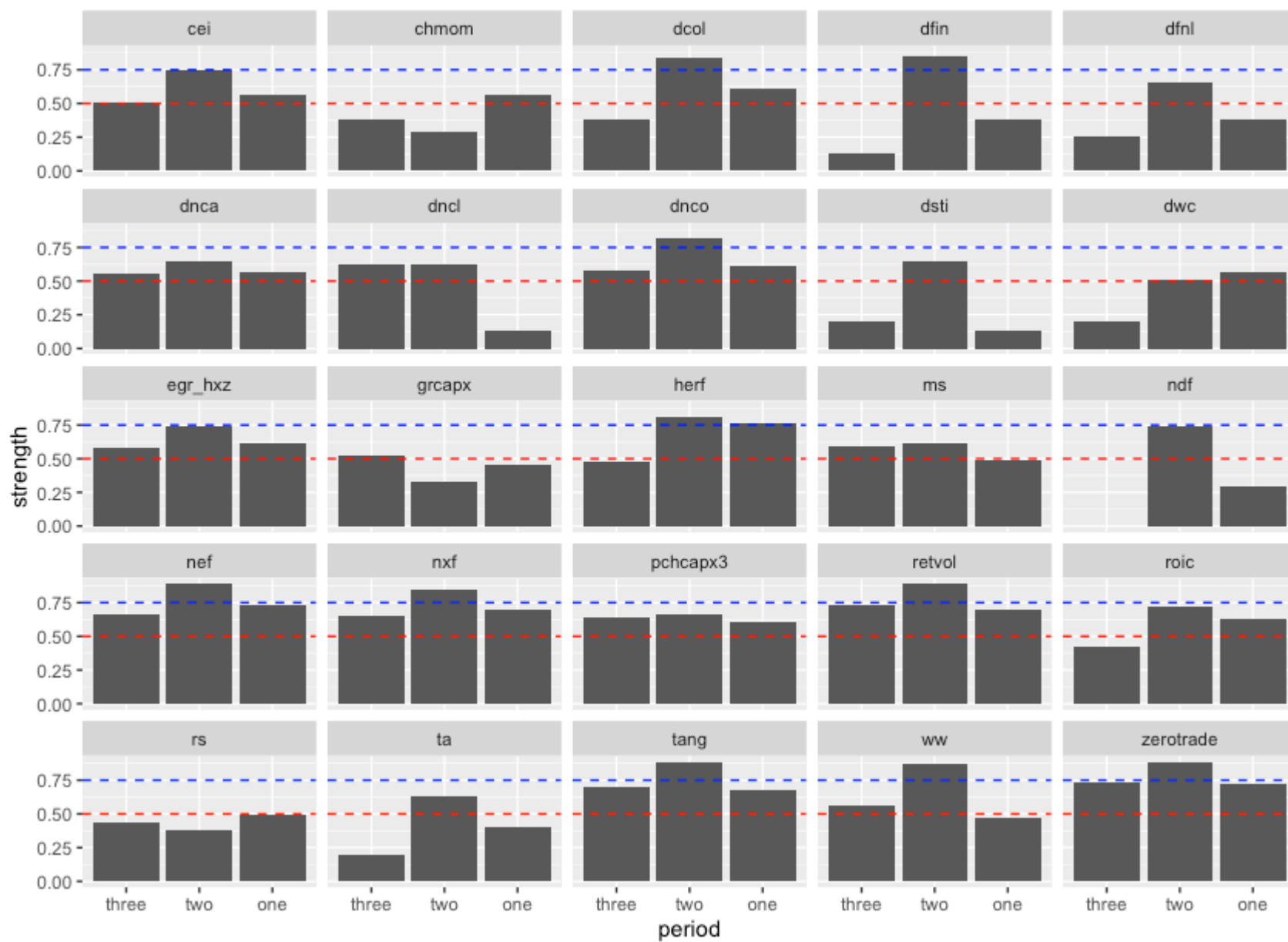
Notes: The figure compare the strength of factor using subsample from the thirty year data.. The x-axis indicates the subsample data set: three is third decade (January 2007 to December 2017), two is second decade (January 1997 to December 2007), and one is the first decade (January 1987 to December 1997). The red dash line and blue dash line represent 0.5 and 0.75 threshold value respectively.