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To my father, Gerrit (1930 - 2012)

Declaration

I certify that the thesis I have presented for examination for the MPhil/PhD degree of the London School of Economics and Political Science (LSE) is solely my own work other than where I have clearly indicated that it is the work of others (in which case the extent of any work carried out jointly by me and any other person is clearly identified in it).

I warrant that this authorisation does not, to the best of my belief, infringe the rights of any third party.

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CHAPTER 1

Is There Really Excess Comovement? Causal Evidence from FTSE 100 Index Turnover

1.1. Abstract

Stock returns seem to comove in excess of common news about stock fundamentals. This article examines if comovement really changes when stocks are added to or deleted from the FTSE 100 stock index, an event containing no news about stock fundamantals. I exploit the FTSE index balancing rule, which represents a natural experiment of exogenous index turnover. I find that random index turnover has no significant effect on comovement. I also show that index turnover can be non-random and introduce a selection bias that overstates the effect on comovement. It therefore appears that index turnover does not cause a change in comovement, but much rather the reverse effect exists: a change in comovement, possibly correlated with unobserved stock characteristics, seems to cause index turnover. My findings are consistent with the fundamentals-based hypothesis; rejections in the previous literature may be due to non-random index turnover.

1.2. Introduction

If investors are rational and there are no limits to arbitrage, then stocks should be valued fundamentally by discounted cash flows. Accordingly, the comovement of stock prices with each other should reflect common variation of news about stock fundamentals, such as future cash flows and discount rates. However, empirical research finds comovement in excess of the common variation of fundamental factors. In particular, events that contain no news about fundamentals seem to affect stock comovement. For example, a stock's comovement with an index increases when the stock is added to the index and decreases when it is deleted. Excess comovement is attributed to correlated trading patterns of investor groups: many institutions are forced to hold index stocks[1] and create a correlated demand shock when a stock is added to the index. Based on these findings, the empirical literature rejects the fundamentals-based hypothesis. However, an important concern with these studies is that they rely on variation in index membership that is unlikely to be random. The correlation between unobserved stock characteristics and index turnover cannot be ruled out. It is therefore difficult to establish whether or not index turnover really causes excess comovement.

I examine if stock index turnover causes a change in the comovement of stock and index returns through investors who allocate capital to categories defined by index membership. FTSE chooses index constituents with simple and transparent

[1]According to the Investment Management Association, in 2012 index tracker funds accounted for £71.7bn of savings in Britain, or 9.6 percent of the total money invested. Five years ago, this figure was £30bn.

rules, based on market capitalization rank. The FTSE 100 balancing rule generates index turnover that is random, after controlling for market capitalization rank. A change in comovement around these events identifies the causal effect of FTSE 100 index membership changes. Using this random sample, I find no significant effect on comovement. I also show that index turnover can be non-random and introduce a selection bias that exaggerates the effect on comovement. It therefore appears that index turnover does not cause a change in comovement, but much rather the reverse effect exists: a change in comovement, possibly correlated with unobserved stock characteristics, seems to cause index turnover.

When a stock is added to the FTSE 100, buying by institutions that are forced to hold the index for benchmarking and tracking purposes creates a correlated demand shock. Provided the covariance structure of fundamental factors is stationary, the fundamentals-based hypothesis predicts that such demand shocks do not affect the comovement of stock returns. However, finding a change in stock comovement upon index turnover alone is not sufficient to reject the fundamentals-based hypothesis. A change in the covariance structure of fundamental factors may cause index turnover and a contemporaneous change in stock comovement. This paper uses a random sample of FTSE 100 index turnover stocks that have a stationary covariance structure of fundamental factors and provides a causal test of the fundamentals-based hypothesis.

The FTSE index membership rules are straightforward. Every quarter all eligible U.K.-listed stocks are ranked by market capitalization. FTSE uses a banding policy in order to avoid frequent index turnover. Stocks must climb to rank 90 or better to be included in the FTSE 100 index, and drop to rank 111 or worse to be excluded. Generally, stocks within the rank band from 91 to 110 are not turned over.

The identification strategy uses three aspects of these rules: first, unobserved variables have no direct influence on index turnover. The sole stock characteristic that causes index turnover is market capitalization rank; therefore, only stock characteristics correlated with market capitalization rank affect index turnover. Second, the FTSE 100 must always have 100 constituents. Whenever the number of additions from banding differs from the number of deletions, FTSE must shift marginal stocks either into or out of the index in order to balance the total to 100 constituents. These marginal stocks are *always located inside the band*. Balancing of these stocks only depends on the rank of *other stocks outside the band* and is therefore plausibly random. Marginal stocks that would otherwise have remained just outside (inside) the index are therefore randomly added to (deleted from) it. Third, the banding policy generates a control group for empirical tests. After every quarterly review, there are 10 index and 10 non-index stocks within the market capitalization rank band on arbitrary and overlapping ranks. The characteristics of marginal stocks are random, conditional on market capitalization rank and prior index membership. Marginal stocks that experience no balancing index turnover are therefore a suitable control group for those that do.

Using the full sample of FTSE 100 index turnover stocks, I regress daily stock on index returns and show that comovement changes significantly around index turnover, a finding consistent with Barberis et al. (2005) analysis of the S&P 500. However, if only balancing index turnover is used in a difference-in-differences (DID) analysis with controls for market capitalization rank, then the effect of index turnover on comovement disappears. Similarly, a DID analysis that matches balancing index turnover with non-turnover stocks by rank also shows no significant effect on comovement. Non-random index turnover therefore appears to create a substantial selection bias that exaggerates the index turnover effect on comovement. However, random FTSE 100 balancing index turnover causes no significant change in comovement. I check these findings using turnover generated from a simulated placebo index. Non-random banding turnover from the placebo index creates a similar selection bias that disappears for random balancing. My results are therefore consistent with the fundamentals-based hypothesis and suggest that rejections in the previous literature may be due to non-random index turnover.

The previous literature maintains that excess comovement in stock returns is connected to trading patterns of investor groups. Delong et al. (1993), Pindyck and Rotemberg (1993), Vijh (1994) find that excess comovement can be explained by common liquidity shocks from the price impact of correlated investor demand. Antón and Polk (2013) find that common analyst coverage and stock ownership increases covariation. Index turnover is frequently used to analyze changes in comovement. Vijh (1994) and Barberis et al. (2005) find that S&P 500 index turnover changes comovement and relate it to investors trading index stocks together. FTSE membership rules are mechanical and fully transparent, but S&P constituents are determined by committee in confidential discussions. These papers therefore cannot rule out that S&P 500 index turnover is correlated with unobserved stock characteristics. Denis et al. (2003) suggest that S&P 500 index turnover causes stock characteristics to change. Antón (2010) finds that S&P selects stocks with increasing betas. Chen et al. (2014) find that S&P additions display high momentum. A closely related paper by Boyer (2011) claims that S&P/Barra stock labeling into investing style categories induces excess comovement. The S&P/Barra balancing index turnover is similar in that it depends on the difference in total market capitalization between two style categories. However, the single cut-off provides neither random index turnover nor a contemporaneous control group. In contrast, FTSE 100 banding creates both random balancing index turnover and a contemporaneous control group. Chang et al. (2013) focus on the Russell 1000 index and find excess comovement in index turnover. However, they use data from before Russell introduced a banding policy and therefore index turnover is unlikely to be random.

The rest of the paper is organized as follows: Section 1.3 explains the FTSE 100 index and balancing index turnover, Section 1.4 introduces the empirical tests, Section 1.5 describes the data, Section 1.6 presents the main results, Section 1.7 analyzes the robustness of the results, and Section 1.8 closes with a summary.

1.3. FTSE 100 Balancing Turnover

The main empirical challenge of measuring the effect of index turnover on comovement is to establish causality: does index turnover cause a change in stock comovement, or does a change in comovement cause an addition to or deletion from the index? Most previous studies simply assume that index turnover, which is usually caused by a change in market capitalization rank, is not correlated with stock characteristics. However, this assumption is questionable. I use the FTSE 100 banding policy to neutralize the non-random effect of market capitalization rank on index turnover. There may be some additional residual endogenous variation, but eliminating the correlation between market capitalization rank and index turnover alone explains almost all the "excess" comovement in the literature. This approach is a departure from most empirical work on comovement, which has failed to establish a causal effect. The rest of the section describes a natural experiment embedded in he FTSE 100 banding policy, which I use as a source of random variation in index turnover. The main goal is to motivate my identification assumption that FTSE 100 index balancing has a random effect on stock characteristics including comovement, when controlled for market capitalization rank.

1.3.1. The FTSE 100 Index

The Financial Times-Stock Exchange 100 Index (FTSE 100), informally called "Footsie", is the most widely used stock market index of the 100 largest firms listed in the U.K. The FTSE 250 index contains stocks too small for the FTSE 100. The FTSE 100 is more popular than the FTSE 250 as a benchmark for investors, and stocks promoted to the FTSE 100 receive a positive demand shock. Stocks moving between the FTSE 100 and the FTSE 250 are the main focus of this study.

FTSE membership is rule-based, fully transparent, and based on market capitalization rank. The FTSE 100 index constituents are reviewed quarterly[2] to ensure that the index remains representative of the largest firms listed in the market. FTSE uses a banding policy in order to avoid frequent membership changes.

There are four types of FTSE 100 index turnover:

(1) Ordinary banding turnover (Type-1). At each quarterly review, index membership changes when stocks leave the market capitalization rank band: stocks ranked 90 or better are included, and stocks ranked 111 or worse are excluded.

(2) Ordinary balancing turnover (Type-2) . If the number of Type-1 additions and deletions does not match, then FTSE shifts marginal stocks into or out of the index in order to balance the total to 100 constituents. If there are more Type-1 banding additions than deletions, then the lowest ranked

[2]Since 1993, on the Wednesday after the first Friday in March, June, September and December. The market capitalization rank is determined based on the closing prices of the quarterly review date. Constituent and weight changes are announced before the market opens the next day and usually become effective 12 calendar days after the review.

FTSE 100 stocks are deleted. If there are more Type-1 banding deletions than additions, then the highest ranked FTSE 250 stocks are added.

(3) Extraordinary turnover (Type-3). Membership changes between quarterly reviews if large new issues are added under fast entry rules, and stocks bound to be de-listed, including firms subject to unconditional takeover bids, are deleted from the index.

(4) Extraordinary balancing turnover (Type-4). For every extraordinary addition, FTSE deletes the lowest-ranked FTSE 100 member on the previous trading day. For every extraordinary deletion, FTSE adds the highest-ranked stock on the reserve list. The reserve list includes the six highest-ranked FTSE 250 members on the previous quarterly review date.

Figure 1.1 shows an example of ordinary FTSE 100 index turnover: Stock A climbs to rank 90 and is added to the index. Stocks C and D fall to rank 111 and 112, respectively, and are both deleted. Stock B has to be added in order to balance the index. Stocks A, C, and D are Type-1 banding index turnover because they move outside the market capitalization band. Stock B is the highest-ranked marginal stock inside the rank band and solely added to the index because the number of Type-1 deletions (i.e. Stocks C and D) exceeds the number of Type-1 additions (i.e. Stock A). Without the Type-1 mismatch Stock B would not be added to the FTSE 100 and remain in the FTSE 250. After the review, the rank band contains the 10 lowest-ranked FTSE 100 stocks, arbitrarily overlapping with the 10 highest-ranked FTSE 250 stocks. In a review these 20 marginal stocks are not turned over other than for balancing purposes.

1.3.2. Natural Experiment: Balancing Index Turnover

An important concern with many previous studies is, that they rely on time-series variation in market capitalization rank and, thus, in index membership, which is likely to be correlated with unobserved stock characteristics. Such index turnover is not random and can create a selection bias.

Figure 1.2 illustrates that index turnover is highest when markets are volatile (Dimson and Marsh (2001)). Moreover, comovement varies greatly over time: the largest change in comovement coincides with the Internet bubble and the subsequent crash, a period when expectations about stock fundamentals changed substantially (Table 1.5). It is therefore entirely possible that a change in unobserved stock characteristics causes a concurrent change in comovement and index turnover.

Whether or not there really is correlation between stock characteristics and index turnover depends on the specific rules governing index membership changes. For most popular indices, including the FTSE 100, market value is an important selection criterion. Marginal stocks just outside the index are therefore more likely to be added if they experience increasing market value, or equivalently high stock returns.

A consequence of market capitalization-based index membership rules is that additions have high recent stock returns. Figure 1.3 displays the cumulative abnormal returns[3] for additions to the FTSE 100 index by type (Figure 1.4 shows deletions). The chart demonstrates that Type-1 banding additions have a much higher pre-event stock price increase than Type-2 balancing additions. The stock price run-up, however, may occur because certain unobserved stock characteristics have changed, altering the stock's systematic risk and comovement (Antón (2010)). It therefore appears that index turnover does not cause a change in comovement, but much rather the reverse effect exists: a change in comovement, possibly correlated with unobserved stock characteristics, seems to cause index turnover.

In order to investigate the selection issue further, it is useful to analyze the relationship between the change in comovement and stock return performance. The change in comovement, commonly measured by stock beta, is most positive for additions, which outperformed the index in strong markets (Table 1.6). It therefore appears that stocks with a high increase in beta join the index when markets rally. This group includes firms that increase their systematic risk either by adding leverage or by entering riskier businesses when stock markets perform well. Stocks that experience a change in comovement therefore seem to self-select into the index.

[3]The event study analysis uses daily returns over a 250-day window ending (starting) 10 trading days before (after) the index turnover announcement date to estimate the pre-(post-)event single-factor market model. Normal returns for the pre-(post-)event are calculated using the pre-(post-) event estimates for alpha and beta.

The FTSE 100 balancing rule can be used to eliminate the self-selection effect. The FTSE rules generate Type-2 balancing index turnover that is driven by market capitalization changes of other stocks. Unlike Type-1 banding additions, Type-2 balancing index turnover is *not solely* caused by the stock's own stock price appreciation. However, in order to move to the top of the list of candidates for balancing additions, the stock must also experience a moderate run-up. Figure 1.3 shows that Type-2 balancing additions have also appreciated, but less than Type-1 banding additions. The moderate appreciation could nonetheless be caused by a change in fundamental stock characteristics concurrently to an increase in systematic risk.

However, since only market capitalization rank causes index turnover, controlling Type-2 balancing turnover for market capitalization rank eliminates the run-up bias. Conditional on rank, stocks located inside the FTSE 100 band are therefore assigned randomly.

In other words, Type-1 banding index turnover is *solely* caused by the stock's own return. Since fundamental stock characteristics, returns and market capitalization rank are likely to be correlated, stock fundamentals are also affect Type-1 banding index turnover. Such non-random index turnover usually results in a selection bias. In contrast, Type-2 balancing index turnover is *not only* caused by the stock's own return but *also* by other stocks. Since the partial effect of the stock's own return can be eliminated by controlling for market capitalization rank, conditional Type-2 balancing index turnover is random. Tests involving conditional Type-2 balancing index turnover are therefore unbiased and have a causal interpretation.

1.4. Tests

I present four models to test the effect of index turnover on comovement: a univariate regression, a bivariate regression, a standard difference-in-differences (DID) analysis, and a DID model with matching. The exposition starts with the two models used in the previous literature before moving to the two DID approaches that generate my main results.

1.4.1. Univariate Regression

Comovement is commonly measured by the regression coefficient beta of stock returns on index returns. A simple benchmark to evaluate the effect of index turnover on comovement is to separately estimate the stock's beta before and after each turnover event and to analyze the average change (Vijh (1994)). This difference is attractive because it provides an estimate of the index turnover effect on comovement that is not affected by the stocks' time-invariant characteristics. For each index turnover event, I estimate the univariate regression model

$$R_{i,t} = \alpha_i + \beta_i R_{100,t} + \epsilon_{i,t} \tag{1.1}$$

separately before and after each index turnover event, and note the change in beta $\Delta\beta_i$. $R_{i,t}$ is the stock's total return between date $t-1$ and t, and $R_{100,t}$ is the corresponding total adjusted return on the FTSE 100 index[4]. The daily returns are over a 250-day period ending (starting) 10 trading days before (after) the index turnover announcement date. The average change in beta is $\overline{\Delta\beta}$ and use I bootstrap simulations in order to compute heteroskedasticity-robust standard errors.

1.4.2. Bivariate Regression

A shortcoming of the univariate analysis is that it only measures the effect of entry into one index, *or* the exit from another, but not both simultaneously. Barberis et al. (2005) present a bivariate analysis to test the prediction that a stock moving from one index to another becomes less sensitive to the former and more sensitive to the latter. In the present analysis, the adjusted FT All Share index[5] serves as a proxy for non-FTSE 100 returns. For each index addition and deletion event, I estimate the bivariate regression

$$R_{i,t} = \alpha_i + \beta_{i,100} R_{100,t} + \beta_{i,AS} R_{AS,t} + \epsilon_{i,t} \tag{1.2}$$

[4]FTSE 100 returns are adjusted by excluding the market capitalization-weighted return of stock i after (before) the stock is added to (deleted from) the index.

[5]FTSE All Share returns are adjusted by excluding the market capitalization-weighted return of the FTSE 100 stocks and the return of stock i after (before) the stock is added to (deleted from) the index.

before and after each event, and record the change in betas, $\Delta\beta_{i,100}$, and $\Delta\beta_{i,AS}$. $R_{i,t}$ is the stock's total return, $R_{100,t}$ is the total adjusted return of the FTSE 100 index, and $R_{AS,t}$ is the total adjusted return of the FT All Share index, between time $t-1$ and t, respectively. The daily returns are again over a 250-day period ending (starting) 10 trading days before (after) the event announcement date. The average change in betas are $\overline{\Delta\beta_{100}}$ and $\overline{\Delta\beta_{AS}}$ and I again bootstrap in order to compute heteroskedasticity-robust standard errors.

1.4.3. Standard Difference-in-Differences

A potential drawback of the univariate and bivariate models is that they determine only the change in comovement for index turnover stocks, but do not control for contemporaneous changes in non-turnover stocks. These models cannot distinguish a change in comovement specific to index turnover stocks from a more general market trend in comovement. A common solution to this problem is using a standard difference-in-differences (DID) analysis relative to a control group. I estimate the effect of index turnover on the change in beta using the model

$$\beta_{i,q}^{Post} - \beta_{i,q}^{Pre} = \alpha_r + \alpha_q + \Delta\beta + \Delta\Delta\beta \text{ Turnover}_{i,q} + \varepsilon_{i,q}. \tag{1.3}$$

The left-hand side is the change in beta for firm i around the index review during quarter q. $\beta_{i,q}^{Pre}$ and $\beta_{i,q}^{Post}$ are the pre- and post-review estimates of beta from

Equation (1.1), collapsed into one observation. α_r is a rank-fixed effect and α_q is a quarter-fixed effect. The coefficient $\Delta\beta$ is the average change between post- and pre-review beta and the coefficient $\Delta\Delta\beta$ is the average change in beta between index turnover and non-turnover stocks. $\text{Turnover}_{i,q}$ is an indicator variable for FTSE 100 index turnover of stock i in quarter q. The control group for index additions are the FTSE 250 stocks, and for deletions I use the FTSE 100 stocks. The standard errors are heteroskedasticity-robust.

Specification (1.3) is first-differenced and eliminates any time-invariant unobserved heterogeneity of stocks. This is equivalent to including stock-fixed effects in a panel estimation and the estimates are therefore attained from the changes in the dependent variable for the same stock.

A key requirement in regression analyses of this type is that index turnover must be uncorrelated with the change in comovement. This assumption is challenging because unobserved stock characteristics correlated with comovement can indeed cause index turnover and introduce a selection bias.

The standard DID model uses market capitalization rank-fixed effects to control for non-randomness in index turnover. The joint null hypothesis is therefore firstly, that markets are weak-form efficient in that market capitalization is a sufficient statistic for index turnover, and secondly, that index turnover has no effect on comovement. The alternative hypothesis is either that markets are not weak-form efficient or that index turnover does have an effect on comovement.

1.4.4. Difference-in-Differences with Matching

Another remedy for non-random index turnover is matching. Within the FTSE rank band from 91 to 110, there is random overlap between Type-2 balancing index turnover stocks and non-turnover stocks, and also between index and non-index stocks. Type-2 balancing index turnover stocks can therefore be matched by rank with non-turnover stocks in order to eliminate the selection bias. I estimate the model

$$\beta_{i,q}^{Post} - \beta_{i,q}^{Pre} = \alpha_q + \Delta\beta + \Delta\Delta\beta \text{ Turnover}_{i,q} + \varepsilon_{i,q}. \tag{1.4}$$

by matching each Type-2 index turnover stock with a sample of non-turnover stocks with the same index membership status that fall into a defined market capitalization rank bandwidth. This method provides a consistent estimator for the causal effect of balancing index turnover on comovement because, conditional on market capitalization rank, index turnover is random and there is overlap (Wooldridge (2010), pp. 934).

This analysis uses matching by rank interval in order to control for residual non-randomness in Type-2 balancing index turnover. As before, the joint null hypothesis is that markets are weak-form efficient in that market capitalization is a sufficient statistic for index turnover and that index turnover has no effect on comovement. The alternative hypothesis is that markets are not weak-form efficient or index turnover does have an effect on comovement.

1.5. Data and Descriptive Statistics

Historical FTSE[6] index members from December 1985 through December 2012 are collected manually from Brumwell (2003) and FTSE. Index membership information is combined with daily stock prices from Compustat Global, LSPD and Datastream. All eligible stocks are ranked by market capitalization at the quarterly FTSE review dates in March, June, September, and December. An index turnover event occurs when a stock's addition to or deletion from the FTSE 100 is announced. Stocks with a history of less than 60 trading days before or after an index turnover event are excluded.

FTSE 100 index turnover falls into four categories: ordinary banding (Type-1), ordinary balancing (Type-2), extra-ordinary turnover (Type-3), and extra-ordinary balancing (Type-4).

[6] The sample includes the FTSE 100 and FTSE 250 index members, which jointly form the FTSE 350 index. The FTSE 250 started in October 1992. Prior to that date the 250 largest members of the FTSE All Share index were used.

Table 1.1 displays index turnover by type. This study focuses on Type-1 banding and Type-2 balancing index turnover[7]: Type-1 banding represents 169 additions and 186 deletions, and Type-2 balancing accounts for 59 additions and 71 deletions.

Figure 1.2 presents the evolution of Type-1 and Type-2 index turnover over time. Type-1 banding index turnover is clustered in periods of high stock market volatility. Type-2 balancing index turnover depends on the difference between Type-1 additions and deletions and appears more stable over time.

Table 1.2 shows the empirical probability of Type-2 balancing index turnover by market capitalization rank and index membership status. Market capitalization rank and past index membership fully determine Type-1 banding and Type-2 balancing index turnover. The difference between the number of Type-1 banding additions and deletions and the proximity to the rank band influence the likelihood of Type-2 balancing turnover. As expected, the closer the rank of non-index stocks to the cut-off at 91, the higher the probability of a Type-2 balancing index addition. Accordingly, the closer the rank of an index member to the threshold at 110, the greater the likelihood of a Type-2 balancing index deletion.

Table 1.3 displays the estimated probability of Type-2 balancing index turnover by lagged position. Position is the Type-1 imbalance required to shift a marginal

[7]Type 3 extra-ordinary turnover is excluded because most time-series are shorter than 60 trading days. I also exclude Type 4 extra-ordinary balancing turnover because it can be anticipated by investors and is therefore unlikely to be random: index additions are from a reserve list that is announced at the previous quarterly review.

stock into becomingType-2 index turnover. Position is used to estimate the likelihood of Type-2 index turnover based on information available on the day before the quarterly review. The table shows that the highest-ranked marginal non-index stock on the day before a review has a 20.6 percent chance of a Type-2 shift into the index, while the lowest-ranked marginal index stock faces a 26.5 percent probability of a Type-2 deletion from the index. Type-2 balancing turnover is negatively correlated with past index returns, indicating that balancing is less likely in volatile markets. After controlling for lagged rank, however, Type-2 index additions can no longer be predicted by lagged position or past index returns and appear to be random. Market capitalization rank therefore seems to be a sufficient statistic for Type-2 balancing additions.

Table 1.4 displays the characteristics for marginal stocks. Stocks experiencing Type-2 balancing index turnover should have the same characteristics as those that do not. In Panel A, Type-2 index additions display no significant difference in pre-event alpha, beta, and stock returns from other stocks in the FTSE rank band. However, Panel B shows that Type-2 deletions have a significantly lower alpha and stock return than other stocks in the band. The results in Panel A are consistent with conditional Type-2 balancing index additions being uncorrelated with stock characteristics.

Table 1.5 displays the change in comovement, measured by univariate change in stock beta, around FTSE 100 index turnover by period. The index turnover effect on beta is time-varying and is stronger for index additions than for deletions. It grows from insignificant, from 1986 to 1988, and reaches a peak between 1995 and 2000. For the years from 1988 to 2000 the change in beta is 0.349 for FTSE 100 index additions. The increase in and the level of excess comovement are consistent with the analysis of Barberis et al. (2005) for the S&P 500[8]. The S&P 500 and the FTSE 100 indices therefore seem to produce similar results.

The magnitude of the effect declines considerably during recent years. Table 1.5 shows that between 2007 and 2012, the change in beta falls to 0.181 for additions and becomes insignificant for deletions.

Table 1.6 shows the change in comovement for stock return performance groups. The change in beta is most positive for additions that outperformed the index in strong markets. When stock markets advance these stocks that outperform are the most likely to be added to the index. Stocks with high increases in beta are therefore added to the index when markets rally. Hence, stocks that experience a change in comovement seem to self-select into the index.

1.6. Main Results

1.6.1. Univariate Regression

The basic univariate model is an intuitive initial reference point.

Table 1.7 presents the univariate change in beta for index turnover by type. In Panel A, Column 2 indicates that all index additions have comparable levels of

[8] For S&P 500 index additions, the univariate change in beta is 0.067 from 1976 to 1987 and increases to 0.214 between 1988 and 2000.

beta before turnover. However, Column 4 shows that for additions the change in beta differs considerably: while Type-1 banding additions experience an increase by 0.313, Type-2 balancing additions display only a change of 0.111. Panel B shows no such difference for deletions: Type-1 banding deletions have a change in beta of -0.152 versus -0.156 for Type-2 balancing deletions.

Table 1.7, Panel A demonstrates that Type-2 balancing eliminates part of the selection problem and reduces the effect of index addition on beta by more than half. As explained in Section 1.3.2, the remainder is removed by conditioning on market capitalization rank. However, the univariate model uses only index turnover stocks and by design excludes stocks that experience no turnover. But eliminating the effect of market capitalization rank requires the use of all stocks, i.e. index turnover and non-index turnover stocks, because otherwise the effects of rank and of index turnover cannot be identified separately. Moreover, the univariate model does not account for general trends in the change in beta. The univariate estimates for Type-2 balancing index turnover are therefore likely to contain an upward (downward) bias resulting from the pre-event increase (decrease) in stock prices for index additions (deletions).

1.6.2. Bivariate Regression

The bivariate model permits a more powerful test of the fundamentals-based hypothesis. It tests simultaneously whether index turnover stocks become less sensitive to the index they leave and more sensitive to the index they join.

Table 1.8 displays the bivariate change in beta for index turnover by type. Columns 3 and 4 show that turnover stocks indeed experience increases in beta with the index they join, and the converse with the index they leave. Column 2 and 3 show that, consistent with Barberis et al. (2005)[9], the bivariate coefficients for the FTSE 100 are greater than the univariate coefficients. However, just as in the univariate model, the change in beta for the FTSE 100 differs by index turnover type: Type-1 banding additions show a significant increase by 0.581, while Type-2 balancing additions display only a change by 0.272. The change in beta is −0.556 for Type-1 banding deletions, whereas it is −0.397 for Type-2 balancing deletions.

Similar to in the univariate case, Type-2 balancing reduces the effect of index addition on beta by approximately half. The remainder cannot be eliminated by conditioning on rank because its effect on comovement is not separately identified. Furthermore, the bivariate model also fails to account for general trends in the change in beta. The bivariate tests are therefore also biased.

Summarizing the results so far, the uni- and bivariate models both show that using Type-2 balancing reduces the effect of index addition on beta by at least half. However, without a good control for market capitalization rank these models cannot eliminate the remaining selection bias and are likely to overstate the index turnover effect on comovement.

[9]Unlike Barberis et al. (2005), my results show no signs of collinearity between the adjusted returns on the FTSE 100 and the FT All Share indices.

1.6.3. Standard Difference-in-Differences

The standard differences-in-differences (DID) analysis estimates the change in beta specific to index turnover relative to the change for non-turnover stocks. Furthermore, the first-differencing on the left-hand-side of Equation (1.3) removes any time-invariant, unobserved heterogeneity of stocks. Moreover, controlling for market capitalization rank eliminates the remainder of the selection bias for Type-2 balancing index turnover.

Table 1.9 displays the difference in differences in beta for FTSE 100 index turnover. The coefficient $\Delta\beta$ is the average change between post- and pre-review beta and the coefficient $\Delta\Delta\beta$ is the average change in beta between index turnover and non-turnover stocks.

Panel A presents the standard DID results for index additions. Column 3 displays a change in beta for Type-1 banding additions of 0.252, and Column 5 shows that for Type-2 balancing additions the corresponding change in beta is 0.122. Quarter-fixed effects eliminate any change in beta that is common across all stocks during a quarter. Column 6 shows that the change in beta for Type-2 balancing additions increases to 0.158, indicating that such turnover coincides with a general decline in beta.

Panel B exhibits the equivalent results for index deletions. Column 3 shows a change in beta for Type-1 banding deletions of -0.0822, and Column 5 displays a change in beta of -0.0922 for Type-2 balancing deletions. The effect of index deletions again appears to be weaker than for additions.

To identify the causal effect of index turnover on comovement, the remaining selection bias in Type-2 balancing turnover must be removed. Since FTSE index turnover is determined exclusively by market capitalization rank, using rank-fixed effects makes index turnover ignorable (Wooldridge (2010), p. 908). Introducing rank-fixed effects eliminates the remaining selection bias for Type-2 index balancing stocks due to the overlap between index turnover and non-index turnover stocks within the FTSE rank band.

In Panel A, Column 7 demonstrates that the change in beta for Type-2 index balancing additions becomes insignificant when rank-fixed effects are added. Column 8 confirms that the change in beta for Type-2 index balancing additions is also insignificant when quarter-fixed effects are included.

Panel B shows a different result for index deletions. Column 7 and 8 demonstrate that Type-2 balancing and rank-fixed effects do not materially alter the effect of index deletion on comovement. Unlike index addition, FTSE 100 index deletion seems to have a weak negative causal effect on comovement.

Type-2 balancing index turnover controlled for market capitalization rank produces unbiased results. Table 1.9 shows that when this approach is used, the effect of FTSE 100 index addition on comovement disappears.

1.6.4. Difference-in-Differences with Matching

Matching is an alternative approach to eliminate the selection bias in index turnover. I take advantage of the overlap between Type-2 balancing stocks and non-turnover stocks within the rank band. Table 1.2 shows that Type-2 balancing additions are usually ranked between 91 and 100. The closest matches that remain outside the FTSE 100 are therefore FTSE 250 stocks ranked between 91 and 100. These stocks form the control group for index additions. For index deletions, the control group are FTSE 100 stocks ranked between 101 and 110.

Table 1.10 presents the difference in differences in beta for Type-2 balancing additions with matching. As before, $\Delta\beta$ is the average change between post- and pre-review beta and $\Delta\Delta\beta$ is the average change in beta between index turnover and non-turnover stocks.

For additions, Panel A, Column 1 shows an insignificant change in beta for Type-2 balancing with matching. In Column 2, quarter-fixed effects do not materially alter the result: the change in beta for Type-2 balancing additions with matching is 0.0685 and remains insignificant.

For deletions, Panel B, Columns 1 and 2 show that the change in beta is economically small and weakly significant.

Matching Type-2 balancing index turnover on market capitalization rank produces unbiased results. Consistent with the previous analysis, Table 1.10 demonstrates that this method equally eliminates the effect of FTSE 100 index addition on comovement.

In summary, both the standard DID controlled for market capitalization rank and the DID analysis with matching by rank produce consistent and unbiased results for Type-2 balancing index turnover. For both approaches the effect of FTSE 100 index addition on comovement is insignificant. Samples using non-random index turnover seem to create a substantial upward selection bias that overstates the index turnover effect on comovement. In the present sample of FTSE 100 index additions, I fail to find evidence for excess comovement and therefore cannot reject the fundamentals-based hypothesis of stock markets.

1.7. Robustness

1.7.1. Placebo Index Test

Section 1.6 demonstrates that non-random FTSE 100 Type-1 banding additions experience a significant increase in comovement, while random Type-2 balancing additions, conditional on market capitalization rank, do not. If the index rules are really the cause for non-random additions and the comovement effect observed in the FTSE 100, then applying these rules to a fictional placebo index should lead to the same effect. However, tests that show a significant change in comovement for additions to an index that does not exist are false rejections: the actual market should not react to a fictional index turnover event.

The placebo index is constructed of 200 members that are selected by market capitalization rank from the universe of FTSE 350 stocks. The Placebo 200 is rebalanced quarterly, equivalently to the FTSE 100: Stocks crossing either border of the market capitalization rank band from 181 to 220 are classified Type-1 banding index turnover; Type-2 balancing occurs when stocks inside the rank band are shifted into or out of the placebo index.

Table 1.11 presents the standard DID analysis of beta for Placebo 200 index turnover. The average difference between post- and pre-review beta is $\Delta\beta$, and between index turnover and non-turnover stocks is $\Delta\Delta\beta$. Panel A, Column 3 shows that the change in beta for Type-1 banding additions is 0.165 and significant. In contrast, Column 7 and 8 demonstrate that the Type-2 balancing turnover, conditional on market capitalization rank, has no significant effect on beta. Since the Placebo 200 is fictional and there is no actual index turnover; the Type-2 balancing sample correctly detects no effect, and the Type-1 banding sample incorrectly reports a change in beta that is caused by non-random sample selection. Panel B shows that the change in beta for all types of deletions is insignificant. Since the test correctly finds no effect for any sample, there seems to be no general selection issue for index deletions.

Table 1.12 shows the results for DID with matching for Type-2 balancing additions to the Placebo 200. The average difference between post- and pre-review beta is $\Delta\beta$, and between index turnover and non-turnover stocks is $\Delta\Delta\beta$. However, now the matching restricts the sample to stocks ranked between 181 and 220. As expected, the effect of addition to (Panel A) and deletion from (Panel B) the Placebo 200 index are insignificant, as in the case of the standard DID analysis.

The placebo index tests indicate that the observed change in comovement for index additions can be attributed to membership rules that generate a severe selection issue. In contrast, index deletions do not seem to create non-random samples.

1.7.2. Non-Synchronous Trading

A non-synchronous trading bias occurs when stocks trade infrequently and no longer incorporate market information in a timely fashion; this was first documented by Scholes and Williams (1977). In such cases, comovement simply increases because a stock is added to a major index and trades more frequently after inclusion. I use a test suggested by Vijh (1994) and adopted by Barberis et al. (2005) to test, if non-synchronous trading might also cause a change in comovement. The sample is divided into two parts: stocks whose average trading volume decreases after inclusion into the index, and those whose trading volume increases. If non-synchronous trading accounts for these results, then comovement should only increase for stocks whose trading volume also increases. Comovement for stocks whose trading volume decreases, however, should not be affected by a non-synchronous trading bias.

Table 1.13 accordingly presents a standard DID analysis of the change in beta for index turnover stocks whose trading volume decreases. Panel A displays the results for index additions. Columns 7 and 8 display that, after controlling for quarter and rank-fixed effects, the change in comovement for Type-2 additions with decreased trading remains insignificant .

Panel B exhibits index deletions. Similarly, Column 7 and 8 show that Type-2 deletions with decreased trading volume experience no significant change in comovement, after controlling for quarter and rank-fixed effects. The magnitude of the results for Type-2 index turnover in Table 1.13 resemble the estimates in Table 1.9, indicating that asynchronous trading does not materially affect the results.

1.7.3. Excluding Turnover Stocks from Index

If either index additions or deletions are highly correlated with each other at the time of turnover, then a bias could arise. The change in comovement would be overstated because a turnover stock would be highly correlated with all other stocks either added to or deleted from the index. The potential bias is therefore eliminated by excluding all turnover stocks from the FTSE 100 index around the review date. Since portfolio betas are weighted averages of stock beta, I adjust the previous beta estimates by subtracting the weighted betas of index turnover stocks.

Table 1.14 displays the difference in differences in beta for FTSE 100 index turnover, where turnover stocks are excluded from the index. Panel A presents index additions and Panel B deletions. Across the board the regression coefficients are very close to those in Table 1.9, indicating that correlation between index turnover stocks does not materially affect the results.

1.8. Conclusion

With noise-trader sentiment and market frictions, forced institutional buying creates a demand shock when stocks are added to or deleted from an index. These shocks could create comovement in stock returns that exceeds that explained by common news about fundamentals, like future cash flows and discount rates. If investors are rational and there are no limits to arbitrage, then events that contain no news about stock fundamentals should have no effect on comovement.

This paper takes advantage of the FTSE 100 index banding policy, which contains a balancing rule that, after controlling for market capitalization rank, generates random index turnover stocks. Using this sample of stocks, I find no significant effect of index turnover on comovement and, hence, cannot reject the fundamentals-based hypothesis.

These findings are in contrast to previous studies that observe a large effect of index turnover on comovement. However, these studies rely on variation in index membership that is unlikely to be random. In fact, I find that non-random turnover generated from a simulated placebo index generates a false effect on comovement. Therefore, index turnover does not cause a change in comovement, but the reverse effect exists: a change in comovement, possibly correlated with unobserved stock characteristics, causes index turnover. This non-randomness can create a substantial selection bias and lead to incorrect inferences.

Using random balancing index turnover is a method that holds promise for the analysis of asset markets phenomena where selection issues are a concern.

1.9. Figures

Figure 1.1: FTSE 100 Index Balancing Policy

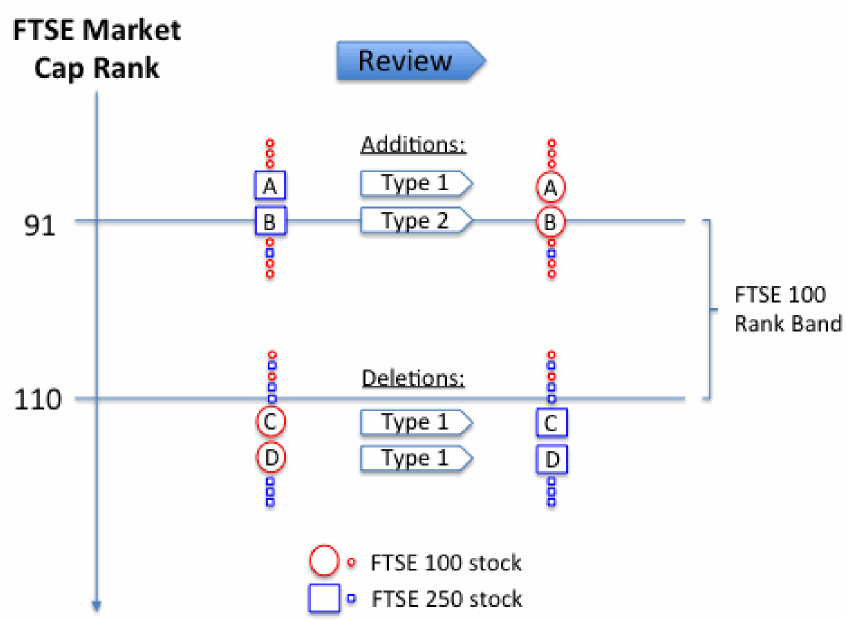

Figure 1.2: Additions to and Deletions from FTSE 100 Index by Quarter

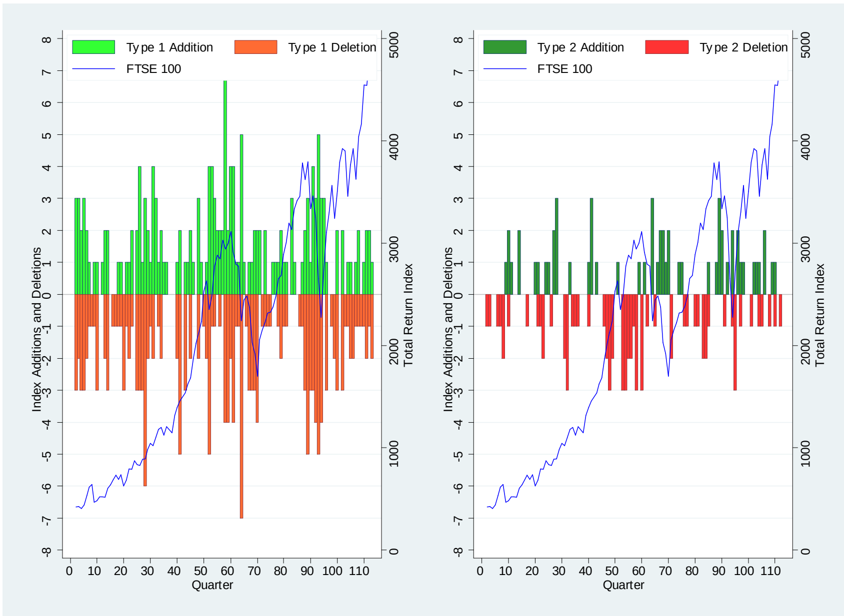

Figure 1.3: Cumulative Abnormal Returns for Additions to FTSE 100 Index

Figure 1.4: Cumulative Abnormal Returns for Deletions from FTSE 100 Index

Figure 1.5: Change in Average Beta of Stocks Added to the FTSE 100 Index

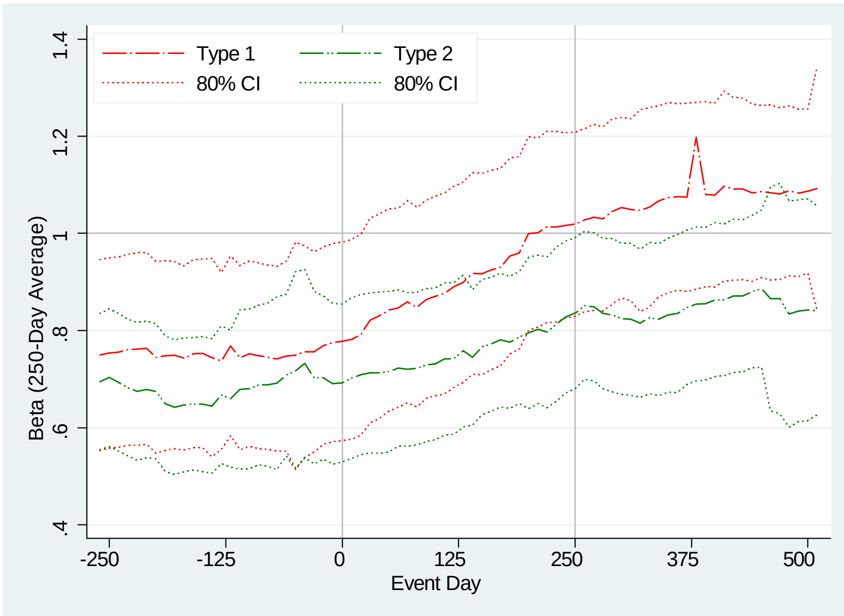

Figure 1.6: Change in Average Beta for Stocks Deleted from FTSE 100 Index

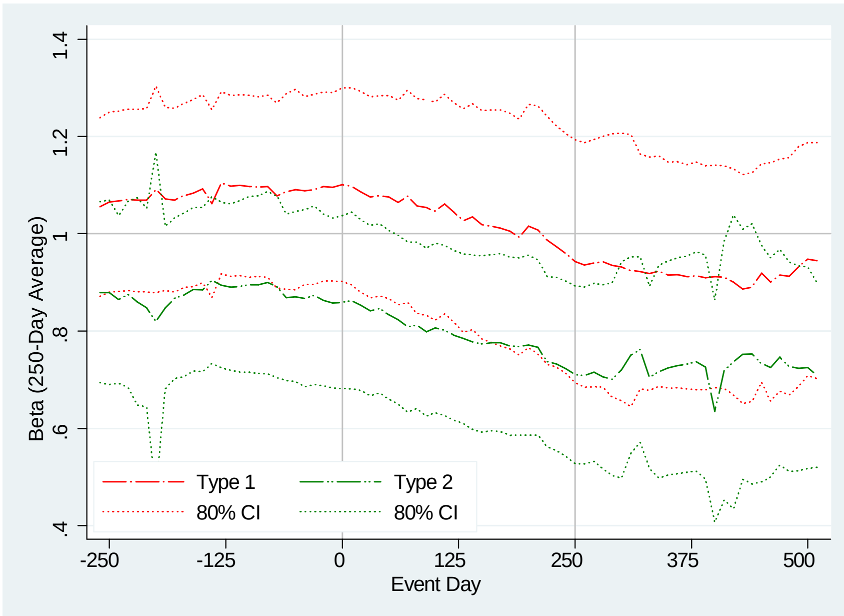

Figure 1.2

Additions to and deletions from the FTSE 100 index by quarter. The sample includes all FTSE 100 index members from December 1985 until December 2012. The sample also includes the FTSE 250 index members (from October 1992, and the 250 largest members of the FTSE All Share index for prior dates), which, together with the FTSE 100, form the FTSE 350 index. An index turnover event occurs when a stock is added to or deleted from the FTSE 100. The FTSE 100 index turnover information is combined with daily stock market information from Compustat Global and Datastream. Stock with less than 60 days of price data before and after the index turnover announcement date are excluded. At each quarterly review date, all eligible stocks are ranked by market capitalization according to FTSE rules and double-checked with LSPD data. Then, I classify index turnover into four categories: Type-1 are additions ranked 90 or better or deletions ranked 111 or worse at a quarterly review. Type-2 are ranked between 91 and 110 at a quarterly review but added to or deleted from the index for balancing purposes. Type-3 are extra-ordinary additions and deletions between quarterly review dates. Type-4 are additions from the reserve list to the index (deletions from the index) to balance extra-ordinary deletions (additions).

Figure 1.3

Cumulative abnormal returns of stocks added to the FTSE 100 index. The sample includes stocks added to from the FTSE 100 index between 1985 and 2012 which have sufficient data. For each stock i, I estimate the market model separately in the pre-and post-index turnover period $R_{i,t} = \alpha_i + \beta_i R_{100,t} + \epsilon_{i,t}$ where $R_{i,t}$ is the stock return between date $t-1$ and t, and $R_{100,t}$ is the corresponding return on the FTSE 100 index, with stock i excluded after being added to (before being deleted from) the index. The pre- and post-turnover estimation periods are [-260, -10] and [10, 260] trading days around the event. The stocks are grouped by index turnover type, as defined in Section 2.

Figure 1.4

Cumulative abnormal returns of stocks deleted from the FTSE 100 index. The sample includes stocks added to from the FTSE 100 index between 1985 and 2012 which have sufficient data. For each stock i, I estimate the market model separately in the pre- and post-index turnover period $R_{i,t} = \alpha_i + \beta_i R_{100,t} + \epsilon_{i,t}$ where $R_{i,t}$ is the stock return between date $t-1$ and t, and $R_{100,t}$ is the corresponding return on the FTSE 100 index, with stock i excluded after being added to (before being deleted from) the index. The pre- and post-turnover estimation periods are [-260, -10] and [10, 260] trading days around the event. The stocks are grouped by index turnover type, as defined in Section 2.

Figure 1.5

Change in average beta for stocks added to the FTSE 100 index. The sample includes stocks added to the FTSE 100 index between 1985 and 2012 which have sufficient data. For each stock i, I use a 250-day rolling estimate of the market model

$R_{i,t} = \alpha_i + \beta_i R_{100,t} + \epsilon_{i,t}$ where $R_{i,t}$ is the stock return between date $t-1$ and t, and $R_{100,t}$ is the corresponding return on the FTSE 100 index, with stock i excluded after being added to (before being deleted from) the index. The coefficients are averaged by index turnover type, as defined in Section 2. The bands represent the 10% and the 90% confidence intervals.

Figure 1.6

Change in average beta for stocks deleted from the FTSE 100 index. The sample includes stocks deleted from the FTSE 100 index between 1985 and 2012 which have sufficient data. For each stock i, I use a 250-day rolling estimate of the market model $R_{i,t} = \alpha_i + \beta_i R_{100,t} + \epsilon_{i,t}$ where $R_{i,t}$ is the stock return between date $t-1$ and t, and $R_{100,t}$ is the corresponding return on the FTSE 100 index, with stock i excluded after being added to (before being deleted from) the index. The coefficients are averaged by index turnover type, as defined in Section 2. The bands represent the 10% and the 90% confidence intervals.

1.10. Tables

Table 1.1: Sample Statistics for Stocks Added to and Deleted from FTSE 100 Index

The table presents the sample statistics for stocks added to and deleted from the FTSE 100 index by type. The sample includes all FTSE 100 index members from December 1985 until December 2012. The sample also includes the FTSE 250 index members (from October 1992, and the 250 largest members of the FTSE All Share index for prior dates), which, together with the FTSE 100, form the FTSE 350 index. An index turnover event occurs when a stock is added to or deleted from the FTSE 100. The FTSE 100 index turnover information is combined with daily stock market information from Compustat Global and Datastream. Stock with less than 60 days of price data before and after the index turnover announcement date are excluded. At each quarterly review date, all eligible stocks are ranked by market capitalization according to FTSE rules and double-checked with LSPD data. Then, I classify index turnover into four categories: Type 1 are additions ranked 90 or better or deletions ranked 111 or worse at a quarterly review. Type 2 are ranked between 91 and 110 at a quarterly review but added to or deleted from the index for balancing purposes. Type 3 are extra-ordinary additions and deletions between quarterly review dates. Type 4 are additions from the reserve list to the index (deletions from the index) to balance extra-ordinary deletions (additions).

	Type 1	Type 2	Type 3	Type 4	Total
Additions	169	59	12	71	311
Deletions	186	71	16	17	290

Table 1.2: Probability of Type 2 Addition to and Deletion from FTSE 100 Index by Rank

The table presents type 2 stocks added to and deleted from FTSE 100 Index by market capitalization rank.Type 2 are stocks used for quarterly balancing purposes, as defined in section 2. Market capitalization rank is determined at the quarterly review date and forms the basis for index additions and deletions. Type 2 stocks are always ranked 91 to 110. N is the number of additions (deletions) conditional on market capitalization rank and index non-membership (membership). Prob is the probability, defined as N divided by the total number of stocks with the same rank and membership status. SE is the sample standard error of Prob.

Rank	Additions			Deletions		
	N	Prob	SE	N	Prob	SE
91	11	0.647	0.051	0	0.000	0.005
92	13	0.520	0.054	0	0.000	0.005
93	10	0.417	0.049	0	0.000	0.005
94	7	0.226	0.042	0	0.000	0.005
95	5	0.156	0.037	0	0.000	0.005
96	3	0.097	0.029	0	0.000	0.005
97	3	0.100	0.029	0	0.000	0.005
98	1	0.024	0.018	0	0.000	0.005
99	2	0.051	0.024	0	0.000	0.005
100	3	0.054	0.029	0	0.000	0.005
101	1	0.018	0.018	1	0.020	0.015
102	0	0.000	0.005	3	0.060	0.024
103	0	0.000	0.005	2	0.044	0.020
104	0	0.000	0.005	11	0.275	0.043
105	0	0.000	0.005	5	0.132	0.031
106	0	0.000	0.005	5	0.227	0.031
107	0	0.000	0.005	8	0.286	0.038
108	0	0.000	0.005	8	0.364	0.038
109	0	0.000	0.005	10	0.455	0.042
110	0	0.000	0.005	18	0.750	0.052
91 - 110	59	0.057	0.000	71	0.067	0.000

Table 1.3: Probability of Type 2 Addition to and Deletion from FTSE 100 Index by Position

Marginal effects for pooled logistic regression of Type 2 FTSE 100 Index turnover on lagged rank, position, and index return. Estimation results of the model:

$$\text{Type 2 Turnover} = \alpha_r + \alpha_{Position} + \beta R_{100} + \epsilon$$

The dependent variable is an indicator of type 2 index turnover. α_r is a 1-day lagged market capitalization rank fixed effect. $\alpha_{Position}$ is a 1-day lagged position fixed effect, where position is an indicator variable for the minimum shift required to cause index turnover. Shift is the absolute difference between type 1 deletions and additions. R_{100} is the past quarter return of the FTSE 100 Index. Standard errors are reported in parenthesis. *, **, *** indicate statistical significance of point estimates at the 10%, 5%, and 1% levels, respectively.

Dep. Variable: Type 2 Turnover	Additions		Deletions	
Position				
<= 0	0.0135	-0.00673	0.0523***	0.0867**
	(0.0126)	(0.00636)	(0.0182)	(0.0372)
1	0.206***	-0.00357	0.265***	0.0148
	(0.0423)	(0.00645)	(0.0437)	(0.00973)
2	0.115***	-0.00394	0.165***	0.0106
	(0.0325)	(0.00602)	(0.0372)	(0.00766)
3	0.122***	0.00187	0.0753***	0.00597
	(0.0345)	(0.00733)	(0.0250)	(0.00564)
4	0.0325	-0.00301	0.0139	0.000253
	(0.0199)	(0.00630)	(0.0114)	(0.00344)
Index return	-0.210***	-0.0101	0.0994**	0.0594***
	(0.0735)	(0.0163)	(0.0386)	(0.0207)
Rank fixed effects	No	Yes	No	Yes

Table 1.4: Characteristics of FTSE Index Stocks Ranked from 91 to 110

The table presents characteristics for FTSE stocks ranked between 91 and 110 by market capitalization. Type 2 are stocks used for quarterly balancing purposes, as defined in section 2. Market capitalization rank is determined at the quarterly review date and forms the basis for index additions and deletions. Type 2 stocks are always ranked 91 to 110. To determine alpha and beta, I estimate the regression

$$R_{i,t} = \alpha_i + \beta_i R_{100,t} + \epsilon_{i,t}$$

where $R_{i,t}$ is the stock return between date $t-1$ and t, and $R_{100,t}$ is the corresponding return on the FTSE 100 index. The estimation period is [-260, -10] trading days before the event. Return is the averagre daily log return over the same period. Standard errors are clustered by event quarter and reported in parenthesis. The standard error for the change is from bootstrap simulations. $***$, $**$, and $*$ denote significant differences from zero at the 1%, 5%, and 10% levels in two-sided tests, respectively.

	Rank 91 - 110		
Variable	Type 2 Balancing	Not Type 2 Balancing	Difference
Panel A: Not FTSE 100 Members			
Beta	0.707	0.777	-0.0704
	(0.0463)	(0.0116)	(0.0477)
Alpha	0.000872	0.000764	0.000108
	(0.000137)	(0.0000350)	(0.000142)
Return	0.00100	0.00111	-0.000113
	(0.000169)	(0.0000398)	(0.000174)
Panel B: FTSE 100 Members			
Beta	0.845	0.905	-0.0596
	(0.0461)	(0.0118)	(0.0476)
Alpha	-0.000479	-0.000131	-0.000348**
	(0.000128)	(0.0000326)	(0.000133)
Return	-0.0000424	0.000242	-0.000285**
	(0.000136)	(0.0000381)	(0.000141)

Table 1.5: Change in Beta for Stocks Added to and Deleted from FTSE 100 Index - Univariate by Period

Changes in the regression coefficients of returns of stocks added to and deleted from the FTSE 100 index on returns of the FTSE 100 index. The sample includes stocks added to and deleted from the FTSE 100 index between 1985 and 2012 which have sufficient data. For each stock i, I estimate the regression separately before and after the turnover event, and determine the average change between the pre- and post-turnover regression coefficient, $\overline{\Delta\beta}$.

$$R_{i,t} = \alpha_i + \beta_i R_{100,t} + \epsilon_{i,t}$$

where $R_{i,t}$ is the stock return between date $t-1$ and t, and $R_{100,t}$ is the corresponding return on the FTSE 100 index, with stock i excluded after being added to (before being deleted from) the index to avoid self-correlation. The pre- and post-turnover estimation periods are [-260, -10] and [10, 260] trading days around the event. Standard errors are clustered by turnover event and reported in parenthesis. The standard error for the change is from bootstrap simulations. $***$, $**$, and $*$ denote significant differences from zero at the 1%, 5%, and 10% levels in two-sided tests.

		Univariate		
Sample	Number of Events	Pre-Event	Post-Event	Change
Additions				
1986 - 1988	27	0.949***	0.929***	-0.0206
		(0.0698)	(0.0856)	(0.105)
1989 - 1994	59	0.789***	0.915***	0.126**
		(0.0496)	(0.0540)	(0.0574)
1995 - 2000	79	0.484***	1.050***	0.566***
		(0.0444)	(0.0818)	(0.0729)
2001 - 2006	61	0.522***	0.869***	0.347***
		(0.0575)	(0.0461)	(0.0524)
2007 - 2012	74	0.841***	1.022***	0.181***
		(0.0388)	(0.0523)	(0.0535)
All	309	0.713***	0.981***	0.268***
		(0.0254)	(0.0305)	(0.0332)
1988 - 2000	147	0.661***	1.010***	0.349***
		(0.0407)	(0.0566)	(0.0623)
Deletions				
1986 - 1988	31	0.930***	0.920***	-0.00943
		(0.0608)	(0.0520)	(0.0739)
1989 - 1994	60	1.064***	0.932***	-0.132***
		(0.0500)	(0.0515)	(0.0502)
1995 - 2000	76	0.793***	0.522***	-0.271***
		(0.0615)	(0.0747)	(0.0518)
2001 - 2006	51	1.269***	1.001***	-0.268***
		(0.0922)	(0.0772)	(0.104)
2007 - 2012	63	1.062***	1.036***	-0.0256
		(0.0453)	(0.0567)	(0.0586)
All	290	1.050***	0.901***	-0.149***
		(0.0310)	(0.0342)	(0.0345)
1988 - 2000	144	0.924***	0.663***	-0.262***
		(0.0409)	(0.0542)	(0.0408)

Table 1.6: Change in Beta for Stocks Added to and Deleted from FTSE 100 Index - Univariate by Performance Group

Changes in the regression coefficients of returns of stocks added to and deleted from the FTSE 100 index on returns of the FTSE 100 index. The sample includes stocks added to and deleted from the FTSE 100 index between 1985 and 2012 which have sufficient data. For each stock i, I estimate the regression separately before and after the turnover event, and determine the average change between the pre- and post-turnover regression coefficient, $\overline{\Delta\beta}$.

$$R_{i,t} = \alpha_i + \beta_i R_{100,t} + \epsilon_{i,t}$$

where $R_{i,t}$ is the stock return between date $t-1$ and t, and $R_{100,t}$ is the corresponding return on the FTSE 100 index, with stock i excluded after being added to (before being deleted from) the index to avoid self-correlation. The pre- and post-turnover estimation periods are [-260, -10] and [10, 260] trading days around the event. The stocks are grouped according to quarterly index and stock returns: FTSE 100 top (bottom) denotes a quarterly index return above (below) the sample median, stock top (bottom) indicates a quarterly stock minus index return above (below) the median. Standard errors are clustered by turnover event and reported in parenthesis. The standard error for the change is from bootstrap simulations. $***$, $**$, and $*$ denote significant differences from zero at the 1%, 5%, and 10% levels in two-sided tests, respectively.

Sample	Number of Events	Univariate: Pre-Event	Univariate: Post-Event	Univariate: Change
Additions				
FTSE 100 return above median / relative stock return above median	77	0.814***	1.203***	0.389***
		(0.0593)	(0.0625)	(0.0653)
FTSE 100 return above median / relative stock return below median	77	0.697***	0.879***	0.183***
		(0.0580)	(0.0485)	(0.0535)
FTSE 100 return below median / relative stock return above median	77	0.659***	0.981***	0.322***
		(0.0512)	(0.0715)	(0.0746)
FTSE 100 return below median / relative stock return below median	78	0.720***	0.918***	0.198***
		(0.0386)	(0.0399)	(0.0454)
All	309	0.713***	0.981***	0.268***
		(0.0254)	(0.0305)	(0.0332)
Deletions				
FTSE 100 return above median / relative stock return above median	72	0.801***	0.804***	0.00273
		(0.0396)	(0.0530)	(0.0581)
FTSE 100 return above median / relative stock return below median	73	0.946***	0.687***	-0.259***
		(0.0587)	(0.0550)	(0.0517)
FTSE 100 return below median / relative stock return above median	72	0.928***	0.893***	-0.0355
		(0.0462)	(0.0616)	(0.0582)
FTSE 100 return below median / relative stock return below median	73	1.279***	1.051***	-0.229***
		(0.0579)	(0.0678)	(0.0773)
All	290	1.050***	0.901***	-0.149***
		(0.0310)	(0.0342)	(0.0345)

Table 1.7: Change in Beta for Stocks Added to and Deleted from FTSE 100 Index - Univariate by Type

Changes in the regression coefficients of returns of stocks added to and deleted from the FTSE 100 index on returns of the FTSE 100 index. The sample includes stocks added to and deleted from the FTSE 100 index between 1985 and 2012 which have sufficient data. For each stock i, I estimate the regression separately before and after the turnover event, and determine the average change between the pre- and post-turnover regression coefficient, $\overline{\Delta\beta}$.

$$R_{i,t} = \alpha_i + \beta_i R_{100,t} + \epsilon_{i,t}$$

where $R_{i,t}$ is the stock return between date $t-1$ and t, and $R_{100,t}$ is the corresponding return on the FTSE 100 index, with stock i excluded after being added to (before being deleted from) the index to avoid self-correlation. The pre- and post-turnover estimation periods are [-260, -10] and [10, 260] trading days around the event. The stocks are grouped by index turnover type, as defined in Section 2. Standard errors are clustered by turnover event and reported in parenthesis. The standard error for the change is from bootstrap simulations. $***$, $**$, and $*$ denote significant differences from zero at the 1%, 5%, and 10% levels in two-sided tests, respectively.

		Univariate		
Sample	Number of Events	Pre-Event	Post-Event	Change
Additions				
All	309	0.713***	0.981***	0.268***
		(0.0254)	(0.0305)	(0.0332)
Type 1 banding	170	0.734***	1.047***	0.313***
		(0.0363)	(0.0481)	(0.0484)
Type 2 balancing	58	0.716***	0.827***	0.111**
		(0.0501)	(0.0397)	(0.0513)
Deletions				
All	290	1.050***	0.901***	-0.149***
		(0.0310)	(0.0342)	(0.0345)
Type 1 banding	185	1.122***	0.970***	-0.152***
		(0.0389)	(0.0422)	(0.0441)
Type 2 balancing	72	0.870***	0.714***	-0.156***
		(0.0505)	(0.0622)	(0.0568)

Table 1.8: Change in Beta for Stocks Added to and Deleted from FTSE 100 Index - Bivariate by Type

Changes in the regression coefficients of returns of stocks added to and deleted from the FTSE 100 index on returns of the FTSE 100 index and the FT All Share index. The sample includes stocks added to and deleted from the FTSE 100 index between 1985 and 2012 which have sufficient data. For each stock i, the unvariate and bivariate models are estimated separately for the pre- and post-index turnover period. For the univariate model, I estimate the mean change between the pre- and post-turnover regression coefficient, $\overline{\Delta\beta}$. For the bivariate model, I estimate the mean change between the pre- and post-turnover regression coefficients $\overline{\Delta\beta_{100}}$ and $\overline{\Delta\beta_{AS}}$.

$$R_{i,t} = \alpha_i + \beta_i R_{100,t} + \epsilon_{i,t}$$

$$R_{i,t} = \alpha_i + \beta_{i,100} R_{100,t} + \beta_{i,AS} R_{AS,t} + \epsilon_{i,t}$$

where $R_{i,t}$ is the stock return between date $t-1$ and t, $R_{100,t}$ is the corresponding return on the FTSE 100 index, with stock i excluded after being added to (before being deleted from) the index to avoid self-correlation, $R_{AS,t}$ is the corresponding orthogonalized return on the FT All Share index (without stock i). The pre- and post-turnover estimation periods are [-260, -10] and [10, 260] trading days around the event. The stocks are grouped by index turnover type, as defined in Section 2. Standard errors are clustered by turnover event and reported in parenthesis. The standard error for the change is from bootstrap simulations. $***$, $**$, and $*$ denote significant differences from zero at the 1%, 5%, and 10% levels in two-sided tests, respectively.

		Univariate	Bivariate	
Sample	Number of Events	FTSE 100	FTSE 100	FT All Share
Additions				
All	309	0.268***	0.513***	-1.903***
		(0.0332)	(0.0413)	(0.291)
Type 1 Banding	170	0.313***	0.581***	-2.315***
		(0.0484)	(0.0608)	(0.460)
Type 2 Balancing	58	0.111**	0.272***	-0.790
		(0.0513)	(0.0758)	(0.514)
Deletions				
All	290	-0.149***	-0.480***	2.898***
		(0.0345)	(0.0611)	(0.514)
Type 1 Banding	185	-0.152***	-0.556***	3.738***
		(0.0441)	(0.0904)	(0.804)
Type 2 Balancing	72	-0.156***	-0.397***	1.477***
		(0.0568)	(0.0606)	(0.446)

Table 1.9: Change in Beta for Stocks Added to and Deleted from FTSE 100 Index

The difference in differences of stock beta for additions to and deleted from the FTSE 100 index by type. Estimation results of specification (3):

$$\hat{\beta}^{Post}_{i,q} - \hat{\beta}^{Pre}_{i,q} = \alpha_r + \alpha_q + \Delta\beta + \Delta\Delta\beta \cdot \text{Turnover}_{i,q} + \epsilon_{i,q}$$

$$R_{i,t} = \alpha_i + \beta_i R_{100,t} + \varepsilon_{i,t}$$

In the first equation, the left-hand side variable is the estimated change in beta for stock i around the index review date in quarter q. α_r is a market capitalization fixed effect, and α_q is a quarter fixed effect, $\Delta\beta$ is the average change in beta around quarterly index reviews, $\Delta\Delta\beta$ is the average change in beta around index turnover events, and $\text{Turnover}_{i,q}$ is a dummy variable for turnover of stock i to the index in quarter q. In the second equation, for each stock i and quarter q the pre- and post-review betas are estimated from separate regressions of the daily return of stock i on the corresponding return of the FTSE 100 index (excluding stock i). The estimation periods are [-260, -10] and [10, 260] trading days around the quarterly index review date. In Panel A, the sample is restricted to stocks that are not members of the FTSE 100 index prior to the quarterly index review. In Panel B, the sample is restricted to stocks that are members of the FTSE 100 index prior to the quarterly index review. The stocks are grouped by index turnover type, as defined in Section 2. Heteroskedasticity robust standard errors are clustered by stock i and reported in parenthesis. *, **, *** indicate statistical significance of point estimates at the 10%, 5%, and 1% levels, respectively.

Dep. Variable: $(\hat{\beta}^{Post} - \hat{\beta}^{Pre})$	All		Type 1		Type 2			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: Additions								
$\Delta\Delta\beta$	0.211***	0.217***	0.252***	0.247***	0.122***	0.158***	0.0151	0.0674
	(0.0243)	(0.0232)	(0.0360)	(0.0342)	(0.0373)	(0.0367)	(0.0550)	(0.0503)
$\Delta\beta$	0.00541***	0.0675***	0.00609***	0.0677***	0.00723***	0.0686***	0.00593***	0.0671***
	(0.00192)	(0.0175)	(0.00192)	(0.0175)	(0.00192)	(0.0175)	(0.00196)	(0.0176)
Panel B: Deletions								
$\Delta\Delta\beta$	-0.116***	-0.118***	-0.0822**	-0.0924***	-0.0922***	-0.0772**	-0.110**	-0.0883**
	(0.0249)	(0.0242)	(0.0323)	(0.0314)	(0.0350)	(0.0335)	(0.0465)	(0.0444)
$\Delta\beta$	0.00573**	-0.0355*	0.00410	-0.0368*	0.00335	-0.0368*	0.00412	-0.0371*
	(0.00291)	(0.0203)	(0.00291)	(0.0205)	(0.00292)	(0.0205)	(0.00305)	(0.0205)
Rank fixed effects	No	No	No	No	No	No	Yes	Yes
Quarter fixed effects	No	Yes	No	Yes	No	Yes	No	Yes

Table 1.10: Change in Beta for Stocks Added to and Deleted from the FTSE 100 Index - Matching

The difference in differences of stock beta for additions to and deleted from the FTSE 100 index by type with matching by market capitalization rank. Estimation results of specification (3):

$$\hat{\beta}_{i,q}^{Post} - \hat{\beta}_{i,q}^{Pre} = \alpha_q + \Delta\beta + \Delta\Delta\beta \cdot \text{Turnover}_{i,q} + \epsilon_{i,q}$$

$$R_{i,t} = \alpha_i + \beta_i R_{100,t} + \varepsilon_{i,t}$$

In the first equation, the left-hand side variable is the estimated change in beta for stock i around the index review date in quarter q. α_q is a quarter fixed effect, $\Delta\beta$ is the average change in beta around quarterly index reviews, $\Delta\Delta\beta$ is the average change in beta around index turnover events, and $\text{Turnover}_{i,q}$ is a dummy variable for turnover of stock i to the index in quarter q. In the second equation, for each stock i and quarter q the pre- and post-review betas are estimated from separate regressions of the daily return of stock i on the corresponding return of the FTSE 100 index (excluding stock i). The estimation periods are [-260, -10] and [10, 260] trading days around the quarterly index review date. In Panel A, the sample is restricted to stocks that are ranked between 91 and 100, and not members of the FTSE 100 index prior to the quarterly index review. In Panel B, the sample is restricted to stocks that are ranked between 101 and 110, and members of the FTSE 100 index prior to the quarterly index review. The stocks are grouped by index turnover type, as defined in Section 2. Heteroskedasticity robust standard errors are clustered by stock i and reported in parenthesis. $*$, $**$, $***$ indicate statistical significance of point estimates at the 10%, 5%, and 1% levels, respectively.

Dep. Variable: $(\hat{\beta}^{Post} - \hat{\beta}^{Pre})$	Type 2	
	(1)	(2)
Panel A: Additions		
$\Delta\Delta\beta$	0.0331	0.0685
	(0.0437)	(0.0523)
$\Delta\beta$	0.0934***	0.131
	(0.0216)	(0.143)
Panel B: Deletions		
$\Delta\Delta\beta$	-0.0935**	-0.0801*
	(0.0402)	(0.0479)
$\Delta\beta$	0.00460	0.136
	(0.0198)	(0.161)
Quarter fixed effects	No	Yes

Table 1.11: Change in Beta for Stocks Added to and Deleted from Placebo 200 Index

The difference in differences of stock beta for additions to and deleted from the Placebo 200 index by type. Estimation results of specification (3):

$$\hat{\beta}^{Post}_{i,q} - \hat{\beta}^{Pre}_{i,q} = \alpha_r + \alpha_q + \Delta\beta + \Delta\Delta\beta \cdot \text{Turnover}_{i,q} + \epsilon_{i,q}$$

$$R_{i,t} = \alpha_i + \beta_i R_{200,t} + \varepsilon_{i,t}$$

In the first equation, the left-hand side variable is the estimated change in beta for stock i around the index review date in quarter q. α_r is a market capitalization fixed effect, and α_q is a quarter fixed effect, $\Delta\beta$ is the average change in beta around quarterly index reviews, $\Delta\Delta\beta$ is the average change in beta around index turnover events, and $\text{Turnover}_{i,q}$ is a dummy variable for turnover of stock i to the index in quarter q. In the second equation, for each stock i and quarter q the pre- and post-review betas are estimated from separate regressions of the daily return of stock i on the corresponding return of the Placebo 200 index (excluding stock i). The estimation periods are [-260, -10] and [10, 260] trading days around the quarterly index review date. In Panel A, the sample is restricted to stocks that are not members of the Placebo 200 index prior to the quarterly index review. In Panel B, the sample is restricted to stocks that are members of the Placebo 200 index prior to the quarterly index review. The stocks are grouped by index turnover type, as defined in Section 2. Heteroskedasticity robust standard errors are clustered by stock i and reported in parenthesis. *, **, *** indicate statistical significance of point estimates at the 10%, 5%, and 1% levels, respectively.

Dep. Variable: $(\hat{\beta}^{Post} - \hat{\beta}^{Pre})$	All		Type 1		Type 2			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: Additions								
$\Delta\Delta\beta$	0.0925***	0.0931***	0.157***	0.146***	0.0124	0.0274	-0.0340	-0.000123
	(0.0221)	(0.0208)	(0.0364)	(0.0342)	(0.0196)	(0.0188)	(0.0328)	(0.0308)
$\Delta\beta$	-0.00433*	0.128***	-0.00417*	0.128***	-0.00223	0.130***	-0.00557**	0.127***
	(0.00255)	(0.0401)	(0.00253)	(0.0402)	(0.00256)	(0.0401)	(0.00273)	(0.0400)
Panel B: Deletions								
$\Delta\Delta\beta$	-0.0189	-0.0235	-0.0255	-0.0309	0.0221	0.0217	0.0201	0.0286
	(0.0256)	(0.0255)	(0.0294)	(0.0292)	(0.0295)	(0.0287)	(0.0368)	(0.0364)
$\Delta\beta$	0.00509**	0.0201	0.00515**	0.0200	0.00469**	0.0196	0.00364	0.0182
	(0.00222)	(0.0235)	(0.00222)	(0.0235)	(0.00224)	(0.0235)	(0.00236)	(0.0234)
Rank fixed effects	No	No	No	No	No	No	Yes	Yes
Quarter fixed effects	No	Yes	No	Yes	No	Yes	No	Yes

Table 1.12: Change in Beta for Stocks Added to and Deleted from the Placebo 200 Index - Matching

The difference in differences of stock beta for additions to and deleted from the Placebo 200 index by type with matching by market capitalization rank. Estimation results of specification (3):

$$\hat{\beta}_{i,q}^{Post} - \hat{\beta}_{i,q}^{Pre} = \alpha_q + \Delta\beta + \Delta\Delta\beta \cdot \text{Turnover}_{i,q} + \epsilon_{i,q}$$

$$R_{i,t} = \alpha_i + \beta_i R_{200,t} + \varepsilon_{i,t}$$

In the first equation, the left-hand side variable is the estimated change in beta for stock i around the index review date in quarter q. α_q is a quarter fixed effect, $\Delta\beta$ is the average change in beta around quarterly index reviews, $\Delta\Delta\beta$ is the average change in beta around index turnover events, and $\text{Turnover}_{i,q}$ is a dummy variable for turnover of stock i to the index in quarter q. In the second equation, for each stock i and quarter q the pre- and post-review betas are estimated from separate regressions of the daily return of stock i on the corresponding return of the Placebo 200 index (excluding stock i). The estimation periods are [-260, -10] and [10, 260] trading days around the quarterly index review date. In Panel A, the sample is restricted to stocks that are ranked between 91 and 100, and not members of the Placebo 200 index prior to the quarterly index review. In Panel B, the sample is restricted to stocks that are ranked between 101 and 110, and members of the Placebo 200 index prior to the quarterly index review. The stocks are grouped by index turnover type, as defined in Section 2. Heteroskedasticity robust standard errors are clustered by stock i and reported in parenthesis. $*$, $**$, $***$ indicate statistical significance of point estimates at the 10%, 5%, and 1% levels, respectively.

Dep. Variable: $(\hat{\beta}^{Post} - \hat{\beta}^{Pre})$	Type 2	
	(1)	(2)
Panel A: Additions		
$\Delta\Delta\beta$	-0.0320	0.0217
	(0.0333)	(0.0361)
$\Delta\beta$	0.0372	-0.0517
	(0.0232)	(0.347)
Panel B: Deletions		
$\Delta\Delta\beta$	0.0199	0.0285
	(0.0369)	(0.0370)
$\Delta\beta$	0.0131	0.203
	(0.0110)	(0.148)
Quarter fixed effects	No	Yes

Table 1.13: Change in Beta for Stocks Added to FTSE 100 Index with Decreased Trading

The difference in differences of stock beta for additions to and deleted from the FTSE 100 index by type. Estimation results of specification (3):

$$\hat{\beta}_{i,q}^{Post} - \hat{\beta}_{i,q}^{Pre} = \alpha_r + \alpha_q + \Delta\beta + \Delta\Delta\beta \cdot \text{Turnover}_{i,q} + \epsilon_{i,q}$$

$$R_{i,t} = \alpha_i + \beta_i R_{100,t} + \varepsilon_{i,t}$$

In the first equation, the left-hand side variable is the estimated change in beta for stock i around the index review date in quarter q. α_r is a market capitalization fixed effect, and α_q is a quarter fixed effect, $\Delta\beta$ is the average change in beta around quarterly index reviews, $\Delta\Delta\beta$ is the average change in beta around index turnover events, and $\text{Turnover}_{i,q}$ is a dummy variable for turnover of stock i to the index in quarter q. In the second equation, for each stock i and quarter q the pre- and post-review betas are estimated from separate regressions of the daily return of stock i on the corresponding return of the FTSE 100 index (excluding stock i). The estimation periods are [-260, -10] and [10, 260] trading days around the quarterly index review date. In Panel A, the sample is restricted to stocks that are members of the FTSE 250 prior to the quarterly index review. In Panel B, the sample is restricted to stocks that are members of the FTSE 100 prior to the quarterly index review. The stocks are grouped by index turnover type, as defined in Section 2. Heteroskedasticity robust standard errors are clustered by stock i and reported in parenthesis. *, **, *** indicate statistical significance of point estimates at the 10%, 5%, and 1% levels, respectively.

Dep. Variable: $(\hat{\beta}^{Post} - \hat{\beta}^{Pre})$	All		Type 1		Type 2			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: Additions								
$\Delta\Delta\beta$	0.179***	0.207***	0.220***	0.242***	0.128**	0.171**	0.0147	0.102
	(0.0441)	(0.0422)	(0.0605)	(0.0568)	(0.0650)	(0.0786)	(0.0937)	(0.0928)
$\Delta\beta$	0.0108***	0.0200	0.0112***	0.0198	0.0126***	0.0210	0.0112***	0.0183
	(0.00366)	(0.0292)	(0.00366)	(0.0292)	(0.00367)	(0.0292)	(0.00374)	(0.0294)
Panel B: Deletions								
$\Delta\Delta\beta$	-0.0992***	-0.109***	-0.0881*	-0.111**	-0.102**	-0.0933*	-0.0860	-0.0975
	(0.0350)	(0.0360)	(0.0476)	(0.0489)	(0.0512)	(0.0490)	(0.0677)	(0.0646)
$\Delta\beta$	-0.00207	-0.0538*	-0.00332	-0.0552*	-0.00433	-0.0540*	-0.00201	-0.0526*
	(0.00539)	(0.0304)	(0.00535)	(0.0303)	(0.00536)	(0.0304)	(0.00563)	(0.0307)
Rank fixed effects	No	No	No	No	No	No	Yes	Yes
Quarter fixed effects	No	Yes	No	Yes	No	Yes	No	Yes

Table 1.14: Change in Beta for Stocks Added to and Deleted from FTSE 100 - Turnover Stocks Excluded from Index

The difference in differences of stock beta for additions to and deleted from the FTSE 100 index by type. Estimation results of specification (3):

$$\hat{\beta}_{i,q}^{Post} - \hat{\beta}_{i,q}^{Pre} = \alpha_r + \alpha_q + \Delta\beta + \Delta\Delta\beta \cdot \text{Turnover}_{i,q} + \epsilon_{i,q}$$

$$R_{i,t} = \alpha_i + \beta_i R_{100,t} + \varepsilon_{i,t}$$

In the first equation, the left-hand side variable is the estimated change in beta for stock i around the index review date in quarter q. α_r is a market capitalization fixed effect, and α_q is a quarter fixed effect, $\Delta\beta$ is the average change in beta around quarterly index reviews, $\Delta\Delta\beta$ is the average change in beta around index turnover events, and $\text{Turnover}_{i,q}$ is a dummy variable for turnover of stock i to the index in quarter q. In the second equation, for each stock i and quarter q the pre- and post-review betas are estimated from separate regressions of the daily return of stock i on the corresponding return of the FTSE 100 index (excluding stock i, and any stock added to or deleted from the index in quarter q). The estimation periods are [-260, -10] and [10, 260] trading days around the quarterly index review date. In Panel A, the sample is restricted to stocks that are not members of the FTSE 100 index prior to the quarterly index review. In Panel B, the sample is restricted to stocks that are members of the FTSE 100 index prior to the quarterly index review. The stocks are grouped by index turnover type, as defined in Section 2. Heteroskedasticity robust standard errors are clustered by stock i and reported in parenthesis. *, **, *** indicate statistical significance of point estimates at the 10%, 5%, and 1% levels, respectively.

Dep. Variable: $(\hat{\beta}^{Post} - \hat{\beta}^{Pre})$	All		Type 1		Type 2			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A: Additions								
$\Delta\Delta\beta$	0.209***	0.216***	0.250***	0.246***	0.121***	0.159***	0.0142	0.0679
	(0.0242)	(0.0231)	(0.0358)	(0.0340)	(0.0373)	(0.0367)	(0.0550)	(0.0503)
$\Delta\beta$	0.00475**	0.0670***	0.00542***	0.0673***	0.00655***	0.0681***	0.00526***	0.0666***
	(0.00192)	(0.0175)	(0.00192)	(0.0175)	(0.00192)	(0.0175)	(0.00196)	(0.0176)
Panel B: Deletions								
$\Delta\Delta\beta$	-0.118***	-0.119***	-0.0854**	-0.0944***	-0.0915***	-0.0765**	-0.109**	-0.0874**
	(0.0253)	(0.0244)	(0.0332)	(0.0320)	(0.0350)	(0.0334)	(0.0466)	(0.0443)
$\Delta\beta$	0.00470	-0.0360*	0.00308	-0.0373*	0.00227	-0.0374*	0.00303	-0.0376*
	(0.00291)	(0.0203)	(0.00291)	(0.0205)	(0.00292)	(0.0205)	(0.00306)	(0.0205)
Rank fixed effects	No	No	No	No	No	No	Yes	Yes
Quarter fixed effects	No	Yes	No	Yes	No	Yes	No	Yes

CHAPTER 2

Do Chair Independence and Succession Planning Influence CEO Turnover?

2.1. Abstract

There is widespread concern that corporate boards do not sufficiently punish chief executive officers (CEOs) for poor performance. Board effectiveness in ousting CEOs may be affected by chief executives who also chair the board or influence the succession planning process. This article explores how chair independence and succession planning influence CEO turnover. I address endogeneity issues using a trinomial probit regression system of CEO turnover that models chair independence and succession planning endogenously.

I find that succession planning has a larger positive effect on CEO turnover than suggested by previous research. I also find that chair independence actually reduces the probability of succession planning because it creates a friction with the common relay succession model. There is a negative overall effect of chair independence on CEO turnover.

2.2. Introduction

There is widespread concern that corporate boards do not sufficiently punish chief executive officers (CEOs) for poor performance. This may be caused by CEO entrenchment where boards retain chief executives who shareholders would rather see fired. Board effectiveness in ousting CEOs may be affected by chief executives who also chair the board (CEO duality) or influence the succession planning process. Empirical research shows that CEO turnover is less sensitive to poor stock returns when firms have dual CEO-chairs (Dahya et al. (2002), Goyal and Park (2002)), and that the likelihood of turnover decreases when firms have no succession plan and no heir apparent is available (Naveen (2006)). Accordingly, corporate governance rules were established to encourage boards to separate the chief executive role from the chairperson[1] and to introduce succession planning procedures[2]. However, an important issue with these studies is that they generally rely on variation in corporate decision variables, which is unlikely to be random.

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[1]On December 16, 2009, the SEC announced a rule (SEC Release No. 33-9089; 34-61175; http://www.sec.gov/rules/final/2009/33-9089.pdf) that requires listed companies to disclose the board leadership structure, including whether the firm has combined the CEO and chairperson position, and explain why such a leadership structure is appropriate.

[2]On October 27, 2009, the SEC eliminated the ordinary business exclusion defense (SEC Release No. 33-9089; 34-61175; http://www.sec.gov/rules/final/2009/33-9089.pdf) employed by firms unable or unwilling to disclose their CEO succession planning process to shareholders. In changing its prior view, the SEC recognized that inadequate CEO succession planning represents an important business risk and flags a firm's governance policy issue that goes beyond daily management of the firm. Succession planning is considered "a key board function and a significant policy (and governance) issue . . . so that a company is not adversely affected by a vacancy in leadership."

In particular, endogeneity in chair independence and succession planning cannot be ruled out and standard regression results may be biased.

In this article, I explore how chair independence and succession planning affect CEO turnover by improving corporate governance and reducing entrenchment. I address concerns regarding simultaneity and omitted variables in chair independence and succession planning by using a trivariate probit system to estimate the effect on CEO turnover. Firms execute their succession plans by appointing an heir apparent to the board of directors, usually a separate President, Chief Operating Officer, or Vice Chair. I find that such succession planning increases the probability of CEO turnover by at least 20%. When there are no succession candidates some chief executives are retained even though shareholders may prefer to have them replaced. Succession planning therefore seems to reduce CEO entrenchment by eliminating a friction to turnover.

The trivariate probit system permits a chair independence effect on succession planning and I find a significantly negative correlation. This may be caused by the common relay succession model, where CEO duality (no independence) coincides with an heir apparent (succession planning). The overall effect of chair independence is therefore negative and reduces the likelihood of CEO turnover by 4%. This unexpected result may arise because the positive effect of improved monitoring by independent chairs is exceeded by the frictions arising from fewer relay successions. Chair independence does not seem to reduce CEO entrenchment enough to compensate for the reduction in heirs apparent by barring relay successions.

I address concerns regarding unobserved managerial ability by selecting samples of natural retirements and forced turnover. CEO ability cannot be directly observed, but corporate boards learn it over time until it becomes a known quantity (Taylor (2010)). CEOs who survive board scrutiny until retirement age are therefore likely to have high average ability while CEOs who are forced to leave earlier most likely have low average ability (Fee et al. (2010)). I find that coefficient estimates are consistent across these samples and conclude that a bias caused by unobserved CEO ability is unlikely.

This article supports corporate governance rule changes that enhance succession planning but provides no evidence for policies that promote chair independence.

The literature on CEO turnover is well established and rooted in corporate governance theory. According to Jensen and Meckling (1976), Fama (1980), and Jensen and Ruback (1983), agency theory predicts that the separation of corporate ownership from control encourages managers to maximize private benefits and decrease shareholder value. Such managerial behavior is typically blamed on the unwillingness or inability of corporate boards to effectively exercise their role as shareholder representatives. Fama and Jensen (1983) show that ineffective corporate governance emerges from boards dominated by firm managers. Weisbach (1988) observes that manager-dominated boards are less likely to dismiss CEOs for poor firm performance. Chair independence has come under particular scrutiny. Agency theory suggests that chair and CEO roles be separated in order to increase board independence and enable better oversight. Consistent with agency theory, Goyal and Park (2002) and Dahya et al. (2002) show that chair independence increases the likelihood of turnover with respect to firm performance.

Parrino (1997) suggests that firms evaluate trade-offs in turnover and succession decisions. The potential benefit of replacing a chief executive with a successor increases with the expected improvement in match quality between firm requirements and executive characteristics, but decreases with uncertainty in measuring these characteristics and fixed costs of CEO turnover. Taylor (2010) shows that corporate boards learn unobservable CEO ability over time until it becomes a know quantity. Vancil (1987) focuses on CEO succession planning and finds that relay successions are a common pattern. The firm selects an heir apparent several years before the CEO's anticipated retirement date, the heir apparent and outgoing chief executive work together until the CEO leaves, and the retiring CEO remains chairperson for a few years before also transferring chairmanship to the successor. Dual CEO-chairs are therefore a normal stage during the common relay succession cycle. Naveen (2006) revisits succession planning and finds that many U.S. firms use a relay process for inside successions. The departing CEO's age also plays an important role in top executive changes. Murphy (1999) documents that most CEO turnover relates to natural retirements.

This article is organized as follows. Section 2.3 develops testable hypotheses. Section 2.4 discusses the empirical strategy. The sample and descriptive statistics are presented in Section 2.5. Section 2.6 shows the main results, and Section 2.7 concludes.

2.3. Hypotheses

Corporate governance theory suggests that chair independence reduces CEO entrenchment and therefore has a positive effect on CEO turnover. Empirical research shows that succession planning also has a positive effect on CEO turnover. However, chair independence is related to succession planning and therefore has an indirect effect on CEO turnover as well: relay successions require both an heir apparent and a dual CEO-chair, who remains as dependent chair after the turnover event. Since chair independence rules out the relay succession model, there may also be fewer heirs apparent and less CEO turnover. Any positive direct effect of chair independence on CEO turnover could therefore be countered by a negative indirect effect from less effective succession planning.

I motivate the test hypotheses for the effect of chair independence and CEO succession planning on turnover as well as their interaction. There are three hypotheses for testing how chair independence and succession planning, both directly and indirectly, affect CEO turnover.

Direct Effects (DE).

Chair independence decreases entrenchment. The dual role of a CEO-chair creates conflicts of interest. Such conflict may arise because incentives to remain CEO are strong and can lead to entrenchment. As chairperson of the board, CEO-chairs may be able to influence the board in their own turnover decisions as well as influence the board's succession planning process. Chief executives usually have superior information regarding candidate ability. CEO entrenchment strategies to delay turnover and succession may include, for example, downplaying candidate ability or ousting an heir apparent. Separating the chairperson from the chief executive role eliminates these conflicts of interest.

DE1: Chair independence makes CEO turnover more likely.

Succession planning facilitates inside successions. Firms engage in succession planning in order to facilitate managerial successions. An heir apparent is typically a firm insider and designated successor to a retiring chief executive. The absence of an heir apparent leaves only other less suitable inside or unknown outside successors, which might be more costly and risky. Succession planning that produces an heir apparent should therefore increase the probability of turnover.

DE2: Succession planning makes CEO turnover more likely.

Indirect Effects (IE).

Relay successions require CEO duality. Relay successions are characterized by chief executives taking the chairperson role and by boards selecting an heir apparent prior to the management transition. The promotion of chief executives to dual CEO-chairs typically takes place before the appointment of the heir apparent. CEO duality usually precedes heir apparent in the relay succession cycle. Since chair independence rules out the relay succession model there may also be fewer heirs apparent.

IE: Chair independence makes succession planning less likely.

These three hypotheses provide tests for both the overall effect of chair independence on CEO turnover (DE1) and the indirect effect through the succession planning channel (IE and DE2). These tests can be used to disentangle the direct and indirect effect of chair independence on CEO turnover and show which dominates.

2.4. Empirical Strategy

Measuring the effect of chair independence and succession planning on CEO turnover is a challenge. The firm's decisions on chair independence, succession planning, and CEO turnover are made simultaneously. For example, if a firm decides to use the common relay succession model (Vancil (1987)) then its succession planning, chair independence, and CEO turnover are affected at the same time: an heir apparent is selected, the incumbent becomes dual CEO-chair, and a target date is set to pass on the CEO title to the successor. Simultaneity can therefore lead to endogeneity and inconsistent estimates.

Unobserved variables may also create endogeneity problems. For example, CEO ability is difficult to observe but influences chair independence and succession planning: a low ability chief executive is more likely to face an independent chair and be replaced by an outside successor. Unobserved ability can therefore generate further inconsistency.

The empirical approach must therefore address endogeneity from both simultaneous and unobserved variables. This problem lends itself to simultaneous systems estimation. My empirical strategy is therefore to estimate a recursive and fully observed system of seemingly unrelated regression (SUR) equations.

Following this general approach, Naveen (2006) uses a bivariate probit regression to estimate the effect of one endogenous variable, succession planning, on CEO turnover. However, the relay succession model is also characterized by CEO duality, which is not part of her analysis. Therefore, I introduce a second endogenous variable, chair independence, in order to better incorporate the effect of relay successions.

The resulting recursive trivariate binary choice model can be specified as a system of SUR equations:

$$\text{(2.1)} \qquad ChairInd_t = \mathbf{1}[\delta_1 Z_{1t} + \delta_2 Z_{2t} + \mathbf{X}_t\boldsymbol{\gamma}_1 + \varepsilon_{1t} > 0]$$

$$\text{(2.2)} \qquad HeirApp_t = \mathbf{1}[\alpha_2 ChairInd_t + \delta_2 Z_{2t} + \mathbf{X}_t\boldsymbol{\gamma}_2 + \varepsilon_{2t} > 0]$$

$$\text{(2.3)} \qquad Turnover_t = \mathbf{1}[\alpha_3 ChairInd_t + \beta_3 HeirApp_t + \mathbf{X}_t\boldsymbol{\gamma}_3 + \varepsilon_{3t} > 0]$$

$$\text{(2.4)} \qquad \boldsymbol{\varepsilon} = (\boldsymbol{\varepsilon}_1, \boldsymbol{\varepsilon}_2, \boldsymbol{\varepsilon}_3)' \sim \mathcal{N}(\mathbf{0}, \boldsymbol{\Sigma})$$

$$\text{(2.5)} \qquad \boldsymbol{\Sigma} = \begin{bmatrix} 1 & . & . \\ \rho_{12} & 1 & . \\ \rho_{13} & \rho_{23} & 1 \end{bmatrix},$$

where $\mathbf{1}[\cdot]$ is the indicator function, $\mathbf{X}$ is a matrix of controls, ρ_{ij} reflects the correlation between the error terms ε_i and ε_j, and the dots refer to symmetrical elements in the lower matrix part.

Stage one (Eq. 2.1) defines the endogenous binary choice variable chair independence. If the chair of the board during year t is neither the current nor a former CEO of the firm, then the chairperson is independent and $ChairInd_t$ is set to 1. Z_1 and Z_2 are instruments.

Stage two (Eq. 2.2) defines the endogenous binary choice variable heir apparent. If the board of directors during year t includes a President, Chief Operating Officer (COO), or Vice Chair who is *not* the current CEO, then the firm has a succession plan and $HeirApp_t$ is set to 1. Z_2 is an instrument.

Stage three (Eq. 2.3) defines the endogenous binary choice variable CEO turnover. If the CEO changes during year t, then the firm experiences a CEO turnover event and $Turnover_t$ is set to 1.

The SUR system is recursive because in each stage the endogenous variables of previous stages appear on the RHS: chair independence is an explanatory variable for heir apparent, while both chair independence and heir apparent are explanatory variables for CEO turnover. The SUR system is also fully observed: the endogenous variables on the RHS (Eq. 2.2 and Eq. 2.3) are actual observations and not estimates. This system permits correlation between the error terms in each stage (Eq. 2.5).

The SUR system can be estimated consistently using limited information maximum likelihood (LIML). Consistency requires identically but not independently distributed errors in each stage, and homoskedasticity in the final stage. Wilde (2000) shows that recursive multi-equation limited dependent variable models do not require exclusion restrictions for parameter identification[3]. Therefore all stages, except the final one, do not need to be fully specified and can omit influential variables.

Wooldridge (2010)[4] cautions against relying solely on nonlinearity in multivariate probit models for parameter identification, and suggests to use exclusion restrictions. It is therefore conservative to use two instruments with three exclusion restrictions for the SUR system:

(1) Post-SOX indicator. The Sarbanes-Oxley (SOX) act, enacted in July 2002, enhances the oversight role of public company boards. It strengthens non-executive director independence, particularly for audit committees. SOX also increases chair independence and can be considered an exogenous shock. However, the legislative scope does not cover succession planning and CEO turnover. The post-SOX indicator is therefore an instrument for chair independence and can be excluded from the succession planning and CEO turnover equations. Any SOX effect on succession planning and CEO turnover is thus attributed to the chair independence channel.

(2) Conditional candidate age indicator. Executives promoted to the executive board are succession candidates well before their official selection

[3]Wilde (2000) proves that a single varying exogenous regressor per equation is sufficient to eliminate problems with small variation identification in multi-equation probit models using endogenous indicator variables.

[4]p. 599

as heir apparent (Naveen (2006)). Candidates for heir apparent are also usually younger than the incumbent CEO. Low candidate age increases the likelihood of succession planning (heir apparent) and can be considered exogenous, after controlling for candidate availability. However, it is not plausible that conditional candidate age has a direct effect on CEO turnover. Candidate age between 44 and 52, conditional on candidate availability, is therefore an instrument for succession planning and chair independence that can be excluded from the CEO turnover equation. Any candidate age effect on CEO turnover is accordingly attributed to the succession planning and chair independence channel.

These exclusion restrictions deliver an identified model. I estimate the SUR system using simulated maximum likelihood methods based on the GHK algorithm[5].

2.4.1. Unobserved Ability

The effect of managerial ability on board decisions could generally be eliminated by conditioning on it. However, it is difficult to directly observe executive ability and there are no good proxies or instruments. My empirical strategy is therefore to condition on managerial ability by selecting samples where executive ability is likely to be similar.

[5]The GHK algorithm was developed independently by Geweke (1989), Hajivassiliou and McFadden (1998), and Keane (1994). It is implemented in Stata for general conditional mixed processes with the user-written command cmp by Roodman (2011).

Corporate boards receive various public and private signals in order to learn unobservable managerial ability over time (Taylor (2010)). CEO survival is accordingly related to ability: chief executives surviving board scrutiny long enough to enter natural retirement should have high average ability, and those that are forced out sooner should have low average ability (Weisbach (1988), Fee et al. (2010)). I therefore select two samples that are likely to differ in CEO ability: natural retirements with high CEO ability, and forced turnover with low CEO ability. If the regression coefficients are robust for different levels of CEO ability then a bias caused by unobserved heterogeneity is unlikely.

2.5. Data

2.5.1. Sample Selection

The primary data source is BoardEx, which provides information on executive management and non-executive board members by firm for the fiscal years from 1999 to 2008. The data set is merged with Compustat for accounting and stock market information. The sample is restricted to non-financial U.S. firms[6] with a minimum of $10 million in total assets where the chief executive is known at the beginning and end of each fiscal year. Interim successors, identified by either the title interim or acting chief executive or by a CEO tenure of less than one year, are excluded. A turnover event occurs when the chief executive leaves the firm.

[6]SIC codes between 6000 and 6999 are excluded.

After selecting the initial sample I categorize CEO turnover further by type. I select news articles from Factiva that contain the name of each departing chief executive during a two-year window around the turnover date to classify the likely cause of the departure. Forced turnover and natural retirements are identified according to the classification used by Parrino (1997). Forced turnover is selected with the following procedure: first, all turnover where a CEOs is reported to be fired is classified as forced. Second, all other turnover in which CEOs are under age 60 are reviewed further. If the report does not mention that: (i) the exit is health-related, (ii) the departing CEO either takes a new job in or outside the firm, leaves for personal or other reasons unrelated to the firm, or (iii) the chief executive departs in a natural retirement, then such turnover is also classified as forced. Retirement is natural when a CEO retires and announces it at least six months before leaving the firm.

Table 3.1 shows a panel data set with $25,622$ firm-years, $2,250$ firms, $4,665$ chief executives, and $2,790$ CEO turnover events. Of these, 690 are natural retirements and $1,090$ are forced CEO turnover.

Each turnover event typically comes with a succession. A relay succession is a planned succession, characterized by an incoming CEO who was previously heir apparent and a departing CEO who stays on as chairperson. An heir apparent is a firm insider with a tenure of at least one year who is either president, chief operating officer, or vice chairperson of the firm prior to the transition. Chair independence is defined here as a chairperson who is neither the current nor a former chief executive. Relay succession and chair independence are mutually exclusive: relay successions by definition require a CEO who stays on as chairperson, and therefore the chair is not independent.

2.5.2. Descriptive Statistics

Since the BoardEx database is not widely used in CEO turnover research, I report several key descriptive statistics for the sample.

Table 2.2 reports the distribution of CEO turnover by year. The overall annual turnover rate is 10.9% and consistent with Parrino (1997), Naveen (2006), and Fee et al. (2010). The average share of natural CEO retirements is 24.7% and the average share of forced CEO turnover is 39.1%, the latter displaying an upward trend.

Table 2.3 illustrates the industry distribution of CEO turnover using the Fama-French 12-industry classification system[7]. While the turnover rate varies little across industry sectors, the proportion of natural retirements and forced turnover varies considerably across sectors, this most likely reflects differences in industry maturity and competition.

Table 2.4 presents firm characteristics. Turnover events are preceded by low operating and stock returns. Firm size, age, and homogeneity, along with the proportion of non-executive board members are also correlated with CEO turnover.

[7]Definition of Fama-French 12-industry classification available at http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/

Table 2.5 shows characteristics for incoming (Panel A) and outgoing CEOs (Panel B). The average CEO successor is 51.8 years old and replaces a 58.2 year-old predecessors after a tenure of 7.7 years. Overall 28.4% of outgoing chief executives have an independent chair of the board and 44.2% appoint an heir apparent. For natural retirements the average departure age is 59.4 years and CEO tenure is 7.2 years, 25.3% have an independent chairperson, and 44.9% have planned for their succession with an heir apparent. For forced turnover the average exit age is 54.8 years and tenure is 6.1 years, 34.2% have an independent chair, and 32.8% have an heir apparent.

Panel B also displays the succession type for departing chief executives. Relay successions account for 23.3%, other inside successions for 41.7%, and outside successions for 34.9% of all CEO turnover, respectively. Relay successions represent only 10.6% but outside successions account for 40.7% of forced turnover.

Table 2.6 presents the prior title of the incoming and subsequent tile of the outgoing CEO, respectively. Of the incoming CEOs 6.8% were CEO at another firm, while 7.6% were chairperson, 40.4% president, 7.8% chief operating officer, and 1.8% vice chair at the firm, respectively. Of the outgoing CEOs 37.1% stay on as chairperson.

There is a close relationship between chair independence, succession planning and CEO turnover.

Figure 2.1 presents the proportion of firms that have an independent chairperson, i.e. a chair who is neither the current nor a former CEO. This figure shows that chair independence is strongly correlated with CEO turnover. The increase in chair independence around CEO turnover reflects the fact that departing dual CEO-chairs do not always become non-executive chairperson.

Figure 2.2 displays the share of firms that plan CEO successions by appointing an heir apparent. It shows that succession planning is strongly correlated with CEO turnover, particularly for natural retirements. The share of heirs apparent increases before the CEO turnover period and decreases afterwards. This reflects that most firms only install one heir apparent who either becomes the next chief executive or typically leaves.

2.6. Results

The multivariate results are presented in three parts. First, I present a standard probit regression of CEO turnover on exogenous covariates. Second, I display a "naïve" probit regression of CEO turnover that adds chair independence and succession planning but erroneously treats these endogenous variables as exogenous. Third, I show my main result: a trinomial probit regression system of CEO turnover that models chair independence and succession planning endogenously. These approaches produce significantly different results and show that treating endogenous variables as exogenous can lead to large errors.

2.6.1. Standard Probit Regression

Table 2.7 shows the marginal effects for a standard probit regression of CEO turnover on exogenous variables. Industry-adjusted operating and stock returns are significantly negative. This is consistent with the relative performance evaluation hypothesis where firm performance measured relative to industry benchmarks reveals CEO ability and untalented chief executives are replaced. The post-Sarbanes-Oxley (SOX) dummy is also significant, indicating that after 2002 CEO turnover increased.

2.6.2. Naïve Probit Regression

Next, I analyze a naïve regression that ignores the endogeneity in chair independence and succession planning. Firms most likely determine chair independence and succession planning simultaneously but ignoring simultaneity usually leads to inconsistent estimates. In order to explore the severity of this issue it is instructive to compare these results with the more robust methods further on.

Table 2.8 displays the marginal effects for a probit regression of CEO turnover on several exogenous variables, as well as on the endogenous variables succession planning and chair independence. Succession planning (heir apparent) seems to have a highly significant effect that increases the probability of CEO turnover by 19.3% for natural retirements, 13.2% for forced turnover, and 8.7% overall. Chair independence also appears to have a highly significantly effect that increases the likelihood of CEO turnover by 6.7% for natural retirements, 7.0% for forced turnover, and 2.6% overall.

The naïve regression results rely on the assumption that succession planning and chair independence are exogenous, which is not plausible. If these variables are functions of other variables then these estimates could be inconsistent. It is therefore better to use a model that is flexible enough to deal with endogenously determined variables.

2.6.3. Trivariate Probit Regression System

I use a system of recursive, fully observed, and seemingly unrelated regressions (SUR) in order to estimate a model with endogenous variables. The SUR model includes three stages: the first stage is a standard probit regression for chair independence (Eq. 2.1); the second stage is a bivariate probit for succession planning (heir apparent) on chair independence (Eq. 2.2); and the third stage is a trivariate probit for CEO turnover on chair independence and succession planning (Eq. 2.3). For better identification I impose one exclusion restriction on the second stage and two on the third stage.

Table 2.9 shows the first stage, reporting the marginal effects of a probit regression for chair independence on exogenous covariates. Firm size has a significantly negative correlation with chair independence since larger firms are less likely to have an independent director chairing the board. Operating return has a significantly negative correlation with chair independence because underperforming firms are more likely to have an independent chair. The insignificant coefficient for the natural retirement sample may reflect upward earnings management by retiring CEOs. Candidate age between 44 and 52 (after controlling for candidate existence) has a significantly positive correlation with chair independence. Executive board members within that age group are more likely to serve under an independent chairperson. Chair independence also increases significantly during the post-SOX years.

The candidate age dummy (after controlling for candidate existence) and the post-SOX dummy serve as instruments in the SUR model. Table 2.9 shows that both are significantly correlated with chair independence and therefore relevant instruments for the first stage.

Table 2.10 presents the second stage, displaying the marginal effects of a bivariate probit regression for succession planning (heir apparent) on chair independence and exogenous variables. Firm size is positively correlated with succession planning; the larger a firm, the larger its internal talent pool and the higher the likelihood of an internal heir apparent. Tobin's Q is positively correlated with succession planning; the higher the marginal value of the firm, the higher the return to talent and the higher the likelihood of an internal heir apparent.

Chair independence is weakly negatively correlated with succession planning since independent chairs are less likely to appoint an heir apparent from inside the firm. Chair independence is structurally incompatible with relay successions where the departing dual CEO-chair remains on the board as a (dependent) chairperson.

The test result is consistent with hypothesis **IE** that chair independence makes succession planning less likely.

The candidate age dummy (after controlling for candidate existence) is an instrument in the SUR model. Table 2.10 shows that it is significantly correlated with succession planning and therefore a relevant instrument for the second stage.

The SUR model uses fully observed dependent variables in all stages and estimates the correlation between the respective error terms. This property makes it robust to omitted variable problems in all stages except the final. The regression estimates are consistent even if influential variables are omitted in the first stage. The correlation between the error terms for the first (chair independence) and second (heir apparent) stage is reported as $atanh(\rho_{12})$ and significantly negative. This shows that there is an endogenous relationship between succession planning and chair independence.

Table 2.11 presents the third and final stage. It presents the marginal effects for a trivariate, recursive probit regression of CEO turnover on succession planning (heir apparent), chair independence and exogenous variables.

Succession planning (heir apparent) is significantly correlated with CEO turnover, increasing the likelihood of CEO turnover by 32.3% for natural retirements, 22.0% for forced turnover, and 20.4% overall. Firms that have an heir apparent are much more likely to fire a chief executive. Without an heir apparent in place, firms show a greatly reduced willingness to dismiss the CEO, possibly due to the higher cost and risk of using an untested successor from inside or outside the company. These results are consistent with hypothesis **DE2** that succession planning makes CEO turnover more likely.

Chair independence is significantly correlated with CEO turnover, *decreasing* the likelihood of CEO turnover by 4.0% overall (the coefficient estimates are similar for both natural retirements and forced turnover but less significant). Independent chairs are less likely to fire a CEO. These test results are not consistent with hypothesis **DE1** because chair independence makes CEO turnover *less* likely.

The explanation seems to be as follows: A relay succession always comes with both an heir apparent and a dependent chair. Chair independence therefore rules out relay successions, and CEO turnover is negatively affected by fewer (relay) heirs apparent. Any positive effect for chair independence on CEO turnover seems to be exceeded by the negative effect from the succession planning (heir apparent) channel.

Industry-adjusted operating and stock returns are significantly negative. This is again consistent with the relative performance evaluation hypothesis.

The correlation between the error terms for the first (chair independence) and second (heir apparent) stage is again $atanh(\rho_{12})$, for the first (chair independence) and third (CEO turnover) stage is $atanh(\rho_{13})$, and for the second (heir apparent) and third (CEO turnover) stage is $atanh(\rho_{23})$. The correlation is in all cases highly significant and shows that there is an endogenous relationship between chair independence, succession planning, and CEO turnover.

When comparing these results with the naïve regressions above it seems that endogeneity indeed greatly influences the estimates for chair independence and the existence of an heir apparent. The correlation between succession planning (heir apparent) and CEO turnover is approximately twice that suggested by the single-equation model. The correlation between chair independence and CEO turnover changes sign and becomes significantly negative. Clearly there is a substantial bias in the naïve single-equation regressions and renders them useless when endogeneity is present.

Succession planning seems to have an even larger effect on CEO turnover than suggested by previous research. Chair independence does not seem to sufficiently improve corporate governance. Instead, chair independence rules out the common relay succession model and appears to cause frictions that exceed its potential benefits.

2.7. Conclusion

There is extensive literature on the individual determinants of CEO turnover. However, only a few articles have examined more complex systems of corporate decision making and address endogeneity issues in observational data.

This paper analyzes how chair independence and succession planning influence CEO turnover. I use a recursive SUR system in order to provide consistent estimates of decision variables that are determined simultaneously with omitted variables. A new comprehensive data set permits the selection of a large sample.

The analysis shows that succession planning has an even larger effect on CEO turnover than suggested by previous research. Chair independence has a significantly negative effect on succession planning due to frictions with the common relay succession model. Overall, chair independence makes CEO turnover less likely.

Subsamples of natural CEO retirements and forced turnover show that these results are not driven by unobserved hetherogeneity in CEO ability.

These results differ markedly from a naïve regression that ignores endogeneity in chair independence and succession planning, as well as demonstrating that great care must be exercised when analyzing the effect of endogenous corporate decision variables.

2.8. Figures and Tables

Figure 2.1: Chair Independence by Period

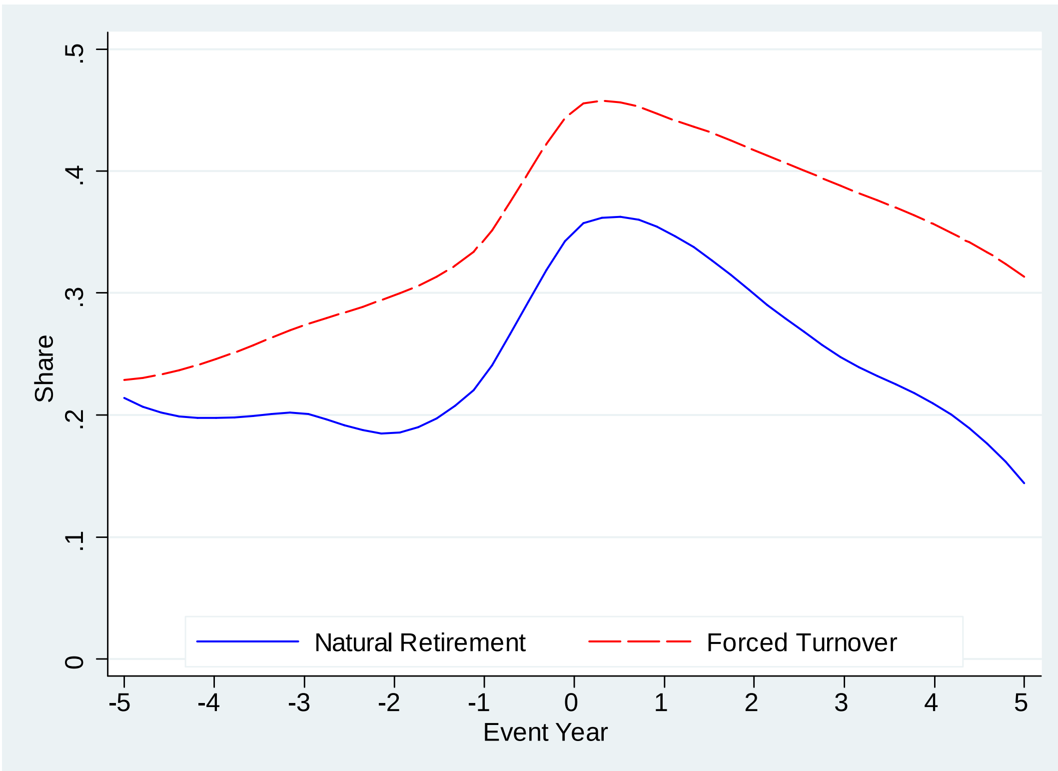

Figure 2.2: Heir Apparent by Period

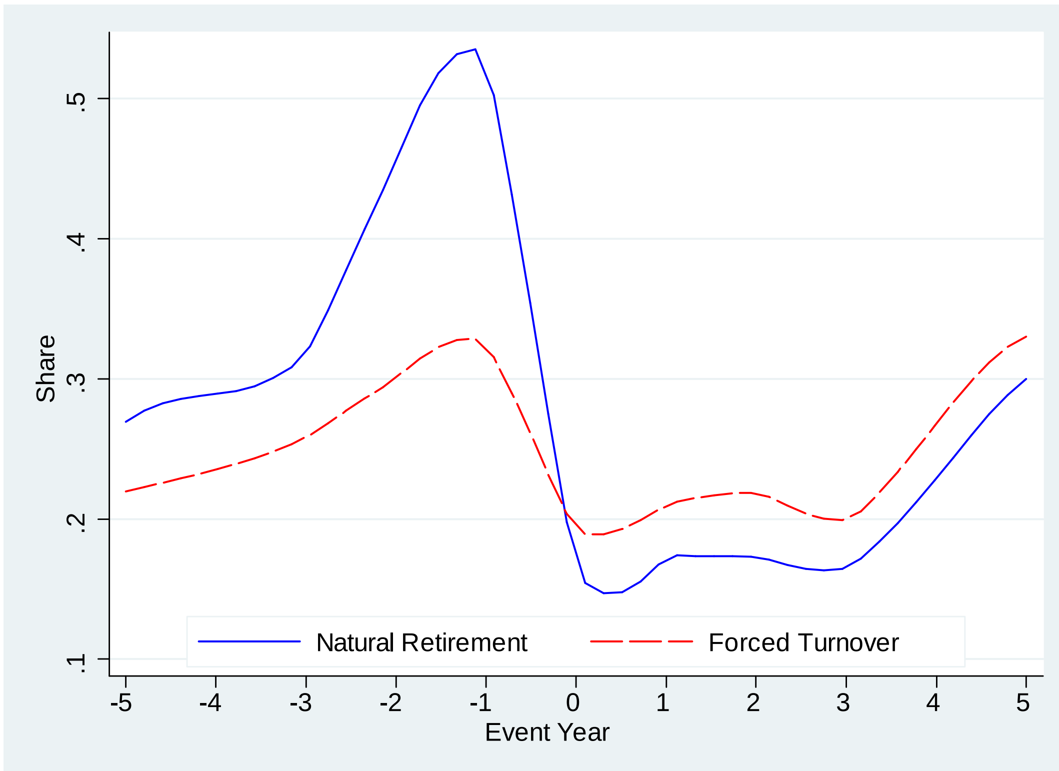

Table 2.1: Sample Statistics

The sample includes all CEOs identified from BoardEx between 1999 and 2008. This data is then merged with Compustat for accounting and stock price information. The dataset is restricted to non-financial firms incorporated in the U.S. with a minimum of US$10 million in total assets where the identity of the CEO is known at the beginning and end of each fiscal year. Interim successors, identified by either the title interim or acting chief executive, or by a CEO tenure of less than one year, are excluded. A turnover event has occurred when the identity of a chief executive at fiscal year-end differs from that at the beginning of a fiscal year. The natural retirement and forced exit subsamples are categorized according to a method described in Parrino (1997).

	No.	Share
All firm-years	25,622	
All companies	2,250	
All CEOs	4,665	
CEO Turnover Samples		
All events	2,790	1.000
Natural retirement	690	0.247
Forced turnover	1,090	0.391

Table 2.2: Event-Years

CEO turnover events are classified by CEO turnover sample. The set of observations in each sample are defined in the first table. The number of CEO turnover events and share of firm-years are reported by year in the column designated "All Events". The number of events and relative share of all events are reported by year in the remaining columns.

Variables	All Events		Natural Retirement		Forced Turnover	
	No.	Share	No.	Share	No.	Share
1999	166	0.090	33	0.199	55	0.331
2000	197	0.096	43	0.218	64	0.325
2001	241	0.103	49	0.203	90	0.373
2002	244	0.094	53	0.217	96	0.393
2003	294	0.107	62	0.211	124	0.422
2004	295	0.104	71	0.241	107	0.363
2005	347	0.121	88	0.254	139	0.401
2006	344	0.120	97	0.282	144	0.419
2007	319	0.115	105	0.329	131	0.411
2008	343	0.127	89	0.259	140	0.408
Total	2,790	0.109	690	0.247	1,090	0.391

Table 2.3: Industry Groups

CEO turnover events are classified by CEO turnover samples. The set of observations in each sample are defined in the first table. The number of events and share of firm-years are reported by industry sector in the column designated "All Events". The number of events and relative share of all events are reported by industry sector in the remaining columns. Firms in FF industry sector eleven (Finance) are excluded.

Variables	All Events		Natural Retirement		Forced Turnover	
	No.	Share	No.	Share	No.	Share
1 Consumer Non-Durables	175	0.113	46	0.263	60	0.343
2 Consumer Durables	85	0.118	25	0.294	20	0.235
3 Manufacturing	362	0.105	102	0.282	120	0.331
4 Energy	80	0.076	15	0.188	23	0.287
5 Chemicals	83	0.111	25	0.301	30	0.361
6 Business Equipment	748	0.123	159	0.213	328	0.439
7 Telecoms	74	0.099	19	0.257	26	0.351
9 Utilities	93	0.102	37	0.398	27	0.290
9 Retail	358	0.108	100	0.279	145	0.405
10 Healthcare	366	0.107	76	0.208	154	0.421
12 Other	366	0.101	86	0.235	157	0.429
Total	2,790	0.109	690	0.247	1,090	0.391

Table 2.4: Firm Characteristics

The reported statistics are sample means for the indicated set of observations. The set of observations in each sample as defined in the first table. The statistics are calculated as of the end of the fiscal year prior to the CEO turnover event. Operating return absolute is operating income (Compustat data item 13) divided by average book assets (average of start and end of year item 6). Operating return is relative and equals the firm's operating return absolute less the median for all firms in the same 2-digit SIC industry sector in the same period. Stock return absolute is the firm's stock return in the fiscal year prior to the CEO turnover event. Stock return is relative and equals stock return absolute less the median for all firms in the same 2-digit SIC industry sector in the same period. Tobin's Q is the sum of book assets (item 6), plus market value of equity (share price, item 24, times number of shares outstanding, item 25), minus deferred taxes (item 74), minus book value of equity (item 60) divided by book assets. Firm size is book assets (item 6) reported in $ million. Firm homogeneity is the Hirshman-Herfindahl index of the firms business segment revenues. Non-executive board is the percentage of board directors that are not firm executives. Non-executive equity is the percentage of ordinary shares outstanding held by non-executive directors. Employees (item 146) is in thousands. Firm age is the current fiscal year less the first fiscal year of available accounting data on Compustat. Asterisks refer to a two-sample mean-comparison test between the all firm-years sample and the indicated set of observations. The indicated set of observations is excluded from the all firm-years sample when conducting the test. Standard errors are reported in parentheses. ***Different means at 1% significance level, **different means at 5% significance level, *different means at 10% significance level.

	All Firm-Years	All Events	Natural Retirement	Forced Turnover
Operating return absolute	0.0333	0.00506***	0.0401	-0.00495***
	(0.00122)	(0.00402)	(0.00703)	(0.00642)
Operating return relative	-0.0216	-0.0479***	-0.0157	-0.0532***
	(0.00113)	(0.00375)	(0.00659)	(0.00603)
Stock return absolute	-0.00682	-0.124***	-0.0912***	-0.219***
	(0.00382)	(0.0122)	(0.0217)	(0.0203)
Stock return relative	0.000456	-0.112***	-0.0942***	-0.194***
	(0.00347)	(0.0111)	(0.0195)	(0.0185)
Tobin's Q	2.109	2.103	2.090	2.163
	(0.0106)	(0.0333)	(0.0659)	(0.0542)
Firm size	2275.5	2730.4***	5598.8***	3923.1***
	(36.19)	(122.9)	(368.1)	(247.0)
Firm homogeneity	0.766	0.746***	0.680***	0.747**
	(0.00177)	(0.00559)	(0.0118)	(0.00913)
Non-executive board	0.761	0.772***	0.805***	0.788***
	(0.000848)	(0.00241)	(0.00393)	(0.00367)
Non-executive equity	0.0406	0.0412	0.0282***	0.0395
	(0.000455)	(0.00140)	(0.00215)	(0.00215)
Employees	8.737	10.84***	20.07***	14.89***
	(0.133)	(0.461)	(1.272)	(0.906)
Firm age	21.29	21.90**	27.87***	22.00
	(0.0931)	(0.292)	(0.666)	(0.474)

Table 2.5: CEO Characteristics

The reported statistics are sample means for the indicated set of observations. The set of observations in each sample as defined in the first table. The statistics are calculated as of the end of the fiscal year prior to the CEO turnover event (unless stated otherwise). Panel A shows statistics for the CEO successor and Panel B for the predecessor. Age is in years at fiscal year-end. College is share of CEOs with graduate degree. MBA is share of CEOs with MBA degree. Organizational tenure is years in same firm at fiscal year-end. Industry tenure is years in public U.S. firm in same 2-digit SIC industry sector at fiscal year-end. Leadership tenure is years as CEO or as heir apparent at fiscal year-end. Chair independence is the share of chairs who are not the current or a former CEO. Heir apparent is share of CEOs who have at least one heir apparent. Asterisks refer to a two-sample mean-comparison test between the all firm-years sample and the indicated set of observations. The indicated set of observations is excluded from the all firm-years sample when conducting the test. Standard errors are reported in parentheses. *** Different means at 1% significance level, ** different means at 5% significance level, * different means at 10% significance level.

	All Firm-Years	All Events	Natural Retirement	Forced Turnover
Panel A: CEO Successor				
Age	55.05	51.78***	52.41***	52.29***
	(0.0512)	(0.142)	(0.269)	(0.238)
College	0.799	0.842***	0.883***	0.861***
	(0.00250)	(0.00691)	(0.0123)	(0.0105)
MBA	0.273	0.324***	0.367***	0.339***
	(0.00278)	(0.00886)	(0.0184)	(0.0143)
Organizational tenure	13.31	7.008***	7.515***	6.335***
	(0.0657)	(0.163)	(0.357)	(0.255)
Panel B: Predecessor				
Age	61.07	58.23***	59.35***	54.84***
	(0.0867)	(0.168)	(0.302)	(0.227)
CEO tenure	7.992	7.664***	7.230***	6.136***
	(0.0704)	(0.138)	(0.264)	(0.170)
Organizational tenure	15.98	13.86***	15.19*	11.56***
	(0.117)	(0.219)	(0.459)	(0.304)
Chair independent	0.257	0.284***	0.253	0.342***
	(0.00276)	(0.00871)	(0.0168)	(0.0147)
Heir apparent	0.289	0.442***	0.499***	0.328***
	(0.00283)	(0.00940)	(0.0190)	(0.0142)
Relay succession	0.0254	0.233***	0.229***	0.106***
	(0.000983)	(0.00801)	(0.0160)	(0.00931)
Other inside succession	0.0454	0.417***	0.401***	0.487***
	(0.00130)	(0.00934)	(0.0187)	(0.0151)
Outside succession	0.0381	0.349***	0.370***	0.407***
	(0.00120)	(0.00903)	(0.0184)	(0.0149)

Table 2.6: CEO Titles

Prior and subsequent CEO titles are classified by CEO turnover samples. The set of observations in each sample as defined in the first table. Prior and subsequent CEO titles are reported by number and share of all CEOs. Panel A shows the prior job title of the CEO successor. For multiple titles, only the first in the list of titles is considered. Panel B displays the subsequent title of the predecessor CEO.

	All Events		Natural Retirement		Forced Turnover	
	No.	Share	No.	Share	No.	Share
Panel A: Prior Title of CEO Successor						
CEO	189	0.068	40	0.058	92	0.084
Chair	211	0.076	40	0.058	122	0.112
President	1,128	0.404	311	0.451	329	0.302
COO	222	0.080	35	0.051	78	0.072
Vice chair	56	0.020	23	0.033	27	0.025
Vice president	344	0.123	83	0.120	145	0.133
Other	640	0.229	158	0.229	297	0.272
Panel B: Subsequent Title of Predecessor						
Chair	1,036	0.371	248	0.359	194	0.178
Total	2,790	1.000	690	1.000	1,090	1.000

Table 2.7: Probit of CEO Turnover

The table reports marginal effects using a pooled maximum likelihood probit model. The dependent variable is set to one if the firm has a CEO turnover event before fiscal year-end and zero otherwise. The columns contain the turnover samples and cover the firm-years for each CEO whose tenure ends with the specified turnover event. For continuous variables, the marginal effect is for a one unit change in that variable, keeping all other variables at their means. For dummy variables, the marginal effect is a change from zero to one, keeping all other variables at their means. Independent variables include lagged firm size (log of book assets), Tobin's Q is lagged market value of assets divided by book value of assets. Stock return is the firm's lagged 2-digit SIC industry-adjusted stock return. Operating return is the firm's lagged 2-digit SIC industry-adjusted operating return. Heir Apparent is set to one if the firm has at fiscal year-end a chief operating officer/president/vice chair who is not also CEO, and zero otherwise. Chair independent is set to one if the firm has an independent chair at fiscal year-end and zero otherwise. Candidate exists dummy is a variable that is set to 1 if there is at least one excutive board member other than the CEO. Candidate age dummy is set to 1 if, other than the CEO, there is an executive board member aged between 44 and 52. Post SOX dummy is 1 for each fiscal year after the Sarbanes-Oxley act was passed in July 2002. All regressions include FF 12 industry group fixed effects. Standard errors are clustered by firm i and reported in parentheses. $*$, $**$, $***$ indicate statistical significance of point estimates at the 10%, 5%, and 1% levels, respectively.

Variables	All Events	Natural Retirement	Forced Turnover
Firm size	0.0109***	0.00443	0.00793**
	(0.00111)	(0.00510)	(0.00385)
Tobin's Q	0.00264**	-0.00217	-0.00423
	(0.00120)	(0.00537)	(0.00399)
Operating return	-0.0992***	-0.135**	-0.155***
	(0.0111)	(0.0573)	(0.0442)
Stock return	-0.0342***	-0.0603***	-0.0786***
	(0.00373)	(0.0165)	(0.0131)
Candidate exists dummy	-0.0206	-0.204*	-0.0618
	(0.0163)	(0.119)	(0.0617)
Candidate age dummy	-0.00454	-0.0147	-0.0215
	(0.00543)	(0.0291)	(0.0198)
Post SOX dummy	0.0196***	0.170***	0.162***
	(0.00383)	(0.0148)	(0.0125)
Firm-years	25,622	2,997	4,208
Pseudo R^2	0.017	0.040	0.042

Table 2.8: Naïve Probit of CEO Turnover

The table reports marginal effects using a pooled maximum likelihood probit model. The dependent variable is set to one if the firm has a CEO turnover event before fiscal year-end and zero otherwise. The columns contain the turnover samples and cover the firm-years for each CEO whose tenure ends with the specified turnover event. For continuous variables, the marginal effect is for a one unit change in that variable, keeping all other variables at their means. For dummy variables, the marginal effect is a change from zero to one, keeping all other variables at their means. Independent variables include lagged firm size (log of book assets), Tobin's Q is lagged market value of assets divided by book value of assets. Stock return is the firm's lagged 2-digit SIC industry-adjusted stock return. Operating return is the firm's lagged 2-digit SIC industry-adjusted operating return. Heir Apparent is set to one if the firm has at fiscal year-end a chief operating officer/president/vice chair who is not also CEO, and zero otherwise. Chair independent is set to one if the firm has an independent chair at fiscal year-end and zero otherwise. Candidate exists dummy is a variable that is set to 1 if there is at least one excutive board member other than the CEO. Candidate age dummy is set to 1 if, other than the CEO, there is an executive board member aged between 44 and 52. Post SOX dummy is 1 for each fiscal year after the Sarbanes-Oxley act was passed in July 2002. All regressions include FF 12 industry group fixed effects. Standard errors are clustered by firm *i* and reported in parentheses. *, **, *** indicate statistical significance of point estimates at the 10%, 5%, and 1% levels, respectively.

Variables	All Events	Natural Retirement	Forced Turnover
Heir apparent	0.0867***	0.193***	0.132***
	(0.00510)	(0.0209)	(0.0183)
Chair independent	0.0264***	0.0668***	0.0704***
	(0.00476)	(0.0257)	(0.0163)
Firm size	0.00923***	-0.00159	0.00488
	(0.00113)	(0.00563)	(0.00415)
Tobin's Q	0.00175	-0.00693	-0.00700*
	(0.00121)	(0.00540)	(0.00411)
Operating return	-0.0938***	-0.159***	-0.153***
	(0.0111)	(0.0570)	(0.0455)
Stock return	-0.0317***	-0.0557***	-0.0765***
	(0.00366)	(0.0166)	(0.0134)
Candidate exists dummy	-0.0127	-0.200	-0.0419
	(0.0158)	(0.122)	(0.0648)
Candidate age dummy	-0.00209	-0.00809	-0.0232
	(0.00535)	(0.0300)	(0.0205)
Post SOX dummy	0.0203***	0.167***	0.163***
	(0.00372)	(0.0147)	(0.0124)
Firm-years	25,155	2,938	4,081
Pseudo R^2	0.070	0.091	0.092

Table 2.9: Probit of Chair Independence

The table reports marginal effects using a pooled maximum likelihood probit model. The dependent variable is set to one if the firm has an independent chair at fiscal year-end and zero otherwise. The columns contain the turnover samples and cover the firm-years for each CEO whose tenure ends with the specified turnover event. For continuous variables, the marginal effect is for a one unit change in that variable, keeping all other variables at their means. For dummy variables, the marginal effect is a change from zero to one, keeping all other variables at their means. Independent variables include lagged firm size (log of book assets), Tobin's Q is lagged market value of assets divided by book value of assets. Stock return is the firm's lagged 2-digit SIC industry-adjusted stock return. Operating return is the firm's lagged 2-digit SIC industry-adjusted operating return. Heir Apparent is set to one if the firm has at fiscal year-end a chief operating officer/president/vice chair who is not also CEO, and zero otherwise. Chair independent is set to one if the firm has an independent chair at fiscal year-end and zero otherwise. Candidate exists dummy is a variable that is set to 1 if there is at least one excutive board member other than the CEO. Candidate age dummy is set to 1 if, other than the CEO, there is an executive board member aged between 44 and 52. Post SOX dummy is 1 for each fiscal year after the Sarbanes-Oxley act was passed in July 2002. All regressions include FF 12 industry group fixed effects. Standard errors are clustered by firm i and reported in parentheses. $*$, $**$, $***$ indicate statistical significance of point estimates at the 10%, 5%, and 1% levels, respectively.

Variables	All Events	Natural Retirement	Forced Turnover
Firm size	-0.0276***	-0.0515***	-0.0423***
	(0.00383)	(0.00890)	(0.00762)
Tobin's Q	-0.00240	-0.00432	-0.00984
	(0.00318)	(0.00747)	(0.00683)
Operating return	-0.165***	-0.0390	-0.123*
	(0.0304)	(0.0768)	(0.0696)
Stock return	-0.00311	-0.00971	-0.0176
	(0.00486)	(0.0132)	(0.0119)
Candidate exists dummy	0.00429	-0.242*	0.0616
	(0.0339)	(0.146)	(0.0638)
Candidate age dummy	0.0325***	-0.00794	-0.0199
	(0.0121)	(0.0342)	(0.0295)
Post SOX dummy	0.0932***	0.0961***	0.0999***
	(0.00703)	(0.0190)	(0.0189)
Firm-years	25,622	2,997	4,208
Pseudo R^2	0.036	0.082	0.060

Table 2.10: Bivariate Probit of Heir Apparent

The table reports marginal effects using a pooled maximum likelihood bivariate probit model. The dependent variable is set to one if the firm has an heir apparent at fiscal year-end and zero otherwise. The columns contain the turnover samples and cover the firm-years for each CEO whose tenure ends with the specified turnover event. For continuous variables, the marginal effect is for a one unit change in that variable, keeping all other variables at their means. For dummy variables, the marginal effect is a change from zero to one, keeping all other variables at their means. Independent variables include lagged firm size (log of book assets), Tobin's Q is lagged market value of assets divided by book value of assets. Stock return is the firm's lagged 2-digit SIC industry-adjusted stock return. Operating return is the firm's lagged 2-digit SIC industry-adjusted operating return. Heir Apparent is set to one if the firm has at fiscal year-end a chief operating officer/president/vice chair who is not also CEO, and zero otherwise. Chair independent is set to one if the firm has an independent chair at fiscal year-end and zero otherwise. Candidate exists dummy is a variable that is set to 1 if there is at least one excutive board member other than the CEO. Candidate age dummy is set to 1 if, other than the CEO, there is an executive board member aged between 44 and 52. Post SOX dummy is 1 for each fiscal year after the Sarbanes-Oxley act was passed in July 2002. atanh(ρ_{12}) is the atanh of the correlation between the error terms of first stage (chair independence, equation 1) and the second stage (heir apparent, equation 2). The corresponding standard error is denoted by se. All regressions include FF 12 industry group fixed effects. Standard errors are clustered by firm i and reported in parentheses. $*$, $**$, $***$ indicate statistical significance of point estimates at the 10%, 5%, and 1% levels, respectively.

Variables	All Events	Natural Retirement	Forced Turnover
Chair independent	-0.0252*	0.0305	0.00575
	(0.0132)	(0.0357)	(0.0245)
Firm size	0.0200***	0.0405***	0.0372***
	(0.00332)	(0.00930)	(0.00666)
Tobin's Q	0.00918***	0.0118	0.0147***
	(0.00302)	(0.00781)	(0.00547)
Operating return	0.0546*	0.0981	0.0450
	(0.0300)	(0.0840)	(0.0653)
Stock return	-0.00359	-0.0226	-0.0118
	(0.00502)	(0.0158)	(0.0117)
Candidate exists dummy	-0.0274	0.177***	-0.0423
	(0.0371)	(0.0630)	(0.0897)
Candidate age dummy	-0.0416***	-0.0451	-0.00596
	(0.0127)	(0.0384)	(0.0252)
atanh(ρ_{12})	-0.194	-0.207	-0.236
se	0.024	0.053	0.047
Firm-years	25,155	2,938	4,081
Pseudo R^2	0.034	0.068	0.062

Table 2.11: Trivariate Probit of CEO Turnover

The table reports marginal effects using a pooled maximum likelihood trivariate probit model, which is specified as a recursive, fully observed, seemingly unrelated regression (SUR). The dependent variable is set to one if the firm has a CEO turnover event before fiscal year-end and zero otherwise. The columns contain the turnover samples and cover the firm-years for each CEO whose tenure ends with the specified turnover event. For continuous variables, the marginal effect is for a one unit change in that variable, keeping all other variables at their means. For dummy variables, the marginal effect is a change from zero to one, keeping all other variables at their means. Independent variables include lagged firm size (log of book assets), Tobin's Q is lagged market value of assets divided by book value of assets. Stock return is the firm's lagged 2-digit SIC industry-adjusted stock return. Operating return is the firm's lagged 2-digit SIC industry-adjusted operating return. Heir Apparent is set to one if the firm has at fiscal year-end a chief operating officer/president/vice chair who is not also CEO, and zero otherwise. Chair independent is set to one if the firm has an independent chair at fiscal year-end and zero otherwise. Candidate exists dummy is a variable that is set to 1 if there is at least one excutive board member other than the CEO. Candidate age dummy is set to 1 if, other than the CEO, there is an executive board member aged between 44 and 52. Post SOX dummy is 1 for each fiscal year after the Sarbanes-Oxley act was passed in July 2002. atanh(ρ_{12}) is the atanh of the correlation between the error terms of first stage (chair independence, equation 1) and the second stage (heir apparent, equation 2). atanh(ρ_{13}) is the atanh of the correlation between the error terms of first stage (chair independence, equation 1) and the third stage (CEO turnover, equation 3). atanh(ρ_{23}) is the atanh of the correlation between the error terms of second stage (heir apparent, equation 2) and the third stage (CEO turnover, equation 3). The corresponding standard errors are denoted by se. All regressions include FF 12 industry group fixed effects. Standard errors are clustered by firm i and reported in parentheses. *, **, *** indicate statistical significance of point estimates at the 10%, 5%, and 1% levels, respectively.

Variables	All Events	Natural Retirement	Forced Turnover
Heir apparent	0.204***	0.323***	0.220***
	(0.00862)	(0.0196)	(0.0184)
Chair independent	-0.0404***	-0.0429	-0.0413*
	(0.00933)	(0.0341)	(0.0246)
Firm size	0.00499***	-0.0185***	-0.00901**
	(0.00129)	(0.00635)	(0.00435)
Tobin's Q	0.000385	-0.0155***	-0.0140***
	(0.00135)	(0.00544)	(0.00415)
Operating return	-0.114***	-0.178***	-0.171***
	(0.0127)	(0.0625)	(0.0468)
Stock return	-0.0317***	-0.0576***	-0.0734***
	(0.00388)	(0.0161)	(0.0131)
atanh(ρ_{12})	-0.212	-0.227	-0.262
se	0.030	0.061	0.054
atanh(ρ_{13})	0.339	0.339	0.318
se	0.036	0.064	0.052
atanh(ρ_{23})	-0.541	-0.665	-0.387
se	0.024	0.048	0.042
Firm-years	25,155	2,938	4,081
Pseudo R^2	0.052	0.082	0.068

CHAPTER 3

How Do Corporate Boards Learn About CEO Ability? Evidence from Structural Estimation

3.1. Abstract

CEO ability is an important determinant of firm performance but is usually not directly observable. I use simulated method of moments (SMM) in order to estimate a dynamic model of learning about CEO ability from the firm's stock market valuations, operating returns, and CEO turnover. This model features an information asymmetry between the firm's board of directors and the stock market, as well as misalignment between the board and shareholders.

I find that learning about CEO ability is influenced by the stock market's public signal, the board's private signal, and operating returns in a ratio of 2.3 : 2.1 : 1. When learning about CEO ability corporate boards rely mostly on public stock market information and inside information available only to the board, but are less concerned with accounting data.

3.2. Introduction

CEO ability is an important determinant of firm performance but is usually not directly observable. A corporate board must rely on a variety of signals to learn about managerial ability over time in order to either reward or replace the CEO. The prior literature establishes that operating and stock returns have an effect on forced CEO turnover. But it is unclear to which extent boards use this information to update their beliefs about CEO ability.

This paper empirically examines how boards learn about CEO ability quarter by quarter from operating returns, stock market valuations, and insider information in order to make costly CEO turnover decisions. I use a dynamic model with a rational board of directors that maximizes expected utility. Each CEO has an unobservable and constant level of ability that affects firm profits. The firm's board uses Bayes' rule in order to learn about CEO ability from news regarding operating return, stock market valuation and a private signal. The market learns about CEO ability from operating return, stock market valuation, and the board's firing decision and sets the firm's valuation accordingly. Each period the market and board update their beliefs, and CEO ability gradually becomes a known quantity. The board optimally decides to keep the chief executive, or to incur the cost of appointing a new CEO of unknown ability based on expected ability and tenure of the incumbent CEO.

In this model four factors influence turnover decisions: the difference in expected CEO ability, the rate of board learning, the turnover cost to shareholders, and the board's personal disutility from CEO turnover.

Measuring these factors empirically for infrequent CEO turnover events poses a challenge. The board's CEO turnover decisions are endogenous and influence firm profits. Both market expectations of CEO ability and the board's optimal turnover policy are endogenously reflected in stock market valuations. Some variables cannot be observed: the CEO talent pool, actual and expected CEO ability, the market's and board's signals of ability, and the board's personal disutility of dismissing a chief executive. No obvious instruments are available. Although reduced-form empirical analysis can been used to determine directional effects, the magnitudes of these effects can only be estimated using an economic model.

I therefore use a structural approach that uses endogenous patterns in firm behavior in order to estimate unobservable model parameters. The advantage of structural methods is that they can determine both directional effects and their magnitude but do not require instruments. Furthermore, structural economic models are normative and can be used to investigate counter-factuals.

I estimate the model's parameters using the simulated method of moments (SMM) applied to a new quarterly sample of firm profitability, stock prices, and CEO turnover for listed U.S. firms between 1999 and 2008. The estimated model parameters include the prior mean ability and variance of the new CEO talent pool, the variance and persistence in firm-specific profitability, the variance in the market's public and the board's private signals of CEO ability, the firm's cost of chief executive turnover, and the board's disutility cost of CEO turnover.

Over time corporate boards learn about CEO ability from observing operating returns, stock market valuations, and private signals available only to the board. I can determine these signals' influence on the board's learning of CEO ability and turnover policy. I find that learning about CEO ability is influenced by the stock market's public signal, the board's private signal, and operating returns in a ratio of 2.3 : 2.1 : 1. In order to learn about CEO ability corporate boards rely primarily on public stock market information and inside information available only to the board, but are less concerned with accounting data.

The model also provides information regarding the CEO talent pool which is defined by the prior mean and dispersion of CEO ability. The prior mean is estimated at 0.68% in the industry-adjusted annual operating return on assets (OROA) per quarter. CEO ability is slightly right-skewed; some high CEO ability outliers are expected. The estimated prior dispersion for CEO ability is 0.44% per quarter. This appears small, but comparing new CEOs at the 5th and 95th percentiles of ability shows a substantial OROA difference of $2 \times 1.96 \times 0.53\% \times \sqrt{4} = 3.45\%$ per year; CEO ability does indeed seem to matter.

Furthermore, I find a significant cost of CEO turnover. The board's effective total turnover cost is 2.99% of firm assets (or $US\$230$ million for the average firm). The real financial cost to the firm is 1.92% of total assets (or $US\$148$ million for the average firm). Corporate boards are reluctant to dismiss CEOs and retain some low ability CEOs that shareholders would rather have fired. The wedge between shareholder interest and board behavior is consistent with CEO entrenchment.

The downside of structural methods is that they require strong assumptions for parameter identification: first, in the model CEO ability fully accounts for long-term variation in firm profitability. Second, the firm's turnover cost is realized during the quarter of the event. Third, the board considers only shareholder value and personal disutility of turnover for the firm's optimal firing policy.

This paper relates to both the corporate finance and asset pricing literatures. Within asset pricing several articles focus on the way learning about firm fundamentals affects stock returns and volatility. Pástor and Pietro (2003) present a stock valuation model that features learning about average profitability. Pastor and Veronesi (2009) survey related papers and show that learning can explain many asset pricing phenomena such as stock return predictability, stock price bubbles, and investor portfolio choices. Within corporate finance, Holmström (1999) shows how learning about management ability influences managerial incentives and corporate governance. Bertrand and Schoar (2003) use CEO turnover events to show that individual managers have an effect on firm performance.

Several papers model learning for managerial turnover. Hermalin and Weisbach (1998) present a static CEO turnover model with endogenous monitoring and CEO compensation. Pan et al. (2013) introduce a dynamic model of CEO turnover and show that learning about CEO ability affects stock return volatility. Eisfeldt and Kuhnen (2013) develop a competitive assignment model of chief executive turnover, pay and firm performance. In a closely related paper Taylor (2010) analyzes CEO turnover using a dynamic discrete choice model estimated with simulated methods of moments (SMM). I extend his model and include stock market valuations, allow asymmetric information between the board and the market, as well as learning by the market, and use a comprehensive set of new quarterly data.

The paper is organized as follows: Section 3.3 describes the model, Section 3.4 introduces the estimation method, Section 3.5 presents the main results, and Section 3.6 closes with conclusions.

3.3. Model

The model formalizes learning about CEO ability and is an extension of Taylor (2010). During each period the market and board draw inferences using the arrival of news regarding firm performance and other signals concerning CEO ability.

In the model each CEO has an unobservable and constant level of ability that affects firm profits. The firm's board and the stock market know all other model parameters. The firm's board uses Bayes' rule in order to learn CEO ability from news regarding the operating return, stock market valuation, and a private signal. The market learns from operating return, a public signal, and the board's firing decision about CEO ability and sets the firm's valuation accordingly. Each period the market and board both update their beliefs and CEO ability gradually becomes a known quantity. Based on expected CEO ability and tenure, the board optimally decides to keep the chief executive, or to incur the cost of appointing a new CEO of unknown ability.

Figure 3.1 shows the model's time-line of events. At t_0 a new CEO of unknown ability α arrives. At t_1 the CEO produces signals that are informative about CEO ability: the firm's operating return y, the market's signal z_m and the board's signal z_b. In turn the board observes these three signals, updates its expectations about CEO ability μ_b, and decides to either retain or to fire the CEO. Finally, the market observes the operating return y, the market's signal z_m, and the board's firing decision d, updates its expectation about CEO ability μ_m, and sets the new firm valuation Q. Each period the board learns more about the CEO's ability until the chief executive either leaves voluntarily or is replaced by a successor of unknown ability and the cycle recommences. If the board only observes a favorable signal during a single period then it cannot be sure if it's due to high CEO ability or luck. However, favorable signals over multiple periods generally correspond to high CEO ability. This model allows mis-pricing in firm valuations and measures the degree of misinformation.

The term "ability" in the model is general and can be interpreted in different ways (Pan et al. (2013)): first, it could mean that the CEO's underlying talent determines firm performance in the broadest sense. Second, "ability" in the model could relate to the quality of the job match between the CEO and the firm. In this case CEO ability would be specific to the firm and would not be transferrable to another firm. Third, "ability" could also refer to the corporate strategy implemented by the CEO. In that case CEO ability would be specific to a particular strategy and firm, and not be transferrable toward implementing another strategy at either the same firm or another firm.

3.3.1. Assumptions

The firm is infinitely-lived and there is an infinite pool of CEO succession candidates. Each period the board makes optimal CEO turnover decisions by either keeping the incumbent or asking a successor to take over the helm. The CEO can resign voluntarily but must retire upon reaching a fixed tenure limit.

Forced CEO turnover creates real costs for the firm (executive search fees, severance packages, and disruption costs), but board members also incur personal costs (disutility from firing the CEO due to personal or professional ties to the CEO, for exerting uncompensated effort, or "rocking the boat" makes reappointment to the board less likely). The board cares about shareholder value to a degree, but personal disutility from firing the CEO can create misalignment with shareholders as well as cause CEO entrenchment.

The board is risk-neutral and maximizes its lifetime utility according to:

$$U_t = \max_{\{d_{t+s}\}_{s=0}^{\infty}} \kappa M_t - \mathbb{E}_t \sum_{s=0}^{\infty} \beta^s B_{t+s} d_{t+s} c^{(pers)} \tag{3.1}$$

with CEO turnover policy $d_t \in \{0, 1\}$, board alignment $\kappa > 0$, discount factor $\beta \in (0, 1)$, book value of assets B_t, board's personal turnover cost $c^{(pers)}$, and expected present value of firm cash flows:

$$M_t = \mathbb{E}_t \sum_{s=0}^{\infty} \beta^s B_{t+s} Y_{t+s} \tag{3.2}$$

where:

$$
\begin{aligned}
Y_t &= \nu_t + y_t - d_t c^{(firm)} \\
y_t &= y_{t-1} + \phi(\alpha_{t-1} - y_{t-1}) + \epsilon_t \\
\alpha_t &= \begin{cases} \alpha_i \sim \mathcal{N}(\mu_0, \sigma_0^2) & \text{if } t = 0 \text{ or } d_t = 1 \\ \alpha_{t-1} & \text{otherwise} \end{cases}
\end{aligned} \tag{3.3}
$$

with industry profitability ν_t, firm-specific profitability before CEO turnover cost y_t, unobservable CEO ability α_t, persistence $\phi \in [0,1]$, profitability shock $\epsilon_t \sim N(0, \sigma_\epsilon^2)$, firm turnover cost $c^{(firm)}$, and firm profitability Y_t.

3.3.2. Model Solution

For a model solution, the board's learning and optimization problems must be solved. The board updates its belief of CEO ability according to Bayes's Rule. The board's beliefs and objective function are used to derive the Bellman equation, which is solved numerically. The market also learns about CEO ability, using a value function and the board's optimal turnover policy in order to value the firm.

3.3.2.1. The Board's Learning Problem. The board observes firm-specific profitability y_t, a public signal observed by the stock market and the board $z_{m,t} \sim \mathcal{N}(\alpha_i, \sigma_m^2)$, and a private signal observed only by the board $z_{b,t} \sim \mathcal{N}(\alpha_i, \sigma_b^2)$ in order to learn CEO ability α_i over time. With each observation $(y_t, z_{m,t}, z_{b,t})$ at CEO tenure τ_t the board's belief of CEO ability $\mu_{b,t} \equiv \mathbb{E}_t \alpha_i$ and MSE $\sigma_{b,t}^2 \equiv Var(\mu_{b,t})$

are updated according to (see appendix for proof):

$$\mu_{b,t} = \mu_{b,t-1} + \sigma_{b,t}^2 \begin{bmatrix} \frac{\phi^2}{\sigma_\epsilon^2} & \frac{1}{\sigma_m^2} & \frac{1}{\sigma_b^2} \end{bmatrix} \begin{bmatrix} \delta_{y,t} \\ \delta_{m,t} \\ \delta_{b,t} \end{bmatrix} \tag{3.4}$$

$$\sigma_{b,t}^2 = \frac{\sigma_0^2}{1 + \tau_t \sigma_0^2 (\frac{\phi^2}{\sigma_\epsilon^2} + \frac{1}{\sigma_m^2} + \frac{1}{\sigma_b^2})} \tag{3.5}$$

$$\begin{bmatrix} \delta_{y,t} \\ \delta_{m,t} \\ \delta_{b,t} \end{bmatrix} = \begin{bmatrix} \frac{1}{\phi}(y_t - y_{t-1}) - y_{t-1} - \mu_{b,t-1} \\ z_{m,t} - \mu_{b,t-1} \\ z_{b,t} - \mu_{b,t-1} \end{bmatrix} \tag{3.6}$$

3.3.2.2. The Board's Optimization Problem. The board updates its belief about CEO ability according to Equation (3.4). The CEO is fired when expected ability falls below an endogenous threshold, depending on CEO tenure and the model's parameters. The board maximizes Equation (3.1) with the optimal firing policy $\{d_{t+s}^*\}_{s=0}^{\infty}$. The model can be solved numerically for the corresponding Bellman equation; for details see appendix.

3.3.2.3. The Market's Learning Problem. The market cannot observe the board's private signal $z_{b,t}$, or the board's belief $\mu_{b,t}$. However, the board's decision not to fire the CEO is an informative signal. The market therefore uses firm-specific profitability y_t, a public signal $z_{m,t} \sim \mathcal{N}(\alpha_i, \sigma_m^2)$, and the board's firing decision d_t, in order to learn CEO ability α_i over time. If the board fires the incumbent CEO then a successor CEO comes in and market learning begins again with $\mu_{m,t} = \mu_0$.

With each observation $(y_t, z_{m,t}, d_t)$ at CEO tenure τ_t the market's belief of CEO ability $\mu_{m,t} \equiv \mathbb{E}_t\alpha_i$ and MSE $\sigma^2_{m,t} \equiv Var(\mu_{m,t})$ are updated according to (see appendix for proof):

$$\mu_{m,t} = \mu_{m,t-1} + \sigma^2_{m,t} \begin{bmatrix} \frac{\phi^2}{\sigma^2_\epsilon} & \frac{1}{\sigma^2_m} & \frac{1}{\sigma^2_d} \end{bmatrix} \begin{bmatrix} \delta_{y,t} \\ \delta_{m,t} \\ \delta_{d,t} \end{bmatrix} \tag{3.7}$$

$$\sigma^2_{m,t} = \frac{\sigma^2_{m,t-1}}{1 + \sigma^2_{m,t-1}(\frac{\phi^2}{\sigma^2_\epsilon} + \frac{1}{\sigma^2_m} + \frac{1}{\sigma^2_{d,t}})} \tag{3.8}$$

$$\begin{bmatrix} \delta_{y,t} \\ \delta_{m,t} \\ \delta_{d,t} \end{bmatrix} = \begin{bmatrix} \frac{1}{\phi}(y_t - y_{t-1}) - y_{t-1} - \mu_{m,t-1} \\ z_{m,t} - \mu_{m,t-1} \\ \mu_{d,t} - \mu_{m,t-1} \end{bmatrix} \tag{3.9}$$

where:

$$\begin{aligned} \mu_{d,t} &\equiv \mathbb{E}_{m,t}[\mu_{b,t}(z_{b,t}) \mid d_t = 0] \\ &= \mathbb{E}_{m,t}[z_{b,t} \mid z_{b,t} \geq \mu^*_t - \sigma^2_b(\frac{\phi^2\delta_{y,t}}{\sigma^2_\epsilon} + \frac{\delta_{m,t}}{\sigma^2_m}) \equiv z^*_t] \\ &= \mu_{m,t} + \sigma_b\lambda(\pi_{m,t}) \end{aligned} \tag{3.10}$$

and:

$$\lambda(\pi_{m,t}) \equiv \frac{\phi(\pi_{m,t})}{1-\Phi(\pi_{m,t})} \tag{3.11}$$

$$\pi_{m,t} \equiv \frac{z_t^* - \mu_{m,t}}{\sigma_b}$$

The variance of the board's expected ability for surviving CEOs is:

$$\begin{aligned} \sigma_{d,t}^2 &\equiv Var_{m,t}[\mu_{b,t}(z_{b,t}) \mid d_{t-1}=0] \\ &= Var_{m,t}[z_{b,t} \mid z_{b,t} \geq z_t^*] \\ &= \sigma_b^2[1-\omega(\pi_{m,t})] \end{aligned} \tag{3.12}$$

where:

$$\omega(\pi_{m,t}) \equiv \lambda(\pi_{m,t})[\lambda(\pi_{m,t}) - \pi_{m,t}] \tag{3.13}$$

3.3.2.4. The Market's Valuation Problem. There is an information asymmetry between the firm's board and the stock market, but otherwise there are no frictions, investors are risk-neutral and have rational expectations. In a rational expectations equilibrium the market is assumed to know the optimal CEO turnover policy $\{d_{t+s}^*\}_{s=0}^{\infty}$, instantly reflecting the updated expectation of CEO ability $\mu_{m,t}$ in the new expected present value of firm cash flows. The board's value function can be modified to express firm value as average Q; for details, see appendix.

3.3.3. Model Predictions

The model predicts the board's optimal CEO firing policy along with the timing and frequency of CEO turnover, as well as the relationship between CEO dismissals, firm-specific profitability, and stock market valuations. Since this dynamic discrete choice model has no known analytical solution it must be solved numerically and therefore I present graphs of empirical simulations rather than formal propositions.

3.3.3.1. Calibration. The nine model parameters are assumed to be constant over time and across firms: the prior mean CEO ability μ_0, the prior dispersion of CEO ability σ_0, the persistence of firm-specific profitability ϕ, the dispersion of firm-specific profitability shocks σ_ϵ, the dispersion of the market's public signal σ_m, the dispersion of the board's private signal σ_b, the firm's financial cost of CEO turnover $c^{(firm)}$, the board's disutility cost of turnover $c^{(pers)}/\kappa$, and the quarterly discount factor β.

Since CEO ability is expressed as the industry-adjusted operating return and the model assumes a normal distribution, I set the expected prior CEO ability to zero, i.e. $\mu_0 = 0\%$. Consistent with the accounting literature, the quarterly persistence of firm-specific profitability is $\phi = 0.25$. Following Taylor (2010) the prior standard deviation of CEO ability is $\sigma_0 = 2.4\%$, the quarterly standard deviation of firm-specific profitability shocks is $\sigma_\epsilon = 1.7\%$, the quarterly standard deviation of the board's private signal is $\sigma_b = 2.6\%$, the firm's cost is $c^{(firm)} = 1.3\%$, and the board's cost is $c^{(pers)}/\kappa = 4.6\%$. I match the precision of the new market signal to the board signal, i.e. $\sigma_m = 2.6\%$. The quarterly discount factor is set to $\beta = 0.98$ and the maximum CEO tenure is 60 quarters.

3.3.3.2. Predictions. The board updates its belief of CEO ability after observing firm-specific profitability, as well as market and board signals. The board replaces a CEO when this belief falls below an endogenous threshold. The cut-off level is a function of CEO tenure and the model's parameters. Increasing the board's effective turnover cost $c^{(board)} = c^{(pers)}/\kappa$ decreases the threshold belief and probability of a CEO turnover event. The higher the cost to replace a CEO, the lower the acceptable level of expected CEO ability. When CEOs have similar ability, the signals about CEO ability are noisy, or CEO turnover costs are high, then a board has little incentive to replace one CEO with another.

Figure 3.2 shows the average CEO turnover hazard rate by tenure quarter for the simulated sample. Since CEO dismissal is costly, it therefore pays to learn about CEO ability. The CEO turnover hazard is therefore increasing. After the first periods of learning the board is still uncertain about CEO ability and reluctant to fire the CEO. However, if bad performance persists then uncertainty about CEO ability diminishes and firing becomes optimal for low ability CEOs. As a chief executive nears mandatory retirement the residual values fall relative to the present value of unknown successors and turnover increases.

Figure 3.3 displays the market's (blue) and the board's (red) average posterior CEO ability μ around turnover events. The board observes firm-specific profitability, the market's and the board's signals, and then updates its belief about CEO ability. When expected ability falls below the endogenous threshold a CEO turnover event is triggered. The firm then recruits a new chief executive of unknown ability and the posterior mean is reset to the prior mean. The board enjoys inside information and therefore learns about CEO ability faster than the market. The market observes firm-specific profitability, the market's signal, and the board's firing decision to update its belief about CEO ability. The speed of learning is determined by the persistence of firm-specific profitability, the size of firm-specific profitability shocks, and the accuracy of the signals.

Figure 3.4 shows the average firm-specific profitability y around turnover events. The board learns about low CEO ability from low profitability, resulting in a turnover event. When the incumbent is dismissed the firm incurs a one-time CEO turnover cost that reduces firm profitability. A new CEO of higher average ability comes in and gradually restores firm profits. Firm-specific profitability accordingly has a V-shape, and a steep slope indicates a fast rate of board learning about chief executive ability (keeping everything else unchanged).

Figure 3.5 displays Q in event time. Like profitability, firm value Q also displays a V-shape in event-time. Q falls as CEO replacement causes turnover costs that reduce profitability; Q rebounds as profitability is restored by eliminating new, low ability CEOs.

3.4. Estimation

3.4.1. Data

The primary data source is BoardEx which identifies CEOs at U.S. public firms during the sampling period from 1999 to 2008. The dataset is merged with Compustat for accounting and stock market information. This sample is then restricted to non-financial firms[1] with a minimum of $US\$10$ million in total assets where the name of the CEO is known at fiscal quarter beginning and end. Interim CEOs, identified by either the title interim or acting chief executive or CEO tenure of less than 90 days, are excluded. A turnover event occurs when the chief executive at the fiscal quarter-end differs from the CEO at the beginning of a fiscal quarter.

After selecting the initial sample I identify instances of forced CEO turnover. I select news articles from Factiva that contain the name of each departing chief executive during a two-year window around the turnover date to classify the likely cause of the departure. Forced turnover is identified according to the classification used by Parrino (1997): first, all turnover where a CEOs is reported to be fired is classified as forced. Second, all other turnover in which CEOs are under age 60 are reviewed further. If the report does not mention that: (i) the exit is health-related, (ii) the departing CEO either takes a new job in or outside the firm, leaves for personal or other reasons unrelated to the firm, or (iii) the chief executive departs in a natural retirement, then such turnover is also classified as forced.

[1]SIC codes between 6000 and 6999 are excluded

Retirement is natural when a CEO retires and announces it at least six months before leaving the firm.

Forced CEO turnover is then further categorized by the firms governance structure and I select subsamples for CEO duality, inside CEOs, less than median firm size, and first half of the sample. Inside CEOs are executives who have worked at the firm for at least one year before a turnover event. CEO duality is when the chief executive is also the chairperson of the firm.

Table 3.1 shows that the final sample includes 40,417 firm-quarters and 2,315 CEO spells ending with a turnover event, of which 1,130 are forced. The turnover sample is divided further in order to examine the effect of corporate governance on CEO turnover: 1,151 turnover events have a CEO-chair (Duality), 1,400 have inside CEOs (Insider), 1,158 are from small firms (Small), and 1,031 are from the first half of the sample (Early). The present sample is to the author's best knowledge the most comprehensive for CEO turnover during the sampling period.

3.4.2. Identification

In this section I motivate the assumptions that identify the model's parameters. The model parameters are constant over time and across firms. Eight of the model parameters[2] are estimated:

$$\Theta = \{\mu_0, \sigma_0, \phi, \sigma_\epsilon, \sigma_m, \sigma_b, c^{(firm)}, c^{(pers)}/\kappa\} \tag{3.14}$$

[2]I use a quarterly discount factor of $\beta = 0.98$ and a rate of voluntary CEO turnover $f(\tau)$ estimated from the sample.

i.e. the prior mean CEO ability μ_0, the prior dispersion of CEO ability σ_0, the persistence of firm-specific profitability ϕ, the dispersion of firm-specific profitability shocks σ_ϵ, the dispersion of the market's public signal σ_m, the dispersion of the board's private signal σ_b, the firm's financial cost of CEO turnover $c^{(firm)}$, and the board's disutility cost of turnover $c^{(pers)}/\kappa$.

In the model firm-specific return is:

$$y_t = \phi\alpha_i + (1-\phi)y_{t-1} + \epsilon_t \tag{3.15}$$

where $\alpha_i \sim \mathcal{N}(\mu_0, \sigma_0^2)$ and $\epsilon_t \sim N(0, \sigma_\epsilon^2)$. Therefore μ_0, ϕ, σ_ϵ, and σ_0 can be identified from firm-specific returns. CEO ability directly affects firm-specific returns; therefore for $0 < \phi \leq 1$, prior mean CEO ability μ_0 is identified by the average firm-specific profitability. The persistence of firm-specific profitability ϕ is identified by the first-order time-series auto-correlation of firm-specific profitability. The dispersion of firm-specific profitability shocks σ_ϵ, is identified by the time series variance of ϵ_t.

Firm-specific returns can be rewritten in order to yield persistence-adjusted returns (Taylor (2010)):

$$X_{it} = \frac{y_t - (1-\phi)y_{t-1}}{\phi} = \alpha_i + \frac{\epsilon_t}{\phi} \tag{3.16}$$

with variance:

$$Var(X_{it}) = \sigma_0^2 + \frac{\sigma_\epsilon^2}{\phi^2} \tag{3.17}$$

Within each CEO spell i, ability is constant. The dispersion of firm-specific profitability shocks σ_ϵ can therefore also be identified using the variance of persistence-adjusted returns within CEO spells. For known persistence of profitability ϕ and dispersion of profitability shocks σ_ϵ the prior dispersion of CEO ability σ_0 can be backed out from the variance of persistence-adjusted returns across CEOs.

The period-by-period change in Q within each CEO spell is directly related to the market's change in expectations about the CEO's ability. Equation (3.8) shows that the precision of the market's public signal is directly related to the variance of the market's expectations about CEO ability. The standard deviation of the market's public signal is therefore indirectly related to the change in Q. The lower the dispersion of the market's publicly signal σ_m, the higher the market's speed of learning for each tenure period τ_t and the lower the dispersion in the market's expectation of CEO ability. Therefore, if the persistence of profitability ϕ, the dispersion of profitability shocks σ_ϵ, and the prior dispersion of CEO ability σ_0 are known, then the dispersion of the market's public signal σ_m can be backed out from the change in average Q within CEO spells.

The time-series change in Q within each CEO spell is also directly related to the board's change in expectations about the CEO's ability. Equation (3.5) shows that precision of the board's public signal is directly related to the variance of the board's expectations about CEO ability. The standard deviation of the board's public signal is therefore indirectly related to the change in Q. The lower the dispersion of the market's publicly signal σ_m, the higher the market's speed of learning for each tenure period τ_t and the lower the dispersion in the market's expectation of CEO ability. The lower dispersion of the board's publicly signal σ_b, the higher the board's speed of learning for each tenure period τ_t, and the lower the dispersion in the board's expectation of CEO ability. If the persistence of profitability ϕ, the dispersion of profitability error σ_ϵ, the prior dispersion of CEO ability σ_0, and the dispersion of the market's publicly signal σ_m are known, then the dispersion of the board's publicly signal σ_b can be backed out from the change in Q within CEO spells.

The board's speed of learning about CEO ability also has an effect on the CEO turnover rate and profitability around turnover events. The higher the speed of learning, the sooner the board replaces low-ability CEOs, the higher the turnover hazard rate in early tenure periods, and the steeper the slope in firm-specific profitability around CEO turnover events. The change of firm-specific profitability around CEO turnover therefore also identifies σ_b.

The firm's turnover cost $c^{(firm)}$ is identified using the average decrease in firm-specific profitability during the period of the forced CEO turnover event. Increasing the board's total cost of turnover $c = c^{(firm)} + c^{(board)}$ decreases the threshold belief of CEO ability and the likelihood of a CEO turnover event. The probability of CEO turnover at different tenure points therefore identifies the total turnover cost.

3.4.3. Simulated Method of Moments

No closed-form solutions are available for most dynamic discrete choice models. For a numerical solution I use the simulated method of moments (SMM) with a Matlab toolkit provided by Miranda and Fackler (2004) and Fackler and Tastan (2008). SMM estimates the parameters of structural economic models by simulating data and determining the parameters that minimize a criterion function for a set of moment conditions. SMM therefore consists of two parts: an economic model that describes the mapping of the parameters, shocks, and exogenous variables into the endogenous variables, and a set of moment conditions that are estimated in reduced form. The SMM estimates of parameters $\widehat{\theta}$ are determined by solving:

$$\widehat{\theta} = \arg\min_{\theta} \left(\widehat{M} - \frac{1}{S} \sum_{s}^{S} \widehat{m}_s(y(\theta)) \right)' W \left(\widehat{M} - \frac{1}{S} \sum_{s}^{S} \widehat{m}_s(y(\theta)) \right) \tag{3.18}$$

where $\widehat{M}$ is the vector of sample moments and $\widehat{m}_s(y(\theta))$ is the vector of moments from simulation s of the endogenous variables y generated by the set of parameters θ. W is the efficient weighting matrix estimated as the inverse of the covariance matrix of moments M. Since the model can have multiple equilibria I use a simulated annealing algorithm in order to avoid being stuck in local minima.

The model's eight parameters are identified using 20 moment conditions and estimated with the following pooled regressions for forced CEO turnover:

$$y_{it} = \lambda_0 + \lambda_1 y_{it-1} + \Delta^{(-4/-3)} + \Delta^{(-2/-1)} + \Delta^{(0)} + \Delta^{(1/2)} + \Delta^{(3/4)} + \delta_{it} \tag{3.19}$$

$$\delta_{it}^2 = Var(\delta) + u_{it} \tag{3.20}$$

$$d_{it} = h^{(1-4)} + h^{(5-12)} + h^{(13-20)} + h^{(20+)} + v_{it} \tag{3.21}$$

$$Var_i(X_{it}) = E(Var(X)) + w_{it} \tag{3.22}$$

$$(E_i(X_{it}) - E(E_i(X_{it})))^2 = Var(E(X)) + e_{it} \tag{3.23}$$

$$Q_{it} - Q_{it-1} = \gamma_0 + \gamma^{(-4/-3)} + \gamma^{(-2/-1)} + \gamma^{(0)} + \gamma^{(1/2)} + \gamma^{(3/4)} + \vartheta_{it} \tag{3.24}$$

The first seven moment conditions are the regression coefficients of Equation (3.19). y_{it} is the firm-specific profitability[3], λ_0 is a constant and identifies prior CEO ability μ_0, and λ_1 is the first-order auto-regression coefficient that identifies the persistence of profitability ϕ. The coefficients $\Delta^{(k)}$ are event quarter-fixed effects, conditioned on CEO turnover during period $t+k$. The turnover period indicator $\Delta^{(0)}$ identifies the firm's CEO turnover cost $c^{(firm)}$. The persistence of profitability and the board's speed of learning CEO ability determine the steepness

[3] $y_{it} = Y_{it} - Y_{it}^{(ind)}$, where Y_{it} is the firm's profitability calculated from quarterly Compustat data item OIADPQ divided by average AT. I subtract the median profitability using the Fama-French 12 industry classification.

in the V-shaped profitability curve around turnover events that jointly identifies σ_m and σ_b.

The eighth moment in Equation (3.20) is the variance of the residual in Equation (3.19) that identifies the dispersion of profitability error σ_ϵ.

The next four moment conditions are hazard rates for forced CEO turnover. d_{it} is an indicator for forced CEO turnover, and $h^{(k)}$ is a tenure-fixed effect, conditioned on CEO tenure interval k that identifies the board's effective turnover cost $c^{(board)}$.

Moments 13 and 14 use persistence-adjusted firm-specific profits $\widehat{X}_{it} = (y_{it} - \widehat{\lambda}_1 y_{it-1})/(1 - \widehat{\lambda}_1)$, where $\widehat{\lambda}_1$ is estimated in Equation (3.19). Equation (3.22) estimates the variance of the persistence-adjusted firm-specific profitability averaged within CEO spells, and identifies the standard deviation of profitability error σ_ϵ. Equation (3.23) estimates the variance of mean persistence-adjusted firm-specific profitability across CEO spells and identifies the standard deviation of CEO ability σ_0.

The remaining six moments in Equation (3.24) use the first difference in log Q[4] within CEO spells. The coefficients $\gamma^{(k)}$ are event time-fixed effects conditioned on CEO turnover in period $t+k$, and γ_0 is a constant. The persistence of profitability and the market's speed of learning CEO ability determine the steepness in the V-shaped Q curve around turnover events and identifies σ_m. Using differences in logs

[4] $Q_{it} = \log(Q_{it}^{(firm)}/Q_{it}^{(ind)})$, where Q_{it} is the market-to-book ratio calculated from quarterly Compustat data using (ATQ + PRCCD * CSHOQ - CEQQ - TXDBQ) / ATQ. The denominator is the industry median using the Fama-French 12 industry classification.

is akin stock returns and eliminates the effect of unobserved firm heterogeneity on the level of Q.

3.5. Empirical Results

3.5.1. Parameter Estimates

The baseline estimates for the model's eight parameters are presented in Table 3.2.

The initial CEO talent pool is defined by the prior mean and dispersion of CEO ability. The prior mean μ_0 is the expected industry-adjusted annual operating return on assets (OROA) for a new CEO and measures initial expectations about CEO ability. The prior dispersion σ_0 is the standard deviation in industry-adjusted annual OROA for new CEOs and measures initial uncertainty about CEO ability. The estimated prior mean CEO ability μ_0 is 0.68% per quarter with a 95% confidence interval [0.67%, 0.69%]. The procedure used to industry-adjust, effectively sets median firm-specific profitability to zero. However, since mean ability is slightly greater than zero then CEO ability is right-skewed; there are some high CEO ability outliers. The estimated prior dispersion of CEO ability is σ_0 is 0.44% per quarter with a 95% confidence interval [0.43%, 0.45%]. Comparing new CEOs at the 5th and 95th percentile of ability shows an OROA difference of $2 \times 1.96 \times \sigma_0 \times \sqrt{4} = 3.45\%$ per year. The estimated difference is slightly less than in Bertrand and Schoar (2003), and Taylor (2010).

Accounting returns are generally known to be persistent (Fama and French (2000)). It comes as no surprise that the estimated quarterly firm-specific profitability persistence ϕ is 0.369 (with 95% confidence interval [0.368, 0.370]), showing some mean-reversion.

The shock in accounting returns y is modeled with the error term in firm-specific profitability ϵ. The estimated standard deviation for the profitability error σ_ϵ is 1.74% per quarter with a 95% confidence interval [1.72%, 1.76%].

The shock in the firm's stock market valuation Q is modeled using the market's public signal of CEO ability z_m. The estimated standard deviation for the market's public signal σ_m is 2.04% per quarter with a 95% confidence interval [2.02%, 2.06%]. It is useful to compare the influence of the market's public signal to the profitability signal's. Taylor (2010) shows that the effect of a one standard deviation z_m shock on expected CEO ability is $P_m = \sigma_\epsilon/(\phi\sigma_m)$ times larger than a one standard deviation profitability shock. Accordingly, the market's public signal is 2.3 times more influential than the profitability signal.

The shock in the board's CEO turnover decision d is modeled using the board's private signal of CEO ability z_b. The estimated standard deviation for the board's public signal σ_b is 2.22% per quarter with a 95% confidence interval [2.19%, 2.26%]. The effect of a one standard deviation z_b shock on expected CEO ability is $P_b = \sigma_\epsilon/(\phi\sigma_b)$ times larger than a one standard deviation profitability shock. The board's private signal is therefore 2.1 times more influential than the profitability signal.

The board's learning about CEO ability is influenced by the stock market's public signal, the board's private signal, and operating returns in a ratio of 2.3 : 2.1 : 1. When learning about CEO ability corporate boards rely primarily on public stock market information and inside information available only to the board, but are less concerned with accounting data.

The firm's cost of turnover relates to a decline in profitability during the quarter when the incumbent CEO departs. The firm's estimated cost of CEO turnover $c^{(firm)}$ is 1.92% in terms of firm assets with a 95% confidence interval [1.89%, 1.96%]. The firm's CEO turnover cost amount is US\$148 million (US\$11 million) for the mean (median) sample firm. This amount is lower than in Taylor (2010), possibly because I only consider one calendar quarter of turnover cost.

The board's effective turnover cost is the financial equivalent of directors' distaste for firing CEOs. The board's estimated total CEO turnover cost $c = c^{(firm)} + c^{(board)}$ is 2.99% of the firm's assets. The board's total CEO turnover cost amount is US\$230 million (US\$17 million) for the mean (median) sample firm. This amount is also less than in Taylor (2010). The board has substantial disutility from firing a CEO and behaves as if it costs the average firm US\$230 million to do so. However, the real financial cost to the average firm is only US\$148 million. Corporate boards are reluctant to dismiss CEOs and retain some low ability CEOs that shareholders would rather have fired. This wedge between shareholder interest and board behavior is consistent with CEO entrenchment.

3.5.2. Model Fit

The overall fit of the model can be measured using a χ^2 test of the over-identifying restrictions, which uses 20 moments conditions for eight parameter estimates. The p-value rejects the null hypothesis at the 1% confidence level that all simulated moments are equal to their sample counterparts. However, this rejection is not particularly surprising because any model can be rejected with a large enough sample. The present data set has $1,130$ forced turnover events and is quite large.

It is therefore relevant to investigate the 20 moments separately in order to assess any specific failures in model fit. Table 3.3 shows each empirical and simulated moment condition separately, testing for the difference. For 3 of the 20 moment conditions equality cannot be rejected at the 1% confidence level. The model matches the moments for the change in Q reasonably well: the difference in moments for the constant γ_0, and the event quarter-fixed effect $\gamma^{(3/4)}$ are statistically insignificant. The event quarter-fixed effects $\gamma^{(-4/-3)}$ and $\gamma^{(-2/-1)}$ are greater, and $\gamma^{(0)}$ and $\gamma^{(1/2)}$ are smaller than the empirical moments. The model also matches the overall firm-specific profitability y quite well: the difference in moments for the constant λ_0, the AR1 coefficient λ_0, and the event-quarter-fixed effects $\Delta^{(-4/-3)}$, $\Delta^{(-2/-1)}$, $\Delta^{(1/2)}$, and $\Delta^{(3/4)}$ are either economically or statistically insignificant. Only the event-quarter-fixed effect $\Delta^{(0)}$ is significantly lower than the empirical moments. The model does not match the hazard rates very well: the simulated moments $h^{(1/4)}$, $h^{(5/12)}$, $h^{(13/20)}$, and $h^{(20+)}$ are significantly lower than their empirical counterparts. Similarly, the model does not match the volatilities very well: the first and second measures of time-series volatility in profitability $Var(\delta)$, and $E(Var(X))$, and the dispersion of average profitability across CEOs $Var(E(X))$, are all lower than the empirical moments.

There seems to be a reasonable match between model and empirical data. The match could possibly be improved by extending the period over which CEO turnover costs are realized. Then CEO turnover would be costlier and lower CEO turnover hazard rates would better match the data.

3.6. Conclusion

CEO ability affects firm performance but is difficult to measure. Corporate boards learn from accounting returns, stock market valuations, and private signals about CEO ability and make costly CEO turnover decisions. Using a dynamic model with a rational board of directors that maximizes expected utility, I estimate the model's parameters using the simulated method of moments (SMM) applied to a new quarterly sample of firm profitability, stock prices, and both voluntary and forced CEO turnover for listed U.S. firms. The estimated model parameters include the mean and variance in the ability of new CEOs, the variance and persistence in firm-specific profitability, the variance in the market's public and the board's private signals of CEO ability, the firm's cost of chief executive turnover, and the board's disutility cost of CEO turnover.

I find that learning about CEO ability is influenced by the market's public signal, the board's private signal, and the profitability signal in a ratio of 2.3 : 2.1 : 1. When learning about CEO ability corporate boards rely primarily on public stock market information and private board information, but are less concerned with accounting data

The dispersion of CEO ability is economically significant, indicating that CEO ability matters for firm profitability. There is also a significant cost of CEO turnover. The board's effective total turnover cost is 2.99% of firm assets (or US\$230 million for the average firm); however, the real financial cost to the firm is 1.92% of total assets (or US\$148 million for the average firm). Corporate boards are reluctant to dismiss CEOs and retain some low ability CEOs that shareholders would rather have fired. This wedge between shareholder interest and board behavior is consistent with CEO entrenchment.

3.7. Figures and Tables

Figure 3.1: Timeline

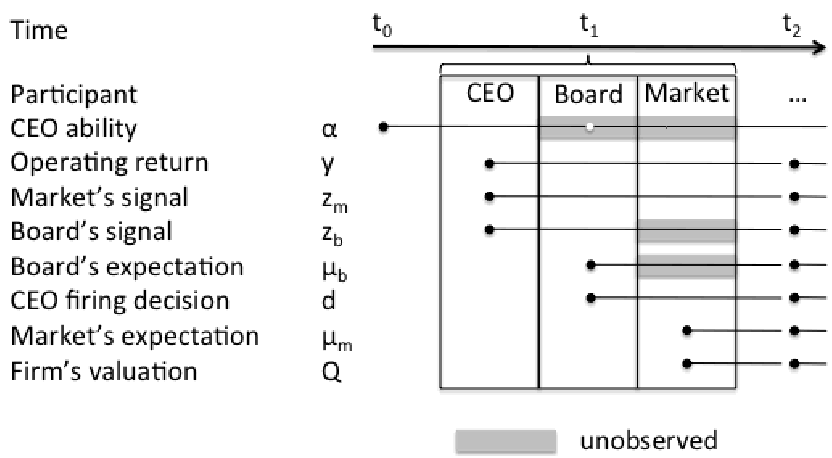

Figure 3.2: CEO Dismissal Hazard Rate

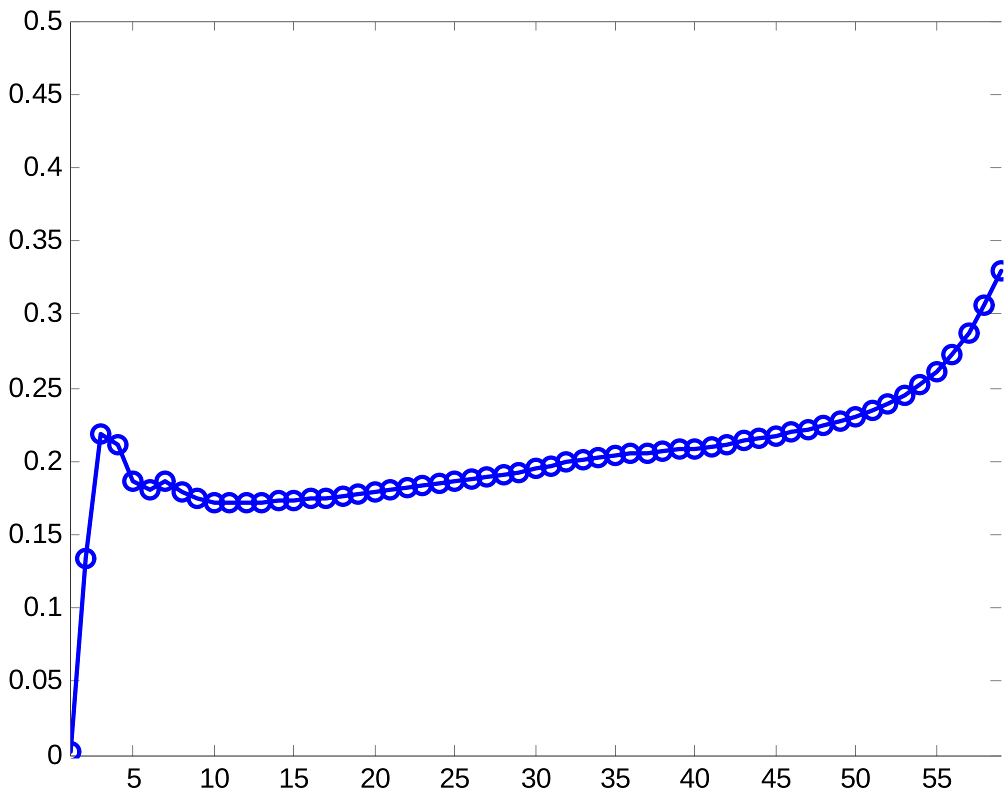

Figure 3.3: Expected Ability Around CEO Dismissals

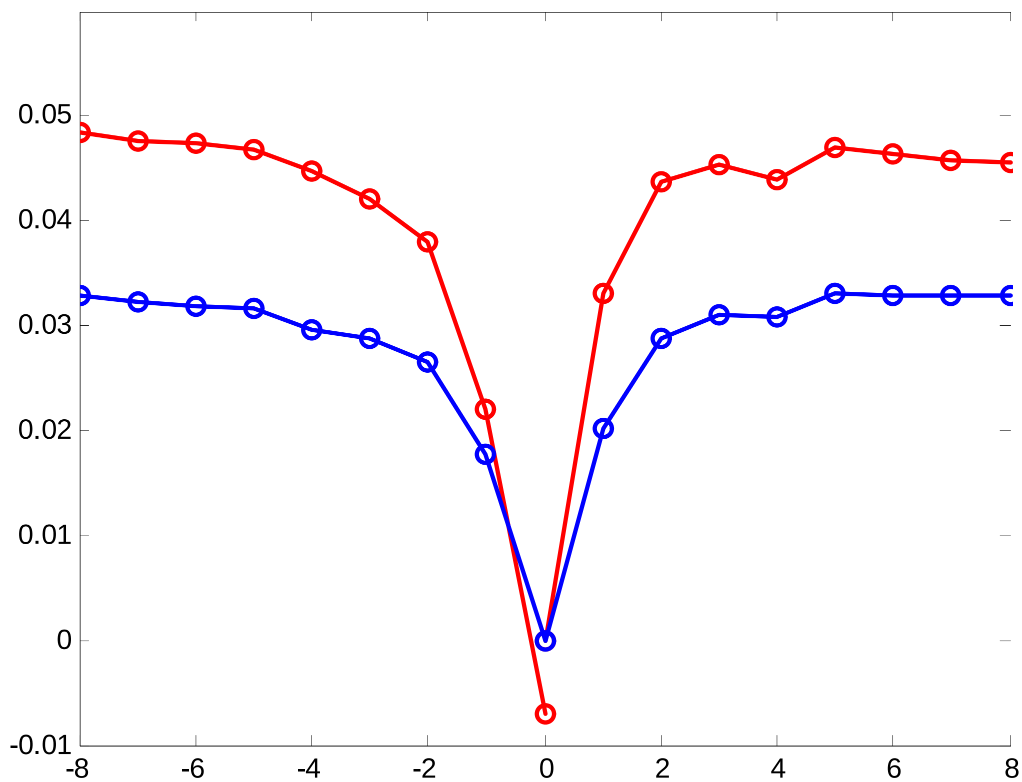

Figure 3.4: Firm-Specific Profitability Around CEO Dismissals

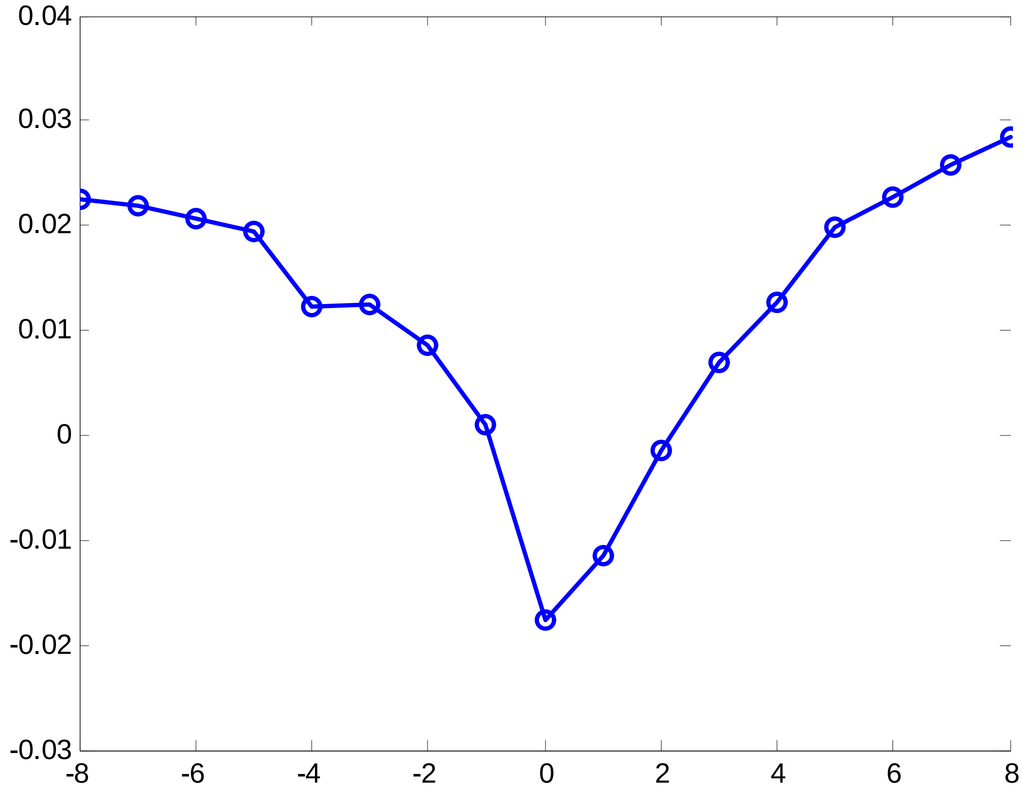

Figure 3.5: Average Q Around CEO Dismissals

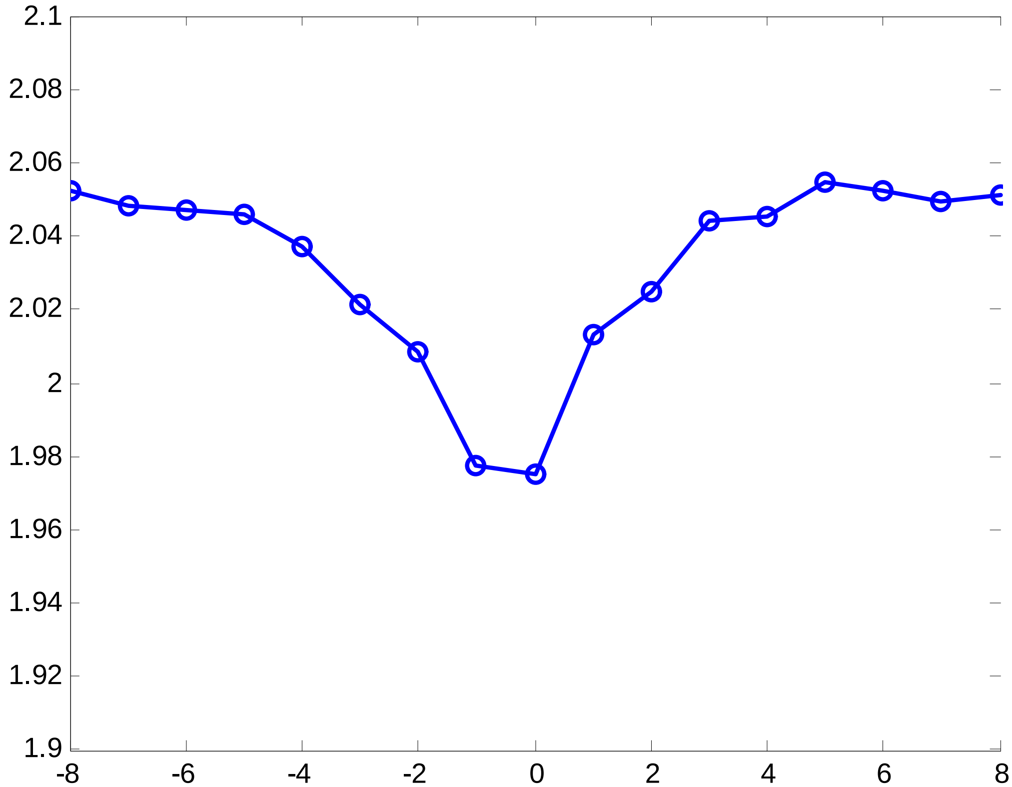

Table 3.1: Descriptive Statistics for Turnover Sample

	All Firm-Quarters	All Turnover	Forced	Duality	Insider	Small	Early
MB	1.324	1.137***	1.151***	1.165***	1.150***	1.174***	1.149***
	(0.00776)	(0.0197)	(0.0263)	(0.0283)	(0.0254)	(0.0321)	(0.0257)
OROA	0.00102	-0.0112***	-0.0152***	-0.00288**	-0.00524***	-0.0312***	-0.00200
	(0.000464)	(0.00163)	(0.00244)	(0.00200)	(0.00167)	(0.00289)	(0.00207)
Assets	7696.4	9868.0	14947.1**	11839.0**	8363.5	152.2***	7492.1
	(278.6)	(1671.2)	(3082.9)	(2141.1)	(1971.8)	(286.8)	(1557.2)
CEO tenure	16.39	17.60***	16.66	22.90***	18.50***	14.41***	16.90
	(0.0750)	(0.337)	(0.452)	(0.540)	(0.466)	(0.403)	(0.498)
N	40,417	2,315	1,130	1,151	1,400	1,158	1,031

Table 3.2: Parameter Estimates

μ_0	σ_0	ϕ	σ_ϵ	σ_m	σ_b	$c^{(firm)}$	$c^{(pers)}$
0.0047	0.0022	0.3720	0.0051	0.2383	0.0032	0.0118	0.0028
0.0001	0.0000	0.0017	0.0001	20.8589	0.0001	0.0003	0.0001

Table 3.3: Moments Used in SMM Estimation

Moment	Notation	Empirical	Simulated	Difference	SE	p
1	λ_0	0.001	0.002	0.001	0.000	0.004
2	λ_1	0.702	0.653	-0.049	0.004	0.000
3	$\Delta^{(-4/-3)}$	-0.007	0.002	0.010	0.001	0.000
4	$\Delta^{(-2/-1)}$	-0.002	0.001	0.003	0.001	0.001
5	$\Delta^{(0)}$	0.000	-0.028	-0.028	0.001	0.000
6	$\Delta^{(1/2)}$	-0.003	-0.000	0.002	0.001	0.015
7	$\Delta^{(3/4)}$	-0.007	-0.000	0.007	0.001	0.000
8	$Var(\delta)$	0.007	0.000	-0.007	0.001	0.000
9	$h^{(1/4)}$	0.070	-0.000	-0.070	0.003	0.000
10	$h^{(5/12)}$	0.061	-0.000	-0.061	0.003	0.000
11	$h^{(13/20)}$	0.057	-0.000	-0.057	0.005	0.000
12	$h^{(20+)}$	0.070	-0.000	-0.070	0.006	0.000
13	$E(Var(X))$	0.034	0.001	-0.033	0.004	0.000
14	$Var(E(X))$	0.013	0.000	-0.013	0.001	0.000
15	γ_0	-0.004	-0.001	0.003	0.001	0.018
16	$\gamma^{(-4/-3)}$	-0.017	0.001	0.019	0.003	0.000
17	$\gamma^{(-2/-1)}$	-0.025	-0.002	0.022	0.003	0.000
18	$\gamma^{(0)}$	0.033	0.061	0.027	0.004	0.000
19	$\gamma^{(1/2)}$	0.012	-0.035	-0.047	0.003	0.000
20	$\gamma^{(3/4)}$	0.008	0.011	0.004	0.003	0.113

3.8. Proofs

3.8.1. The Board's Learning Problem

Proof. Equation (3.4)

The problem is a Kalman filter with a constant parameter matrix (see Hamilton (1994), chapter 13.2).

The recursion begins with:

$$
\begin{aligned}
\widehat{\boldsymbol{\xi}}_{1|0} &= \mathbb{E}(\boldsymbol{\xi}_1) \equiv \boldsymbol{\mu}_0 \\
\mathbf{P}_{1|0} &= \mathbb{E}((\boldsymbol{\xi}_1 - \widehat{\boldsymbol{\xi}}_1)(\boldsymbol{\xi}_1 - \widehat{\boldsymbol{\xi}}_1)') \equiv \boldsymbol{\sigma}_0^2
\end{aligned}
$$

and updates inferences regarding state variable and associated MSE according to:

$$
\begin{aligned}
\widehat{\boldsymbol{\xi}}_{t+1|t} &= \mathbb{E}_t(\boldsymbol{\xi}_{t+1}) \equiv \boldsymbol{\mu}_t \\
&= \mathbf{F}\widehat{\boldsymbol{\xi}}_{t|t-1} + \mathbf{K}_t\boldsymbol{\delta}_t \\
\widehat{\mathbf{P}}_{t+1|t} &= \mathbb{E}_t((\boldsymbol{\xi}_{t+1} - \widehat{\boldsymbol{\xi}}_{t+1})(\boldsymbol{\xi}_{t+1} - \widehat{\boldsymbol{\xi}}_{t+1})') \equiv \boldsymbol{\sigma}_t^2 \\
&= (\mathbf{F} - \mathbf{K}_t\mathbf{H}')\mathbf{P}_{t|t-1}(\mathbf{F}' - \mathbf{H}\mathbf{K}_t') + \mathbf{K}_t\mathbf{R}\mathbf{K}_t' + \mathbf{Q}
\end{aligned}
$$

with gain matrix and innovation:

$$
\begin{aligned}
\mathbf{K}_t &= \mathbf{F}\mathbf{P}_{t|t-1}\mathbf{H}(\mathbf{H}'\mathbf{P}_{t|t-1}\mathbf{H} + \mathbf{R})^{-1} \\
\boldsymbol{\delta}_t &= \mathbf{y}_t - \mathbf{A}'\mathbf{x}_t - \mathbf{H}'\widehat{\boldsymbol{\xi}}_{t|t-1}
\end{aligned}
$$

The state equation is then:

$$\underbrace{\alpha_{t+1}}_{\boldsymbol{\xi}_{t+1}} = \underbrace{1}_{\mathbf{F}} \underbrace{\alpha_t}_{\boldsymbol{\xi}_t} + \underbrace{v_t}_{\mathbf{v}_t}$$

and the observation equations are:

$$\underbrace{\begin{bmatrix} \frac{y_t}{\phi} \\ z_{m,t} \\ z_{b,t} \end{bmatrix}}_{\mathbf{y}_t} = \underbrace{\begin{bmatrix} \frac{1}{\phi} - 1 \\ 0 \\ 0 \end{bmatrix}}_{\mathbf{A}'} \underbrace{y_{t-1}}_{\mathbf{x}_t} + \underbrace{\begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}}_{\mathbf{H}'} \underbrace{\alpha_t}_{\boldsymbol{\xi}_t} + \underbrace{\begin{bmatrix} \frac{\epsilon_{y,t}}{\phi} \\ \epsilon_{z_{m,t}} \\ \epsilon_{z_{b,t}} \end{bmatrix}}_{\mathbf{w}_t}$$

The terms $\mathbf{v}_t$ and $\mathbf{w}_t$ are white noise and satisfy:

$$\begin{aligned}
\mathbb{E}_t(\mathbf{v}_t \mathbf{v}_\tau) &= \begin{cases} \mathbf{Q} = \mathbf{0} & \text{for } t = \tau \\ \mathbf{0} & \text{otherwise} \end{cases} \\
\mathbb{E}_t(\mathbf{w}_t \mathbf{w}'_\tau) &= \begin{cases} \mathbf{R} = \begin{bmatrix} \sigma_\epsilon^2/\phi^2 & 0 & 0 \\ 0 & \sigma_m^2 & 0 \\ 0 & 0 & \sigma_b^2 \end{bmatrix} & \text{for } t = \tau \\ 0 & \text{otherwise} \end{cases} \\
\mathbb{E}_t(\mathbf{v}_t \mathbf{w}'_\tau) &= \mathbf{0}' \text{ for all } t \text{ and } \tau \\
\mathbb{E}_t(\mathbf{v}_t \boldsymbol{\xi}_1) &= \mathbf{0} \text{ for all } t \\
\mathbb{E}_t(\mathbf{w}_t \boldsymbol{\xi}_1) &= \mathbf{0} \text{ for all } t
\end{aligned}$$

Applying standard results yields:

$$\begin{aligned}
\mu_t &= \mu_{t-1} + \mathbf{K}_t \boldsymbol{\delta}_t \\
&= \mu_{t-1} + \sigma_t^2 \Big(\frac{\phi^2}{\sigma_\epsilon^2}\big(\frac{1}{\phi}(y_t - y_{t-1}) - y_{t-1} - \mu_{t-1}\big) + \frac{1}{\sigma_m^2}(z_{m,t} - \mu_{t-1}) + \frac{1}{\sigma_b^2}(z_{b,t} - \mu_{t-1})\Big) \\
\sigma_t^2 &= (\mathbf{F} - \mathbf{K}_t \mathbf{H}')\mathbf{P}_{t|t-1}(\mathbf{F}' - \mathbf{H}\mathbf{K}_t') + \mathbf{K}_t \mathbf{R} \mathbf{K}_t' + \mathbf{Q} \\
&= (1 - \mathbf{K}_t \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix})\sigma_{t-1}^2 (1 - \begin{bmatrix} 1 & 1 & 1 \end{bmatrix} \mathbf{K}_t') + \mathbf{K}_t \begin{bmatrix} \sigma_\epsilon^2/\phi^2 & 0 & 0 \\ 0 & \sigma_m^2 & 0 \\ 0 & 0 & \sigma_b^2 \end{bmatrix} \mathbf{K}_t' \\
&= \frac{\sigma_{t-1}^2}{1 + \sigma_{t-1}^2 (\frac{\phi^2}{\sigma_\epsilon^2} + \frac{1}{\sigma_m^2} + \frac{1}{\sigma_b^2})} \\
&= \frac{\sigma_0^2}{1 + t\sigma_0^2 (\frac{\phi^2}{\sigma_\epsilon^2} + \frac{1}{\sigma_m^2} + \frac{1}{\sigma_b^2})} \\
\mathbf{K}_t &= \mathbf{F}\mathbf{P}_{t|t-1}\mathbf{H}(\mathbf{H}'\mathbf{P}_{t|t-1}\mathbf{H} + \mathbf{R})^{-1} \\
&= \sigma_{t-1}^2 \begin{bmatrix} 1 & 1 & 1 \end{bmatrix} \left(\begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} \boldsymbol{\sigma^2_{t-1}} \begin{bmatrix} 1 & 1 & 1 \end{bmatrix} + \begin{bmatrix} \sigma_\epsilon^2/\phi^2 & 0 & 0 \\ 0 & \sigma_m^2 & 0 \\ 0 & 0 & \sigma_b^2 \end{bmatrix} \right)^{-1} \\
&= \frac{\sigma_{t-1}^2}{1 + \sigma_{t-1}^2 (\frac{\phi^2}{\sigma_\epsilon^2} + \frac{1}{\sigma_m^2} + \frac{1}{\sigma_b^2})} \begin{bmatrix} \frac{\phi^2}{\sigma_\epsilon^2} & \frac{1}{\sigma_m^2} & \frac{1}{\sigma_b^2} \end{bmatrix} \\
&= \sigma_t^2 \begin{bmatrix} \frac{\phi^2}{\sigma_\epsilon^2} & \frac{1}{\sigma_m^2} & \frac{1}{\sigma_b^2} \end{bmatrix} \\
\boldsymbol{\delta}_t &= \mathbf{y}_t - \mathbf{A}'\mathbf{x}_t - \mathbf{H}'\widehat{\boldsymbol{\xi}}_{t|t-1} \\
&= \begin{bmatrix} \frac{1}{\phi}(y_t - y_{t-1}) - y_{t-1} - \mu_{t-1} \\ z_{m,t} - \mu_{t-1} \\ z_{b,t} - \mu_{t-1} \end{bmatrix}
\end{aligned}$$

Therefore:

$$\mu_{b,t} = \mu_{b,t-1} + \sigma^2_{b,t} \begin{bmatrix} \frac{\phi^2}{\sigma^2_\epsilon} & \frac{1}{\sigma^2_m} & \frac{1}{\sigma^2_b} \end{bmatrix} \begin{bmatrix} \delta_{y,t} \\ \delta_{m,t} \\ \delta_{b,t} \end{bmatrix} \tag{3.25}$$

$$\sigma^2_{b,t} = \frac{\sigma^2_0}{1 + \tau_t \sigma^2_0 (\frac{\phi^2}{\sigma^2_\epsilon} + \frac{1}{\sigma^2_m} + \frac{1}{\sigma^2_b})}$$

$$\begin{bmatrix} \delta_{y,t} \\ \delta_{m,t} \\ \delta_{b,t} \end{bmatrix} = \begin{bmatrix} \frac{1}{\phi}(y_t - y_{t-1}) - y_{t-1} - \mu_{b,t-1} \\ z_{m,t} - \mu_{b,t-1} \\ z_{b,t} - \mu_{b,t-1} \end{bmatrix}$$

Note that:

$Var(\delta_{y,t}) = \sigma^2_\epsilon / \phi^2 + \sigma^2(\tau)$

$Var(\delta_{m,t}) = \sigma^2_m + \sigma^2(\tau)$

$Var(\delta_{b,t}) = \sigma^2_b + \sigma^2(\tau)$

Subtract μ_0 from both sides and forward one period, and then:

$$\eta_{t+1} = \eta_t + \sigma^2(\tau_{t+1}) \begin{bmatrix} \frac{\phi^2}{\sigma^2_\epsilon} & \frac{1}{\sigma^2_m} & \frac{1}{\sigma^2_b} \end{bmatrix} \begin{bmatrix} \delta_{y,t+1} \\ \delta_{m,t+1} \\ \delta_{b,t+1} \end{bmatrix}$$

where:

$$\begin{bmatrix} \delta_{y,t+1} \\ \delta_{m,t+1} \\ \delta_{b,t+1} \end{bmatrix} \sim N(\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \sigma^2_\epsilon/\phi^2 + \sigma^2(\tau_{t+1}) & 0 & 0 \\ 0 & \sigma^2_m + \sigma^2(\tau_{t+1}) & 0 \\ 0 & 0 & \sigma^2_b + \sigma^2(\tau_{t+1}) \end{bmatrix})$$

By standardizing:

$$\begin{bmatrix} \overline{\delta}_{y,t+1} \\ \overline{\delta}_{m,t+1} \\ \overline{\delta}_{b,t+1} \end{bmatrix} = \begin{bmatrix} \delta_{y,t+1}(\sigma_\epsilon^2/\phi^2 + \sigma^2(\tau_{t+1}))^{-\frac{1}{2}} \\ \delta_{m,t+1}(\sigma_m^2 + \sigma^2(\tau_{t+1}))^{-\frac{1}{2}} \\ \delta_{b,t+1}(\sigma_b^2 + \sigma^2(\tau_{t+1}))^{-\frac{1}{2}} \end{bmatrix}$$

we can rewrite:

$$\eta_{t+1} = \eta_t + \sigma^2(\tau_{t+1})$$

$$\begin{bmatrix} \frac{\phi^2}{\sigma_\epsilon^2}\sqrt{\frac{\sigma_\epsilon^2}{\phi^2} + \sigma^2(\tau_{t+1})} & \frac{1}{\sigma_m^2}\sqrt{\sigma_m^2 + \sigma^2(\tau_{t+1})} & \frac{1}{\sigma_b^2}\sqrt{\sigma_b^2 + \sigma^2(\tau_{t+1})} \end{bmatrix} \begin{bmatrix} \overline{\delta}_{y,t+1} \\ \overline{\delta}_{m,t+1} \\ \overline{\delta}_{b,t+1} \end{bmatrix}$$

where:

$$\begin{bmatrix} \overline{\delta}_{y,t+1} \\ \overline{\delta}_{m,t+1} \\ \overline{\delta}_{b,t+1} \end{bmatrix} \sim N(\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix})$$

Therefore:

$$\eta_{b,t+1} = \eta_{b,t} + \sigma_{b,t+1}^2 \begin{bmatrix} \frac{\phi^2}{\sigma_\epsilon^2}\sqrt{\frac{\sigma_\epsilon^2}{\phi^2} + \sigma_{b,t+1}^2} & \frac{1}{\sigma_m^2}\sqrt{\sigma_m^2 + \sigma_{b,t+1}^2} & \frac{1}{\sigma_b^2}\sqrt{\sigma_b^2 + \sigma_{b,t+1}^2} \end{bmatrix} \begin{bmatrix} \overline{\delta}_{y,t+1} \\ \overline{\delta}_{m,t+1} \\ \overline{\delta}_{b,t+1} \end{bmatrix} \tag{3.26}$$

$$\begin{bmatrix} \overline{\delta}_{y,t+1} \\ \overline{\delta}_{m,t+1} \\ \overline{\delta}_{b,t+1} \end{bmatrix} \sim N(\mathbf{0}, \mathbf{I}) \tag{3.27}$$

□

3.8.2. The Board's Optimization Problem

Proof. The board's optimization problem can be solved by dividing (3.1) by B_t and κ, using (3.2) with $c^{(fire)} = c^{(firm)} + \frac{c^{(pers)}}{\kappa}$, and yielding the value function (proof below):

$$\max_{\{d_{t+s}\}_{s=0}^{\infty}} \frac{U_t}{B_t\kappa} = \max_{\{d_{t+s}\}_{s=0}^{\infty}} \mathbb{E}_t \sum_{s=0}^{\infty} \beta^s(\nu_{t+s} + y_{t+s} - b_{t+s}c^{(retire)} - d_{t+s}c^{(fire)}) \tag{3.28}$$

$$= \mathbb{E}_t \sum_{s=0}^{\infty} \beta^s \nu_{t+s} + VF_t$$

$$VF_t = \max_{\{d_{t+s}\}_{s=0}^{\infty}} \mathbb{E}_t \sum_{s=0}^{\infty} \beta^s(y_{t+s} - b_{t+s}c^{(retire)} - d_{t+s}c^{(fire)})$$

$$= y_{t-1}\frac{1-\phi}{1-\beta(1-\phi)} + \frac{\mu_0}{1-\beta}\frac{\phi}{1-\beta(1-\phi)} + \mathbb{E}_t V_t^*$$

$$V_t^* = \max_{d_t}\left\{\eta_{b,t}\frac{\phi}{1-\beta(1-\phi)} - b_t c^{(retire)} - d_t c^{(fire)} + \beta\mathbb{E}_t V_{t+1}^*\right\}$$

with board belief of excess ability $\eta_{b,t} \equiv \mu_{b,t} - \mu_0$.

The Bellman equation is:

$$V(\eta_{b,t}, \tau_t, b_t) = \max_{d_t}\{\eta_{b,t}\frac{\phi}{1-\beta(1-\phi)} - b_t c^{(retire)} - d_t c^{(fire)} + \beta\mathbb{E}_t V(\eta_{b,t+1}, \tau_{t+1}, b_{t+1})\} \tag{3.29}$$

If the current CEO retires ($b_t = 1$), then the firm pays the retirement cost and hires a new chief executive:

$$V^{(retire)} = V(\eta_{b,t}, \tau_t, 1) = V(0,0,0) - c^{(retire)} \tag{3.30}$$

If the CEO does not retire ($b_t = 0$) but gets fired ($d_t = 1$), then the firm pays the firing cost and appoints a new CEO:

$$V^{(fire)} = V(\eta_{b,t}, \tau_t, 0) = V(0,0,0) - c^{(fire)} \tag{3.31}$$

If the firm keeps the CEO ($b_t = 0$ and $d_t = 0$), then:

$$\begin{aligned} V^{(keep)} &= V(\eta_{b,t}, \tau_t, 0) \\ &= \eta_{b,t} \frac{\phi}{1-\beta(1-\phi)} + \beta[f(\tau_t)V^{(retire)} + (1-f(\tau_t))V(\eta_{b,t+1}, \tau_{t+1}, 0)] \end{aligned} \tag{3.32}$$

The board maximizes:

$$V(\eta_{b,t}, \tau_t, 0) = \max_{d_t} \left\{ V^{(keep)}, V^{(fire)} \right\} \tag{3.33}$$

and the policy function is:

$$d_t^* = \arg\max_{d_t} \left\{ V^{(keep)}, V^{(fire)} \right\} \tag{3.34}$$

□

Proof. Solution to Value Function (following Taylor (2010)):

$$\begin{aligned} VF_t &\equiv \max_{\{d_{t+s}\}_{s=0}^{\infty}} \mathbb{E}_t \sum_{s=0}^{\infty} \beta^s (y_{t+s} - b_{t+s} c^{(retire)} - d_{t+s} c^{(fire)}) \\ &= y_{t-1} \frac{1-\phi}{1-\beta(1-\phi)} + \frac{\mu_0}{1-\beta} \frac{\phi}{1-\beta(1-\phi)} \\ &\quad + \frac{\phi}{1-\beta(1-\phi)} \max_{\{d_{t+s}\}_{s=0}^{\infty}} \sum_{s=0}^{\infty} \beta^s \mathbb{E}_t (\eta_{t+s} - b_{t+s} c^{(retire)} - d_{t+s} c^{(fire)}) \end{aligned}$$

$y_t = y_{t-1} + \phi(\alpha_{t-1} - y_{t-1}) + \epsilon_t$

$\frac{1}{\phi}(y_t - y_{t-1}) + y_{t-1} = \alpha_{t-1} + \frac{\epsilon_t}{\phi}$

$\frac{1}{\phi}(y_t - y_{t-1}) + y_{t-1} - \mu_t = \alpha_{t-1} + \frac{\epsilon_t}{\phi} - \mu_t \equiv \delta_{y,t}$

$\phi\alpha_{t-1} + \epsilon_t = \phi\mu_t + \phi\delta_{y,t}$

$y_t = y_{t-1}(1-\phi) + \phi\alpha_{t-1} + \epsilon_t$

$y_t = y_{t-1}(1-\phi) + \phi\mu_t + \phi\delta_{y,t}$

$y_{t+1} = y_t(1-\phi) + \phi\mu_{t+1} + \phi\delta_{y,t+1} =$

$(y_{t-1}(1-\phi) + \phi\mu_t + \phi\delta_{y,t})(1-\phi) + \phi\mu_{t+1} + \phi\delta_{y,t+1} =$

$y_{t-1}(1-\phi)^2 + \phi\mu_t(1-\phi) + \phi\mu_{t+1} + \phi\delta_{y,t}(1-\phi) + \phi\delta_{y,t+1}$

$y_{t+s} = y_{t-1}(1-\phi)^{s+1} + \phi\sum_{\tau=0}^{s} \mu_{t+\tau}(1-\phi)^{s-\tau} + \phi\sum_{\tau=0}^{s} \delta_{y,t+\tau}(1-\phi)^{s-\tau}$

$\mathbb{E}_t[y_{t+s}] = \mathbb{E}_t[y_{t-1}(1-\phi)^{s+1} + \phi\sum_{\tau=0}^{s} \mu_{t+\tau}(1-\phi)^{s-\tau} + \phi\sum_{\tau=0}^{s} \delta_{y,t+\tau}(1-\phi)^{s-\tau}] =$

$y_{t-1}(1-\phi)^{s+1} + \phi\sum_{\tau=0}^{s} \mathbb{E}_t[\mu_{t+\tau}](1-\phi)^{s-\tau} + \phi\sum_{\tau=0}^{s} \mathbb{E}_t[\delta_{y,t+\tau}](1-\phi)^{s-\tau} =$

$y_{t-1}(1-\phi)^{s+1} + \phi\sum_{\tau=0}^{s} \mathbb{E}_t[\mu_{t+\tau}](1-\phi)^{s-\tau}$

$\mathbb{E}_t[\sum_{s=0}^{\infty} \beta^s y_{t+s}] = \sum_{s=0}^{\infty} \beta^s \mathbb{E}_t[y_{t+s}] =$

$$\sum_{s=0}^{\infty} \beta^s (y_{t-1}(1-\phi)^{s+1} + \phi \sum_{\tau=0}^{s} \mathbb{E}_t[\mu_{t+\tau}](1-\phi)^{s-\tau}) =$$

$$y_{t-1}(1-\phi) \sum_{s=0}^{\infty} \beta^s (1-\phi)^s + \phi \sum_{s=0}^{\infty} \sum_{\tau=0}^{s} \beta^s \mathbb{E}_t[\mu_{t+\tau}](1-\phi)^{s-\tau} =$$

$$y_{t-1}\tfrac{1-\phi}{1-\beta(1-\phi)} + \phi \sum_{s=0}^{\infty} \sum_{\tau=0}^{s} \beta^s \mathbb{E}_t[\mu_{t+\tau}](1-\phi)^{s-\tau} =$$

$$y_{t-1}\tfrac{1-\phi}{1-\beta(1-\phi)} + \phi \sum_{\tau=0}^{\infty} \sum_{s=\tau}^{\infty} \beta^s \mathbb{E}_t[\mu_{t+\tau}](1-\phi)^{s-\tau} =$$

$$y_{t-1}\tfrac{1-\phi}{1-\beta(1-\phi)} + \phi \sum_{\tau=0}^{\infty} \mathbb{E}_t[\mu_{t+\tau}](1-\phi)^{-\tau} \sum_{s=\tau}^{\infty} \beta^s (1-\phi)^s =$$

$$y_{t-1}\tfrac{1-\phi}{1-\beta(1-\phi)} + \phi \sum_{\tau=0}^{\infty} \mathbb{E}_t[\mu_{t+\tau}](1-\phi)^{-\tau} \tfrac{(\beta(1-\phi))^\tau}{1-\beta(1-\phi)} =$$

$$y_{t-1}\tfrac{1-\phi}{1-\beta(1-\phi)} + \tfrac{\phi}{1-\beta(1-\phi)} \sum_{\tau=0}^{\infty} \beta^\tau \mathbb{E}_t[\mu_{t+\tau}] =$$

$$y_{t-1}\tfrac{1-\phi}{1-\beta(1-\phi)} + \tfrac{\phi}{1-\beta(1-\phi)} \sum_{s=0}^{\infty} \beta^s (\mu_0 + \mathbb{E}_t[\eta_{t+s}]) =$$

$$y_{t-1}\tfrac{1-\phi}{1-\beta(1-\phi)} + \tfrac{\mu_0}{1-\beta}\tfrac{\phi}{1-\beta(1-\phi)} + \tfrac{\phi}{1-\beta(1-\phi)} \sum_{s=0}^{\infty} \beta^s \mathbb{E}_t[\eta_{t+s}] \qquad \square$$

3.8.3. The Market's Learning Problem

Proof. Equation (3.7)

The market cannot observe the board's private signal about CEO ability. However, by observing that a CEO is repeatedly not fired the market updates its expectation of CEO ability $\mu_{d,t}$, which can also be treated as a signal. The problem is a Kalman filter with a time-varying parameter matrix $\mathbf{R}_t$ (see Hamilton (1994), chapter 13.8).

The recursion begins with:

$$\begin{aligned} \widehat{\boldsymbol{\xi}}_{1|0} &= \mathbb{E}(\boldsymbol{\xi}_1) \equiv \boldsymbol{\mu}_0 \\ \mathbf{P}_{1|0} &= \mathbb{E}((\boldsymbol{\xi}_1 - \widehat{\boldsymbol{\xi}}_1)(\boldsymbol{\xi}_1 - \widehat{\boldsymbol{\xi}}_1)') \equiv \boldsymbol{\sigma}_0^2 \end{aligned}$$

and updates inferences regarding state variable and associated MSE according to:

$$\begin{aligned}
\widehat{\boldsymbol{\xi}}_{t+1|t} &= \mathbb{E}_t(\boldsymbol{\xi}_{t+1}) \equiv \boldsymbol{\mu}_t \\
&= \mathbf{F}\widehat{\boldsymbol{\xi}}_{t|t-1} + \mathbf{K}_t \boldsymbol{\delta}_t \\
\widehat{\mathbf{P}}_{t+1|t} &= \mathbb{E}_t((\boldsymbol{\xi}_{t+1} - \widehat{\boldsymbol{\xi}}_{t+1})(\boldsymbol{\xi}_{t+1} - \widehat{\boldsymbol{\xi}}_{t+1})') \equiv \boldsymbol{\sigma}_t^2 \\
&= (\mathbf{F} - \mathbf{K}_t\mathbf{H}')\mathbf{P}_{t|t-1}(\mathbf{F}' - \mathbf{H}\mathbf{K}_t') + \mathbf{K}_t\mathbf{R}_t\mathbf{K}_t' + \mathbf{Q}
\end{aligned}$$

with gain matrix and innovation:

$$\begin{aligned}
\mathbf{K}_t &= \mathbf{F}\mathbf{P}_{t|t-1}\mathbf{H}(\mathbf{H}'\mathbf{P}_{t|t-1}\mathbf{H} + \mathbf{R}_t)^{-1} \\
\boldsymbol{\delta}_t &= \mathbf{y}_t - \mathbf{A}'\mathbf{x}_t - \mathbf{H}'\widehat{\boldsymbol{\xi}}_{t|t-1}
\end{aligned}$$

The state equation is then:

$$\underbrace{\alpha_{t+1}}_{\boldsymbol{\xi}_{t+1}} = \underbrace{1}_{\mathbf{F}}\underbrace{\alpha_t}_{\boldsymbol{\xi}_t} + \underbrace{v_t}_{\mathbf{v}_t}$$

and the observation equations are:

$$\underbrace{\begin{bmatrix} \frac{y_t}{\phi} \\ z_{m,t} \\ \mu_{d,t} \end{bmatrix}}_{\mathbf{y}_t} = \underbrace{\begin{bmatrix} \frac{1}{\phi} - 1 \\ 0 \\ 0 \end{bmatrix}}_{\mathbf{A}'} \underbrace{y_{t-1}}_{\mathbf{x}_t} + \underbrace{\begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}}_{\mathbf{H}'} \underbrace{\alpha_t}_{\boldsymbol{\xi}_t} + \underbrace{\begin{bmatrix} \frac{\epsilon_{y,t}}{\phi} \\ \epsilon_{z_{m,t}} \\ \epsilon_{\mu_{d,t}} \end{bmatrix}}_{\mathbf{w}_t}$$

The terms $\mathbf{v}_t$ and $\mathbf{w}_t$ are white noise and satisfy:

$$
\begin{aligned}
\mathbb{E}_t(\mathbf{v}_t\mathbf{v}_\tau) &= \begin{cases} \mathbf{Q}=\mathbf{0} & \text{for } t=\tau \\ \mathbf{0} & \text{otherwise} \end{cases} \\
\mathbb{E}_t(\mathbf{w}_t\mathbf{w}'_\tau) &= \begin{cases} \mathbf{R}_t = \begin{bmatrix} \sigma_\epsilon^2/\phi^2 & 0 & 0 \\ 0 & \sigma_m^2 & 0 \\ 0 & 0 & \sigma_{d,t}^2 \end{bmatrix} & \text{for } t=\tau \\ 0 & \text{otherwise} \end{cases} \\
\mathbb{E}_t(\mathbf{v}_t\mathbf{w}'_\tau) &= \mathbf{0}' \text{ for all } t \text{ and } \tau \\
\mathbb{E}_t(\mathbf{v}_t\boldsymbol{\xi}_1) &= \mathbf{0} \text{ for all } t \\
\mathbb{E}_t(\mathbf{w}_t\boldsymbol{\xi}_1) &= \mathbf{0} \text{ for all } t
\end{aligned}
$$

Applying standard results yields:

$$
\begin{aligned}
\mu_t &= \mu_{t-1} + \mathbf{K}_t \boldsymbol{\delta}_t \\
&= \mu_{t-1} + \sigma_t^2 \Big(\frac{\phi^2}{\sigma_\epsilon^2} \Big(\frac{1}{\phi}(y_t - y_{t-1}) - y_{t-1} - \mu_{t-1}\Big) + \frac{1}{\sigma_m^2}(z_{m,t} - \mu_{t-1}) + \frac{1}{\sigma_{d,t}^2}(\mu_{d,t} - \mu_{t-1})\Big) \\
\sigma_t^2 &= (\mathbf{F} - \mathbf{K}_t \mathbf{H}')\mathbf{P}_{t|t-1}(\mathbf{F}' - \mathbf{H}\mathbf{K}_t') + \mathbf{K}_t \mathbf{R}_t \mathbf{K}_t' + \mathbf{Q} \\
&= (1 - \mathbf{K}_t \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}) \sigma_{t-1}^2 (1 - \begin{bmatrix} 1 & 1 & 1 \end{bmatrix} \mathbf{K}_t') + \mathbf{K}_t \begin{bmatrix} \sigma_\epsilon^2/\phi^2 & 0 & 0 \\ 0 & \sigma_m^2 & 0 \\ 0 & 0 & \sigma_{d,t}^2 \end{bmatrix} \mathbf{K}_t' \\
&= \frac{\sigma_{t-1}^2}{1 + \sigma_{t-1}^2 (\frac{\phi^2}{\sigma_\epsilon^2} + \frac{1}{\sigma_m^2} + \frac{1}{\sigma_{d,t}^2})} \\
\mathbf{K}_t &= \mathbf{F}\mathbf{P}_{t|t-1}\mathbf{H}(\mathbf{H}'\mathbf{P}_{t|t-1}\mathbf{H} + \mathbf{R})^{-1} \\
&= \sigma_{t-1}^2 \begin{bmatrix} 1 & 1 & 1 \end{bmatrix} \left(\begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} \boldsymbol{\sigma}_{\mathbf{t-1}}^{\mathbf{2}} \begin{bmatrix} 1 & 1 & 1 \end{bmatrix} + \begin{bmatrix} \sigma_\epsilon^2/\phi^2 & 0 & 0 \\ 0 & \sigma_m^2 & 0 \\ 0 & 0 & \sigma_{d,t}^2 \end{bmatrix} \right)^{-1} \\
&= \frac{\sigma_{t-1}^2}{1 + \sigma_{t-1}^2 (\frac{\phi^2}{\sigma_\epsilon^2} + \frac{1}{\sigma_m^2} + \frac{1}{\sigma_{d,t}^2})} \begin{bmatrix} \frac{\phi^2}{\sigma_\epsilon^2} & \frac{1}{\sigma_m^2} & \frac{1}{\sigma_{d,t}^2} \end{bmatrix} \\
&= \sigma_t^2 \begin{bmatrix} \frac{\phi^2}{\sigma_\epsilon^2} & \frac{1}{\sigma_m^2} & \frac{1}{\sigma_{d,t}^2} \end{bmatrix} \\
\boldsymbol{\delta}_t &= \mathbf{y}_t - \mathbf{A}'\mathbf{x}_t - \mathbf{H}'\widehat{\boldsymbol{\xi}}_{t|t-1} \\
&= \begin{bmatrix} \frac{1}{\phi}(y_t - y_{t-1}) - y_{t-1} - \mu_{t-1} \\ z_{m,t} - \mu_{t-1} \\ \mu_{d,t} - \mu_{t-1} \end{bmatrix}
\end{aligned}
$$

The market cannot observe the board's private signal $z_{b,t}$ but can learn from the board's firing decisions d_{t-1}. Define $\mu_{d,t}$ as the market's expectation of the board's expected ability provided the CEO was not fired, i.e. $d_t = 0$. The board keeps the CEO if and only if the expected ability remains above the known threshold μ_t^*. Solve for the unobserved board signal $z_{b,t}$, take the expectation of a truncated normal distribution, and use market expectations to find:

$$
\begin{aligned}
\mu_{d,t} &\equiv \mathbb{E}_{m,t}[\mu_{b,t}(z_{b,t}) \mid d_t = 0] \\
&= \mathbb{E}_{m,t}[\mu_{b,t}(z_{b,t}) \geq \mu_t^*] \\
&= \mathbb{E}_{m,t}[\mu_{b,t-1} + \sigma_{b,t}^2 \begin{bmatrix} \frac{\phi^2}{\sigma_\epsilon^2} & \frac{1}{\sigma_m^2} & \frac{1}{\sigma_b^2} \end{bmatrix} \begin{bmatrix} \delta_{y,t} \\ \delta_{m,t} \\ \delta_{b,t}(z_{b,t}) \end{bmatrix} \geq \mu_t^*] \\
&= \mathbb{E}_{m,t}[z_{b,t} \mid z_{b,t} \geq \mu_t^* - \sigma_b^2(\frac{\phi^2 \delta_{y,t}}{\sigma_\epsilon^2} + \frac{\delta_{m,t}}{\sigma_m^2}) \equiv z_t^*] \\
&= \mathbb{E}_{m,t}[\mathbb{E}_{b,t}[z_{b,t} \mid z_{b,t} \geq z_t^*]] \\
&= \mathbb{E}_{m,t}[\mu_{z_{b,t}} + \sigma_{z_{b,t}} \lambda(\pi_{b,t})] \\
&= \mu_{m,t} + \sigma_b \lambda(\pi_{m,t})
\end{aligned}
$$

where:

$$
\begin{aligned}
\lambda(\pi_{m,t}) &\equiv \frac{\phi(\pi_{m,t})}{1 - \Phi(\pi_{m,t})} \\
\pi_{m,t} &\equiv \frac{z_t^* - \mu_{m,t}}{\sigma_b}
\end{aligned}
$$

The variance of the board's expected ability for surviving CEOs is:

$$\begin{aligned}\sigma^2_{d,t} &\equiv Var_{m,t}[\mu_{b,t}(z_{b,t}) \mid d_t = 0] \\ &= Var_{m,t}[z_{b,t} \mid z_{b,t} \geq z^*_t] \\ &= \sigma^2_b[1 - \omega(\pi_{m,t})]\end{aligned}$$

where:

$$\omega(\pi_{m,t}) \equiv \lambda(\pi_{m,t})[\lambda(\pi_{m,t}) - \pi_{m,t}]$$

□

3.8.4. The Market's Valuation Problem

Proof. By normalizing (3.2) firm value can be written recursively as the average Q:

$$\begin{aligned}Q_t &\equiv \frac{M_t}{B_t} = \mathbb{E}_t \sum_{s=0}^{\infty} \beta^s(\nu_{t+s} + y_{t+s} - b_{t+s}c^{(retire)} - d^*_{t+s}c^{(firm)}) \\ &= \mathbb{E}_t \sum_{s=0}^{\infty} \beta^s \nu_{t+s} + QF_t \\ QF_t &= \mathbb{E}_t \sum_{s=0}^{\infty} \beta^s(y_{t+s} - b_{t+s}c^{(retire)} - d^*_{t+s}c^{(firm)}) \\ &= y_{t-1}\frac{1-\phi}{1-\beta(1-\phi)} + \frac{\mu_0}{1-\beta}\frac{\phi}{1-\beta(1-\phi)} + \mathbb{E}_t Q^*_t \\ Q^*_t &= \eta_{m,t}\frac{\phi}{1-\beta(1-\phi)} - b_t c^{(retire)} - d^*_t c^{(firm)} + \beta \mathbb{E}_t Q^*_{t+1}\end{aligned} \tag{3.35}$$

where market belief of excess ability $\eta_{m,t} \equiv \mu_{m,t} - \mu_0$ and:

$$Q^*(\eta_{m,t}, \tau_t, b_t) = \eta_{m,t} \frac{\phi}{1-\beta(1-\phi)} - b_t c^{(retire)} - d_t^* c^{(firm)} + \beta \mathbb{E}_t Q^*(\eta_{m,t+1}, \tau_{t+1}, b_{t+1}) \tag{3.36}$$

If the current CEO retires ($b_t = 1$), then the firm pays the CEO retirement cost and selects a new chief executive from the talent pool:

$$Q^{(retire)} = Q(\eta_{m,t}, \tau_t, 1) = Q(0,0,0) - c^{(retire)} \tag{3.37}$$

If the CEO does not retire ($b_t = 0$) but is fired ($d_t^* = 1$), then the firm pays the cost to fire the CEO and recruits a new one from the talent pool:

$$Q^{(fire)} = Q(\eta_{m,t}, \tau_t, 0) = Q(0,0,0) - c^{(firm)} \tag{3.38}$$

If the firm keeps the CEO ($b_t = 0$ and $d_t^* = 0$), then:

$$\begin{aligned} Q^{(keep)} &= Q(\eta_{m,t}, \tau_t, 0) \\ &= \eta_{m,t} \frac{\phi}{1-\beta(1-\phi)} + \beta[f(\tau_t) Q^{(retire)} + (1 - f(\tau_t)) Q(\eta_{m,t+1}, \tau_{t+1}, 0)] \end{aligned} \tag{3.39}$$

□

References

Angrist, J. D. and J.-S. Pischke (2008). Mostly Harmless Econometrics: An Empiricist's Companion.

Antón, M. (2010). Cash-Flow Driven Covariation. Working Paper.

Antón, M. and C. Polk (2013). Connected Stocks. *The Journal of Finance*.

Barberis, N. and A. Shleifer (2003). Style Investing. *Journal of Financial Economics 68*(2), 161–199.

Barberis, N., A. Shleifer, and J. Wurgler (2005). Comovement. *Journal of Financial Economics 75*(2), 283–317.

Bertrand, M. and A. Schoar (2003). Managing with Style: The Effect of Managers on Firm Policies. *The Quarterly Journal of Economics 118*(4), 1169–1208.

Boyer, B. H. (2011). Style-Related Comovement: Fundamentals or Labels? *The Journal of Finance 66*(1), 307–332.

Brumwell, J. (2003). Notes on the FTSE Actuaries Share Indices (United Kingdom Series) in 2002. *British Actuarial Journal 9*(2), 457–480.

Buraschi, A., F. Trojani, and A. Vedolin (2011). When Uncertainty Blows in the Orchard: Comovement and Equilibrium Volatility Risk Premia. In *EFA 2009 Bergen Meetings Paper*.

Campbell, J. Y., A. W. Lo, and A. C. MacKinlay (1997). The Econometrics of Financial Markets.

Chang, Y.-C., H. Hong, and I. Liskovich (2013). Regression Discontinuity and the Price Effects in Stock Market Indexing. Working Paper.

Chen, H., V. Singal, and R. F. Whitelaw (2014). Comovement and Momentum. Working Paper.

Dahya, J., J. McConnell, and N. Travlos (2002). The Cadbury Committee, Corporate Performance, and Top Management Turnover. *Journal of Finance 57*(1), 461–483.

Delong, J., A. Shleifer, L. H. Summers, and R. J. Waldmann (1993). Noise Trader Risk in Financial Markets. *Journal of Political Economy 98*(4).

Denis, D. K., J. J. McConnell, A. V. Ovtchinnikov, and Y. Yu (2003). S&P 500 Index Additions and Earnings Expectations. *The Journal of Finance 58*(5), 1821–1840.

Dimson, E. and P. Marsh (2001). Index Rebalancing and the Technology Bubble. *Journal of Asset Management 1*(4), 311–320.

Eisfeldt, A. L. and C. M. Kuhnen (2013). CEO Turnover in a Competitive Assignment Framework. *Journal of Financial Economics*.

Fackler, P. and H. Tastan (2008). A Framework for Indirect Inference.

Fama, E. (1980). Agency Problems and the Theory of the Firm. *Journal of Political Economy*, 288–307.

Fama, E. and M. Jensen (1983). Separation of Ownership and Control. *Journal of Law & Econonmics 26*, 301.

Fama, E. F. and K. R. French (2000). Forecasting Profitability and Earnings. *The Journal of Business 73*(2), 161–175.

Fee, C., C. Hadlock, and J. Pierce (2010). Managers Who Lack Style: Evidence from Exogenous CEO changes. Working paper, Michigan State University.

Geweke, J. (1989). Bayesian Inference in Econometric Models Using Monte Carlo Integration. *Econometrica*, 1317–1339.

Goyal, V. and C. Park (2002). Board Leadership Structure and CEO Turnover. *Journal of Corporate Finance 8*(1), 49–66.

Greenwood, R. (2008). Excess Comovement of Stock Returns: Evidence from Cross-Sectional Variation in Nikkei 225 Weights. *Review of Financial Studies 21*(3), 1153–1186.

Greenwood, R. M. and N. Sosner (2007). Trading Patterns and Excess Comovement of Stock Returns. *Financial Analysts Journal*, 69–81.

Hajivassiliou, V. and D. McFadden (1998). The Method of Simulated Scores for the Estimation of LDV Models. *Econometrica*, 863–896.

Harris, L. and E. Gurel (1986). Price and Volume Effects Associated with Changes in the S&P 500 list: New Evidence for the Existence of Price Pressures. *The Journal of Finance 41*(4), 815–829.

Hermalin, B. E. and M. S. Weisbach (1998). Endogenously Chosen Boards of Directors and their Monitoring of the CEO. *American Economic Review*, 96–118.

Holmström, B. (1999). Managerial Incentive Problems: A Dynamic Perspective. *The Review of Economic Studies 66*(1), 169–182.

Jensen, M. and W. Meckling (1976). Theory of the Firm: Managerial Behavior, Agency Costs and Ownership Structure. *Journal of Financial Economics 3*(4), 305–360.

Jensen, M. and R. Ruback (1983). The Market for Corporate Control: The Scientific Evidence. *Journal of Financial Economics 11*(1-4), 5–50.

Keane, M. (1994). A Computationally Practical Simulation Estimator for Panel Data. *Econometrica*, 95–116.

King, M. A. and S. Wadhwani (1990). Transmission of Volatility between Stock Markets. *Review of Financial studies 3*(1), 5–33.

Kumar, A. and C. Lee (2006). Retail Investor Sentiment and Return Comovements. *The Journal of Finance 61*(5), 2451–2486.

Mase, B. (2008). Comovement in the FTSE 100 Index. *Applied Financial Economics Letters 4*(1), 9–12.

Miranda, M. J. and P. L. Fackler (2004). Applied Computational Economics and Finance.

Murphy, K. (1999). Executive Compensation. *Handbook of Labor Economics 3*, 2485–2563.

Naveen, L. (2006). Organizational Complexity and Succession Planning. *Journal of Financial & Quantitative Analysis 41*(03), 661–683.

Pan, Y., T. Y. Wang, and M. S. Weisbach (2013). Learning about CEO Ability and Stock Return Volatility.

Parrino, R. (1997). CEO Turnover and Outside Succession a Cross-Sectional Analysis. *Journal of Financial Economics 46*(2), 165–197.

Pástor, L. and V. Pietro (2003). Stock Valuation and Learning about Profitability. *The Journal of Finance 58*(5), 1749–1790.

Pastor, L. and P. Veronesi (2009). Learning in Financial Markets. *Annual Review of Financial Economics 1*(1), 361–381.

Pindyck, R. S. and J. J. Rotemberg (1993). The Comovement of Stock Prices. *The Quarterly Journal of Economics 108*(4), 1073–1104.

Roodman, D. (2011). Fitting Fully Observed Recursive Mixed-Process Models with CMP. *Stata Journal 11*(2), 159–206.

Scholes, M. and J. Williams (1977). Estimating Betas from Nonsynchronous Data. *Journal of Financial Economics 5*(3), 309–327.

Shleifer, A. (1986). Do Demand Curves for Stocks Slope Down? *The Journal of Finance 41*(3), 579–590.

Shleifer, A. and R. W. Vishny (1997). The Limits of Arbitrage. *The Journal of Finance 52*(1), 35–55.

Taylor, L. A. (2010). Why are CEOs Rarely Fired? Evidence from Structural Estimation. *The Journal of Finance 65*(6), 2051–2087.

Vancil, R. F. (1987). *Passing the Baton: Managing the Process of CEO Succession*. Harvard Business School Press, Boston, MA.

Vijh, A. M. (1994). S&P 500 Trading Strategies and Stock Betas. *Review of Financial Studies 7*(1), 215–251.

Weisbach, M. (1988). Outside Directors and CEO Turnover. *Journal of Financial Economics 20*, 431–460.

Wilde, J. (2000). Identification of Multiple Equation Probit Models with Endogenous Dummy Regressors. *Economics Letters 69*(3), 309–312.

Wooldridge, J. M. (2010). Econometric Analysis of Cross-Section and Panel Data, 2nd edition.