

Selecting Directors Using Machine Learning

By ISIL EREL, LÉA H. STERN, CHENHAO TAN, AND MICHAEL S. WEISBACH*

Can an algorithm assist firms in their nominating decisions of corporate directors? We construct algorithms tasked with making out-of-sample predictions of director performance. We run tests of the quality of these predictions and show that directors predicted to do poorly indeed do poorly compared to a realistic pool of candidates. Predictably unpopular directors are more likely to be male, have held more directorships, have fewer qualifications, and larger networks than the directors the algorithm recommends. Machine learning holds promise for understanding the process by which governance structures are chosen, and has potential to help firms improve their governance. (JEL G34, M12, M51)

1. Introduction

A company's board of directors is legally responsible for managing the company. In principle, the board of directors reports to the shareholders and represents their interests. In practice, however, there is much variation in director quality and the extent to which they serve shareholders' interests.¹

Many of the concerns about boards come from the director selection process, which has been a source of debate since at least Berle and Means (1932).² Despite the checks and balances built into a public corporation's governance system, the

* Stern: Foster School of Business, University of Washington (leastern@uw.edu); Erel: Fisher College of Business, Ohio State University (erel@fisher.osu.edu); Tan: Department of Computer Science, University of Colorado, Boulder (chenhao.tan@colorado.edu); Weisbach: Fisher College of Business, Ohio State University (weisbach.2@osu.edu). We thank Renée Adams, Lucian Bebchuk, Philip Bond, Lisa Cook, Ran Duchin, Shan Ge, Jarrad Harford, Ben Hermalin, Joan MacLeod Heminway, Nadya Malenko, Miriam Schwartz-Ziv, Anil Shivdasani, Tracy Yue Wang, and conference and seminar participants at North Carolina, Ohio State, Tennessee, Washington, 2017 Pacific Northwest Finance Conference, 2017 WAPFIN Conference at NYU Stern, 2017 NABE TEC Conference, 2018 University of Miami-AFFECT conference, 2018 Drexel Corporate Governance Conference, ICWSM BOD-18 workshop, 2018 NBER Economics of AI. Special thanks to Ronan Le Bras for providing invaluable help throughout the project.

¹ See Hermalin and Weisbach (2003), Adams, Hermalin and Weisbach (2010), and Adams (2017) for surveys.

² Berle and Means (1932) wrote: "Control will tend to be in the hands of those who select the proxy committee and by whom the election of directors for the ensuing period will be made. Since the proxy committee is appointed by the existing management, the latter can virtually dictate their own successors" (p. 87). Hermalin and Weisbach (1998) present a formal model of this process in which boards vary in their independence from the CEO in equilibrium.

CEO often controls the selection of new directors.³ In practice, appointed directors are almost always supporters of the CEO and his policies. Aside from occasional proxy contests, shareholders have virtually no control over the choice of the directors whose mandate is to represent their interests.

We consider a potential alternative approach to select directors: one that uses algorithms that rely on data on firms, potential directors, and their attributes, to identify the quality of directors being considered for a given firm's board. We take advantage of advances in machine learning that have revolutionized many fields and have led to innovations ranging from self-driving cars to facial recognition. In the social sciences, machine learning has great potential for prediction problems such as the one we consider here, the way in which one determines which potential director would be the best for a particular firm. While "traditional" econometrics is typically designed for estimating structural parameters and drawing causal inferences, machine learning is substantially better at making predictions, in part because it does not impose unnecessary structure on the data.⁴

We construct a large database of publicly traded U.S. firms and directors appointed between 2000 and 2014. We build several machine learning algorithms designed to predict director performance using director and firm level data available to the nominating committee at the time of the nominating decision. We compare the algorithms' selections to the directors who were actually chosen by firms. The discrepancies between firms' actual choices of directors and the choices based on the predictions from our algorithms allow us to characterize which individual features are overrated by decision makers. Therefore, our goal is to use the

³ See Shivdasani and Yermack (1999) and Kramarz and Thesmar (2013) for anecdotal evidence suggesting that the CEO typically holds a veto power over the choice of directors. See also Cai, Nguyen, and Walkling (2017), who document that more complex firms and firms in more competitive environments are more likely to appoint directors who are connected to the CEO or the existing board.

⁴ See Athey and Imbens (2017) and Mullainathan and Spiess (2017).

algorithm's predictions as a diagnostic tool to shed light on the decision-making process behind the selection of directors.

A crucial element of any algorithm designed to select valuable directors is a process for assessing a director's performance in a particular firm. The task of measuring the performance of an individual director is challenging since directors generally act collectively on the board and it is usually impossible for a researcher to ascertain the actions of any particular director. Nevertheless, as Hart and Zingales (2017) emphasize, directors' fiduciary duty is to represent the interests of the firm's shareholders and therefore their popularity among shareholders is a natural metric for evaluating them. We rely on shareholders' support for a particular director as our measure of her quality and performance partly for this reason.

We recognize that investors often have limited resources and vote based on simple, check-the-box criteria in routine director elections. However, the recent literature on director elections documents that the level of shareholder support received by a director is positively related to measures of director performance and shareholder votes do appear to capture shareholders' discontent when present (see Cai et al. (2009), Fischer et al. (2009), Iliev et al. (2015), Aggarwal et al. (2017), and Ertimur et al. (2017)). To adjust for firm-specific factors and to measure shareholder support of an individual director, we use the excess votes (relative to the slate of directors) a *new* independent director receives in *subsequent* elections as a market-based measure of an individual director's performance.⁵ We call this measure "excess votes".

Using excess votes in subsequent elections as the market's assessment of a new director's performance, we construct algorithms tasked with predicting the performance of any potential director at any particular company. These algorithms rely on methodological approaches common in the computer science literature (i.e.,

⁵ All results are qualitatively unchanged if we use the fraction of votes in favor and do not subtract the slate's average.

lasso, ridge, neural networks, and gradient boosting trees). On our sample of public firms, we train each algorithm (i.e. fit a model) on a “training” set (directors appointed between 2000 and 2011), and then compare the predictions to the observed data out-of-sample using a “test” set (directors appointed between 2012 and 2014).

We find that these algorithms make accurate out-of-sample predictions of shareholder support in director elections. The directors the algorithm predicted would do poorly did much worse on average than the directors the algorithm predicted would do well. In comparison, the directors predicted to do poorly by an OLS model do not actually have worse performance out of sample than those the OLS model predicted would do well. The machine learning algorithms can predict the level of shareholder support new directors will receive out of sample, while the OLS model cannot. Machine learning algorithms, by letting the data speak about the underlying relationships among the variables, ends up fitting the data much better and consequently does better at predicting future outcomes out of sample.

From a decision maker’s perspective, it is also necessary to predict the performance of potential alternative directors. However, we only observe the subsequent votes of directors who were actually nominated to the board but do not observe subsequent votes for potential candidates who were *not* nominated. This “*selective labels*” problem of having voting data at the company in question only for directors who were actually selected is a common issue in prediction problems (see Kleinberg et al. (2017)). In addition, if decision makers consider features that are not observable to our algorithm in their nominating decisions of directors, the distribution of outcomes in the set with observed labels (nominated directors) could differ from that in the set with missing labels (not nominated directors), even if they share exactly the same observable characteristics. In other words, if boards are skilled at using unobservables in their nominating decisions, nominated directors

could have higher expected performance than otherwise similar (based on observables) passed-over directors.

To determine whether our algorithm could be of use to decision makers, we wish to compare the performance of potential alternative directors to that of the individuals who actually did join the company's board. Our empirical strategy to deal with the selective labels and unobservables issues involves matching each new board appointment to its own realistic pool of potential candidates, consisting of directors who joined the board of a smaller neighboring company in the past year or the following year. Presumably these potential candidates would have found the opportunity to be on the board of a larger nearby company to be attractive, since directorships at larger companies tend to be better paying and more prestigious than directorships at smaller companies. We use the machine learning model to predict the performance of each potential director the firm could nominate using the firm and board characteristics (including committee assignments) of the focal firm.

Although we do not observe the performance (*label*) of potential candidates that were not nominated to the focal board, the design of our candidate pools allows us to observe what we refer to as their "*quasi-label*": their performance on the board they actually joined. We exploit the observation that there is on average little variation in director performance -- the fraction of votes received in director elections -- across the different boards any particular director joined during our sample period. Therefore, the performance on the board they ended up joining is informative about the algorithm's ability to assess the quality of potential directors.

Quasi-labels are not a perfect substitute for the level of support a director would have gathered on a particular board she was not selected for. However, it is important to keep in mind that the purpose of constructing candidate pools and using quasi-labels is *not* to identify the best director. The purpose of using quasi-labels is to evaluate the predictive accuracy of our algorithm in the presence of the

selective labels problem and unobservables.⁶ In particular, the results from this exercise are not affected by the endogenous board-director matching as they would be if the purpose of the exercise was to draw causal inference.

It is possible that due to the endogenous nature of the board-director match, some quasi-labels could be inflated. For example, the performance of the available candidate potentially could not have been as high on the focal board if team dynamics and personality compatibility were (correctly) considered in the nomination process. However, note that our results go both ways: whereas the *observed* performance of directors our machine-learning models predicted would do poorly ranks low, that of directors predicted to do well ranks high in the distribution of quasi-labels. In contrast, directors rank around the 75th percentile in the distribution of quasi-labels, regardless of whether OLS predicted they would perform well or not. It is the symmetry of our results that provides reassurance that our quasi-labels are not systematically inflated due to the endogenous nature of the board-director match. Quasi-labels are simply a noisier benchmark than the ideal benchmark and the algorithm is able to identify the directors who will gather higher shareholder approval rates at a particular board and those who will not.

An important issue in interpreting these results is whether shareholder votes reflect directors' quality rather than their popularity with shareholders. While these notions are to some extent the same since a director's duty is to serve the interests of shareholders, it is possible that the algorithm is picking up the recommendations of shareholder services like ISS or shareholders' biases and views on certain director characteristics (e.g. gender), rather than the true interests of shareholders.

Several pieces of evidence reassure us that this is not the case. First, ISS introduced guidelines to vote in favor of proposals aimed at increasing gender diversity in 2010. Less than 20% of appointments in our training set occur when

⁶ The algorithm can give a prediction for *any* candidate, not only those in the potential candidate pool. In addition, decision makers could still rely on unobservables to nominate a director among candidates predicted to do well.

ISS had those guidelines in place. Second, Iliev and Lowry (2014) show that institutional investors with larger size of ownership vote independently from ISS recommendations. We repeat all our tests by focusing on a subsample of firms with larger-than-median (26%) ownership by the top-5 institutional owners. Our results are unchanged. Third, we compute the mean cumulative abnormal returns around the announcement of director appointments in our test set. We find that directors predicted to do poorly by the algorithm have a mean CAR that is significantly lower than that of directors predicted to do well. Finally, we train the algorithm using firm profitability following director appointments as an alternative measure of performance. While this measure reflects the collective decisions of all management rather than the individual directors, it still reflects the ability of the directors to some extent. Importantly, we find that selecting directors based on predictions of the level of shareholder support does not come at the expense of lower profitability. On the contrary, we show that directors whose subsequent shareholder votes are predictably poor are associated with significantly lower subsequent firm profitability than that for directors with predictably high shareholder votes. Put together, those results strongly suggest that unpopular directors are indeed worse directors.

While machine learning models do not generate estimates of the underlying structural parameters of a model, we can use the algorithm's predictions to understand the characteristics that the model indicates are overvalued and undervalued by firms when they choose directors. A striking result in this paper is that machine-learning models consistently suggest directors who would have been likely both to accept the directorship and to outperform the directors that are actually chosen by firms. Relative to algorithm-selected directors, firm-selected directors who receive predictably low shareholder approval are more likely to be male, have larger networks, sit on more boards, and are more likely to have a finance background. These attributes characterize the stereotypical director in most

large companies. A plausible interpretation of our results is that firms that nominate predictably unpopular directors tend to choose directors who are like existing directors, while the algorithm suggests that adding diversity would be a better idea.

Machine-learning tools have the potential to help answer many unanswered questions in the social sciences, both by academics wishing to understand the way the world actually works, and by practitioners and policy makers wishing to make better real-world decisions. In terms of boards of directors, the algorithm could allow firms to choose better among existing candidates. In addition, it could enable firms to identify alternative choices of potential directors that companies could consider, thereby opening up board seats to a new set of candidates with more diverse backgrounds and experiences who would have otherwise been overlooked.⁷

This paper is organized as follows. The next section describes the machine-learning algorithms we use and develops a framework that helps us assess the performance of these algorithms. In the third section, we present our data and summary statistics. In the fourth section, we present the performance of our prediction models and compare firms' actual choices of directors with potential alternatives. Section 5 compares the characteristics of model-selected directors with those of directors actually chosen by firms to evaluate the types of directors that tend to be overvalued in the decision-making process. The final section includes an extensive discussion of our approach and findings, puts them in perspective, discusses possible extensions, and concludes.

2. Using Machine Learning to Predict Director Performance

2.1. Algorithms to Predict Performance

We build algorithms designed to make an ex ante prediction of directors' level of shareholder support, Y , over the first three years of their tenure. The algorithms

⁷ We thank Oren Etzioni for originally pointing out this additional benefit of our proposed approach.

use a set of observable director, board, and firm features that are available to the nominating committee at the time of the nominating decision. The algorithms are among the most commonly used in the machine learning literature: *lasso*, *ridge*, *neural networks* and *gradient boosting trees*. We train each of these algorithms, i.e. estimate model parameters, on directors appointed between 2000 and 2011 and test them on directors appointed between 2012 and 2014. Following the terminology in machine learning, we call the data from 2000-2011 the “training set” (in-sample data) and the data from 2012 to 2014 the “test set” (out-of-sample data).

The variable the algorithms try to predict is the average level of shareholder support over the first three years of director tenure, adjusted each year by the average support for the entire slate of directors. The data on director elections is from ISS Voting Analytics and it is not always available for all election years. Using the average of available election outcomes over the first three years of tenure allows us to expand the number of usable observations.⁸

There are a number of well-known machine learning algorithms that can be used for prediction. We use four of these algorithms to predict director performance, and give a brief summary of each in this section.

2.1.1. *Lasso* and *Ridge*

OLS regressions tend to generate poor out-of-sample predictions as they are designed to minimize the in-sample residual sum of squares. This observation is known as bias-variance tradeoff in the machine learning literature: if an algorithm fits in-sample data too well (low bias), it has high variance and thus does not perform as well on out-of-sample data. *Lasso* and *ridge* are both linear models that use a regularization term to achieve a balance between bias and variance. They do so by minimizing a loss function that includes in-sample fit and a penalty term that

⁸ The distribution of shareholder support does not change over the first few years of a director's tenure. We obtain similar results using voting data at year one, year two or year three instead of using the average over the first three years.

favors simple models, thereby reducing variance (see online appendix for more details).

2.1.2. Gradient Boosting Trees

Gradient Boosting Trees are similar to random forest algorithms. A *random forest* algorithm is an ensemble method that combines multiple decision trees. Intuitively, a single decision tree presents a flow chart where a data point can follow the flow starting from the root to a leaf node associated with its final prediction. The selection of attributes at each node in decision trees is inspired by information theory to maximize information gain. In the *random forest* algorithm, multiple trees are estimated by using a random subset of covariates in each tree. Among those, the covariate that provides the best binary split based on information gain is used to split the data into two partitions and functions as the root of the tree. The algorithm repeats this process until it reaches the bottom of the tree, where each “leaf” or terminal node is comprised of similar observations. Then, a new data point can start at the top of each tree and follow the splits at each node all the way to a leaf node. The prediction for this new data point is the average outcome of observations in the leaf it ends up in. The random forest algorithm takes an average of the predictions from all the decision trees.

Similar to random forest, *gradient boosting trees* is an ensemble method that combines multiple trees. The key difference lies in that the final prediction is a linear sum of all trees and the goal of each tree is to minimize the residual error of previous trees. The *XGBoost* algorithm provides an efficient implementation of this algorithm that is scalable in all scenarios (Chen and Guestrin, 2016). In the rest of the paper, we use *XGBoost* and *gradient boosting trees* interchangeably.

2.1.3. Neural Networks

Artificial neural networks are designed to mimic the way the brain processes information. It is structured in layers of neurons connected by synapses. The first layer comprises the input neurons and the final layer represents the output. Layers

of neurons between the first and final layers are hidden layers. The figure in the online appendix depicts the structure of a basic neural network with two hidden layers. Neurons x_i are input neurons connected to the next layer of neurons by synapses which carry weights w^l . Each synapse carries its own weight. An activation function (usually a sigmoid to allow for non-linear patterns) is embedded in each neuron in the hidden layers to evaluate its inputs. The set of weights carried by the synapses that reach a neuron are fed into its activation function, which will determine whether or not that neuron is activated. If activated, it triggers the next layer of neurons with the value it was assigned, with weight w^2 (again with each synapse carrying its own weight). Similar to the neurons in the hidden layers, the output neuron judges its input via an activation function and decides from which neurons to accept the triggered values. The output is a weighted sum of the activated neurons in the last hidden layer. Training a network involves modifying the weights on the synapses to minimize a cost function (e.g. the sum of squared errors).

2.2. Assessing Algorithms' Predictions

Assessing whether the algorithmic predictions can actually lead to better outcomes is not a straightforward task. We cannot simply compare the predictions to the actual outcomes in the test set as is typically done in most machine learning applications because of two important challenges. First, we can only observe our algorithm's predictions for directors who are actually appointed to that position (the *selective labels* problem). Second, when deciding on their choice of directors, decision makers presumably take factors into account that are not observable to the algorithm. Therefore, directors who were nominated, although they could share the same observable features as potential alternatives, could differ in terms of unobservables. In particular, they could have been chosen because they have a set of skills that are valuable to the firm, or because they have a personal relationship with the CEO or existing directors. A firm could also have decided not to nominate a candidate based on some characteristics unobservable to the algorithm that would

make this candidate a poor choice. Since we cannot observe these factors, they could lead to different average outcomes for nominated vs. not nominated, even if both are identical on the basis of observable characteristics.

To formalize these concepts, we develop a framework similar to that presented by Kleinberg et al. (2017) and present it in the online appendix. Our empirical strategy to address these concerns involves designing a pool of potential candidates for each vacant board position. The goal is to evaluate the algorithm's predictions of the performance of directors who were actually nominated. In cases where our algorithm predicted low performance, for example, we are interested in whether there were plausible alternatives available, how they would have performed, and how the director who was nominated actually performed compared to those alternatives. In Section 4.3 we explain how we construct the candidate pools and present results of this comparison between actual choices of directors and potential candidates. We first describe below our sample of directors of focal firms and our algorithms' predictions of director performance.

3. Constructing a Sample on which Algorithms Can Select Directors

3.1. Measuring Director Performance Through Election Results

A challenging part of designing an algorithm to select directors is the way in which the algorithm measures director performance. Most actions that directors take are done collectively with other directors in the privacy of the boardroom, making it harder to assess the performance of a given director. Also, for an outside observer or an algorithm to assess the performance of an individual director, it should rely on a measure that incorporates the information available to market participants. We use the proportion of votes that an individual receives in director elections as a market-based measure of individual directors' performance.

An important feature of director elections is that the vast majority of the time, directors receive overwhelming majorities of the vote, with most studies reporting

a mean vote of around 95% in favor of the directors. Therefore, there is virtually no variation in the *outcome* of the elections.⁹ If the election results reflect the market's perception of a director's quality, it must be that variation among winning votes contains meaningful differences in the market's assessment. Consistent with this notion, Cai et al. (2009), Fischer et al. (2009), and Iliev et al. (2015) suggest that variation in vote outcomes does in fact reflect market perceptions of director quality. These papers find that vote totals predict stock price reactions to subsequent turnover. In addition, vote totals are negatively related to CEO turnover, board turnover, management compensation levels, and the probabilities of removing poison pills and classified boards.

In addition, the results of director elections appear to have real consequences, even if the elections are not contested and the nominated directors are elected. Fos et al. (2017) find that when directors are closer to elections, they are more likely to fire CEOs, presumably to persuade shareholders that they are being more diligent. Aggarwal et al. (2017) suggest that directors with low relative support are more likely to leave the board, and if they stay, tend to move to less prominent positions. Finally, Ertimur et al. (2017) find that when votes are withheld from directors, boards explicitly attempt to address shareholders' concerns. Overall, the recent literature strongly suggests that vote outcomes do reflect perceptions of director quality, that directors care about these perceptions, and take actions designed to influence them. Furthermore, while many papers show the influence of recommendations by proxy advisory firms (e.g., ISS) on voting by institutional

⁹ On a side note, this equilibrium is arguably a consequence of the widespread perception that board members almost always get reelected and are almost always supporters of the CEO. One might argue that if director selection decisions were increasingly made in accordance to algorithmic predictions, shareholders would be increasingly incentivized to devote resources to vote. The mere use of the algorithm in practice could therefore in principle improve the quality of the outcome variable.

investors on various governance proposals, including director elections,¹⁰ recent research provides evidence on the decline in this influence.¹¹

3.2. *Sample Selection*

To evaluate the performance of an algorithm to select directors, we must gather a sample in which we can observe the attributes of firms and boards, and also for which we can measure the performance of directors. Because of these requirements, we analyze a sample of boards from large, publicly-traded, U.S. firms with an average market capitalization of \$6.6 billion. We identify 41,015 new independent directors appointed to 4,887 unique corporate boards of these firms between 2000 and 2014 using *BoardEx*, which is our main data source for director and board-level characteristics.

We obtain data on the level of shareholder support for individual directors from *ISS Voting Analytics* and focus on new directors only. To construct *excess votes*, our measure of performance, we use the number of votes in favor over all votes cast (yes, no, withheld). We then subtract the average for the entire slate of directors and take the average over the first three years of tenure. Our sample contains the voting outcome, i.e. the *excess votes*, for 24,054 new director appointments.

3.3. *Summary Statistics*

Table 1 presents summary statistics for average shareholder support over the first three years of tenure. As previously documented in the literature on uncontested director elections, the overall level of shareholder support is typically very high. Given that the mean level of support is .95 and the median is .975 (with

¹⁰ See, for example, Cai, Garner, and Walkling (2009), Daines, Gow and Larcker (2010), Alexander, Chen, Seppi, and Spatt (2010), Ertimur, Ferri and Oesch (2015), Larcker, McCall and Ormazabal (2015), Malenko and Shen (2016), and Ertimur, Ferri and Oesch (2017).

¹¹ For example, Iliiev and Lowry (2014) find that mutual funds vary greatly in their reliance on ISS recommendations. Aggarwal, Erel, and Starks (2016) show that investor voting has become more independent of ISS recommendations in shareholder proposals where ISS recommends a vote against the proposal. A recent striking example of investors choosing to dismiss the recommendation of the lead proxy advisors is when ADP shareholders voted to reelect all incumbent board members in a proxy fight against activist investor William Ackman. All three main proxy advisors had recommended shareholders to oppose the reelection of ADP's directors. See <https://www.nytimes.com/2017/11/07/business/dealbook/adp-ackman.html>.

a standard deviation of .07), a voting outcome below 95% is a relatively poor outcome. Consequently, a voting outcome below 95% likely reflects a perception of poor performance by the director. Starting in Column 4, we report shareholder support after subtracting the average support for the entire slate of directors in that year. Although shareholder support in uncontested elections is typically very high, shareholders do on occasion oppose newly nominated directors (see figure in online appendix). The question is whether an algorithm can pick up signals in the data that can reliably predict which directors will ultimately fall in that left tail.

	n	mean total votes	median total votes	mean excess votes	std excess votes	25th ptcl excess votes	median excess votes	75th ptcl excess votes
2000	331	0.950	0.974	0.0008	0.0300	-0.0058	0.0004	0.0082
2001	772	0.944	0.970	-0.0001	0.0455	-0.0050	0.0017	0.0134
2002	1,057	0.946	0.970	0.0022	0.0387	-0.0038	0.0015	0.0115
2003	1,774	0.951	0.974	0.0064	0.0359	-0.0014	0.0028	0.0149
2004	2,019	0.953	0.977	0.0069	0.0442	-0.0008	0.0033	0.0153
2005	1,893	0.948	0.974	0.0049	0.0369	-0.0011	0.0033	0.0136
2006	1,789	0.941	0.969	0.0051	0.0412	-0.0016	0.0036	0.0153
2007	1,942	0.940	0.971	0.0045	0.0434	-0.0023	0.0026	0.0157
2008	1,691	0.944	0.973	0.0067	0.0431	-0.0032	0.0034	0.0180
2009	1,541	0.948	0.976	0.0072	0.0435	-0.0020	0.0045	0.0187
2010	1,842	0.948	0.977	0.0039	0.0431	-0.0044	0.0027	0.0152
2011	1,825	0.954	0.981	0.0038	0.0462	-0.0019	0.0035	0.0160
2012	1,862	0.952	0.981	0.0045	0.0422	-0.0007	0.0038	0.0162
2013	2,148	0.948	0.980	0.0027	0.0444	-0.0021	0.0032	0.0139
2014	1,568	0.959	0.985	0.0063	0.0408	-0.0004	0.0045	0.0149
	24,054	0.9484	0.9755	0.0044	0.0413	-0.0024	0.0030	0.0147

TABLE 1: SHAREHOLDER SUPPORT SUMMARY STATISTICS

Notes: This table presents summary statistics for total (columns labeled as *mean/median total votes*) and excess shareholder support over time. Shareholder support is defined as the fraction of votes in favor of a given director over all votes cast for the director’s reelection within three years of her tenure. To compute *Excess Votes*, we subtract the average of that variable for the slate of directors up for reelection that year on the focal board. Then we take the average of this relative vote measure over the first three years of the new director’s tenure. The data is from ISS Voting Analytics.

Table 2 illustrates that the frequency of shareholder discontent varies by director and board characteristics. For example, the fraction “bad outcomes”, representing the bottom 10% of the sample in terms of excess votes, is 10.6% for male directors and 7.9% for female directors. Similarly, busy directors (serving on three or more boards) experience low shareholder support more frequently than non-busy directors. However, theory provides little guidance about the particular variables and functional forms of the relation between director characteristics and

performance. For example, we do not know whether we should expect female busy directors serving on a large board to receive higher or lower shareholder support on average than a male director who serves on a single small board. For this reason, we rely on an estimation procedure that does not impose the specific form for the relationship between potential explanatory variables.

	Full sample	yes	no	Difference p-value
Director level				
Male	0.102	0.106	0.079	0.000
Foreign	0.101	0.115	0.100	0.138
Qualifications > median	0.102	0.094	0.106	0.005
Network size > median	0.102	0.108	0.096	0.002
Generation BBB	0.101	0.093	0.118	0.000
Generation X	0.101	0.151	0.096	0.000
Busy director	0.102	0.145	0.090	0.000
Finance background	0.102	0.106	0.101	0.328
Board level				
Fraction male > median	0.102	0.116	0.091	0.000
Board size > median	0.102	0.089	0.114	0.000
Nationality mix > median	0.102	0.108	0.100	0.064
Attrition rate > median	0.098	0.106	0.086	0.000

TABLE 2: AVERAGE FRACTION OF BAD OUTCOME

Notes: This table presents the average fraction of “bad outcome”. A director is considered to experience a bad outcome if her excess votes is < -2%. Bad outcomes represent 10% of the sample. Shareholder support is defined as the fraction of votes for a director over all votes cast for that director. To compute *Excess Votes*, we subtract the average of that variable for the slate of directors up for reelection that year on the focal board. Then we take the average of this relative vote measure over the first three years of the new director’s tenure. Shareholder discontent is presented for various director-level and board-level characteristics.

4. Evaluating Machine Learning Predictions of Director Performance

4.1. Model Specification

Using this sample, we develop machine-learning algorithms that predict the quality of a potential director, using the subsequent voting as a measure of a director’s quality. There are 24,054 appointments for which we observe the vote outcome and can compute *excess votes*. We first “train” each algorithm on the 2000-2011 portion of our sample containing 18,476 new independent director appointments, of which 12,815 are unique, at 2,407 firms. Training involves having the algorithm determine which combinations of variables best predict future

performance.¹² We evaluate the models’ out-of-sample predictions on the held out 2012-2014 portion of our sample containing 5,578 new director appointments, of which 4,019 are unique directors, at 569 firms. We compare those out-of-sample predictions to those from an OLS model. All comparisons are based on predictions for the 2012-2014 subsample of director appointments, which does not overlap with the 2000-2011 subsample on which the algorithm is trained.

4.2. Predictions of Director Performance

Table 3 summarizes the ability of the machine learning models, once trained on the earlier portion of the sample, to predict director success in the later part.¹³

		Average Observed Performance for Directors in a Given Percentile of Predicted Performance as Predicted by:					
		Predicted Percentile of Excess Votes	OLS	XGBoost	Ridge	Lasso	Neural Network
Directors predicted to perform poorly	{	1%	0.028	-0.031	-0.012	-0.024	-0.014
		5%	-0.018	-0.014	-0.013	-0.015	-0.010
		10%	0.014	-0.008	0.000	-0.008	-0.001
Directors predicted to perform well	{	90%	0.013	0.013	0.011	0.011	0.011
		95%	0.007	0.012	0.014	0.013	0.016
		100%	0.006	0.011	0.009	0.016	0.015

TABLE 3: OLS VS. MACHINE LEARNING TO PREDICT DIRECTOR PERFORMANCE

Notes: This table reports the average observed level of excess shareholder support over the first three years of a new director’s tenure for directors who were ranked by their predicted level of shareholder support by an OLS model and several machine-learning algorithms (XGBoost, Ridge, Lasso and Neural Network). Shareholder support is defined as the fraction of votes in favor of a given director over all votes cast for the director’s reelection within three years of her tenure. To compute *Excess Votes*, we subtract the average of that variable for the slate of directors up for reelection that year on the focal board. Then we take the average of this relative vote measure over the first three years of the new director’s tenure.

A simple test of a model for predicting performance is whether actual performance is an increasing function of predicted performance. Table 3 indicates that average observed shareholder support almost monotonically increases across model predicted performance percentiles for each machine learning model but not for the OLS one. In contrast to the machine learning models, the average observed

¹² The algorithm relies on a regularizer that balances out in-sample fit and out-of-sample overfitting.

¹³ See online appendix for details on the OLS model used. Using alternative models, for example, without fixed effects, lead to similar results in terms of OLS’s performance in predicting director performance.

outcome of directors in the bottom of the predicted performance distribution using the OLS model (.028) is actually higher than that of directors in the top of the predicted performance distribution (.006).

Among the alternative machine learning algorithms, *XGBoost* and *lasso* perform best at predicting the subsequent success of directors using excess votes as a measure of director performance. Using total votes (not adjusted for the mean vote in the slate) as a performance measure, *XGBoost* performs better.^{14, 15} Directors predicted to be in the bottom percentile as predicted by *XGBoost* have an average observed excess shareholder support of -3.1%, whereas the average observed support is 1.1% for directors in the top percentile of predicted performance. This pattern highlights the difference between the machine learning model and OLS in their ability to predict future performance.

Figure 1 shows the average observed level of shareholder support for directors across the ten deciles of predicted performance for OLS and the machine learning algorithms in the 2012-14 test period. The figure shows how the mean shareholder support for a director is an increasing function of the predicted one for all the machine learning algorithms, but not for the OLS model. The difference in the predictive ability of various models illustrates the difference between standard econometric approaches and machine learning. OLS fits the data well in sample but poorly out of sample. In contrast, machine learning algorithms are specifically designed to predict well out of sample.

¹⁴ These results are not reported but are available from the authors on request.

¹⁵ *XGBoost* is an algorithm with a reputation for generating excellent predictions on a variety of problems, and was the most often used algorithm among the winning solutions in the 2015 machine learning Kaggle competition.

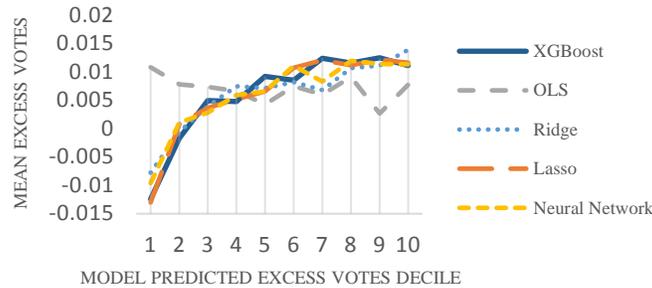


FIGURE 1: MEAN OBSERVED *EXCESS VOTES* VS. PREDICTED *EXCESS VOTES*

Notes: This figure shows the average observed level of excess shareholder support for directors across the ten deciles of predicted performance for OLS and *XGBoost* in the 2012-14 test set. To compute *excess votes*, we first compute the fraction of votes in favor of a given director over all votes cast for the director. Next, we subtract the average of that variable for the slate of directors up for reelection that year on the focal board. Finally, we take the average of this relative vote measure over the first three years of the new director’s tenure.

The fact that machine learning models perform substantially better than OLS at predicting director performance out of sample is consistent with the arguments of Athey and Imbens (2017) and Mullainathan and Spiess (2017), who emphasize that machine learning should be the preferred approach for prediction problems such as this one. One possible reason why the machine learning models do much better is because they let the data decide which transformations of which variables are relevant, while in OLS (or other standard econometric technique), the researcher must specify the structure of the equation before estimating it. Machine learning, by letting the data speak about the underlying relationships among the variables, ends up fitting the data better and consequently does better at predicting outcomes out of sample.

4.3. Comparing Firms’ Actual Choices of Directors with Potential Alternatives

The results suggest that directors identified by our algorithm as likely to have low (high) future shareholder support, are in fact more likely to have low (high) support in subsequent elections. However, accurate out of sample predictions are not sufficient to argue that our algorithm could assist firms in their nominating decisions of corporate directors. The algorithm should be able to assess how the nominated directors performed compared to the way alternatives would have

performed. In this section, we describe a pool of potential alternatives for our sample of directors and present results comparing the performance of directors actually chosen to that of these potential alternatives.

To construct candidate pools, we consider directors who joined the board of a neighboring company around the same time.¹⁶ These directors were available to join a board at that time and were willing to travel to that specific location for board meetings. Furthermore, to alleviate concerns related to the ability of a particular firm to attract promising directors, we restrict the pool of potential candidates to directors who joined a *smaller* neighboring company within a year around the focal appointment, since the prestige and remuneration of being a director tends to increase with company size (see Masulis and Mobbs, 2014). There are on average 147 candidates in a candidate pool.¹⁷ However, recall that the algorithm could give a prediction for any potential candidate, not only those in the candidate pool.

There are 19,464 directors in our sample who joined multiple boards of companies in our sample. The median standard deviation of shareholder support over the first three years of their tenure across the different boards they join is .024. This low standard deviation suggests that on average directors tend to receive similar support from shareholders on the different boards they join. Therefore, the key to dealing with the selective labels issue in this prediction problem is to note that although we do not observe the performance of potential candidates that were not nominated, we observe what we refer to as their “*quasi-label*”: their performance on the board they actually joined, which we use as an indication of how they would have performed on the focal board. To arrive at predictions for potential candidates, our algorithms use the board and firm characteristics as well

¹⁶ A neighboring firm is defined as a firm whose headquarters is within 100 miles of the focal firm’s headquarters.

¹⁷ All our results are similar if we further restrict the set of candidates in candidate pools to directors who join the board of a firm in the same industry (same SIC 3-digit code as the focal firm or same industry using Hoberg and Phillips (2010, 2016) industry definitions). There are on average 33 candidates in these more restrictive candidate pools.

as the committee assignments of the appointment at the focal firm with the individual potential candidate's features.

We use quasi-labels as follows. First we rank all nominated directors in our test set according to their predicted performance. Then, for each of the nominated directors in the bottom decile of predicted performance, we consider their associated candidate pool and rank candidates in this candidate pool according to their predicted performance *on the focal board*. We retain the top decile of candidates, who are the most promising candidates based on our algorithms' predictions. We then re-rank these promising candidates according to their quasi-labels, i.e. their performance on the board they actually joined. The goal is then to compare the observed performance of the nominated director on the focal board to the quasi-labels of promising candidates.

If the observed performance of the nominated director ranks high in the distribution of quasi-labels, this would suggest that even though our algorithm predicted that director would do poorly, she ended up doing well relative to available alternatives. The focal board might have relied on unobservables in the nomination process, and it was a good call, i.e. unobservables were used as signal. On the other hand, if the observed performance ranks low in the distribution of quasi-labels, then our algorithm identified *ex ante* that this director would perform poorly, and relative to alternatives, she indeed did perform poorly. What this would suggest, is that any unobservables that were used in the nomination process was not signal, but either noise, bias, or related to agency problems.

Table 4 presents the median rank in the distribution of quasi-labels for directors in the bottom and top deciles of predicted performance for several machine-learning algorithms, as well as for an OLS model. For all machine-learning models, the candidates identified as having high performance performed noticeably better than the candidates predicted to have low performance. *XGBoost* and *lasso* again appear to be the preferred algorithms. They can best discriminate *ex ante* the directors who

will do well from those who will not. In the rest of the paper, we focus on results with *XGBoost* to simplify the discussion. The median director predicted by the *XGBoost* algorithm to be in the bottom decile of performance ranks at the 27th percentile in the distribution of quasi-labels. The median director predicted to be in the top decile ranks at the 78th percentile in the distribution of quasi-labels. In contrast, the predictions from the OLS model are uninformative about subsequent performance; directors rank around the 75th percentile in the distribution of quasi-labels, regardless of whether OLS predicted they would perform well or not.

	Median percentile of observed performance in the distribution of quasi-labels (candidate pools)				
	OLS	XGBoost	Ridge	Lasso	Neural Network
Bottom decile of predicted performance	77 th	27 th	37 th	23 rd	29 th
Top decile of predicted performance	75 th	78 th	82 nd	79 th	69 th

TABLE 4: EVALUATING THE PREDICTIONS USING QUASI-LABELS

Notes: This table reports how nominated directors rank in the distribution of quasi-labels of their candidate pool. For each nominated director in our test set, we construct a pool of potential candidates who could have been considered for the position. Those candidates are directors who accepted to serve on the board of a smaller nearby company within a year before or after the nominated director was appointed. The quasi-label for each of these candidates is how she performed on the competing board she chose to sit on. The first (second) row shows the median percentile of observed performance in the distribution of quasi-labels for directors the model predicted to be in the bottom (top) decile of predicted performance. Each column presents the results from a different model.

These results suggest that machine-learning models can predict, at least to some extent, whether an individual will be successful as a director in a particular firm.

We emphasize that board-director matches are not exogenous, and are likely chosen with the intent of maximizing the “fit” between directors and firms. Therefore, our quasi-labels are not a perfect substitute for the level of support a director would have gathered on the focal board. However, note that our empirical strategy only uses candidate pools and quasi-labels to evaluate the algorithm’s performance in the presence of selective labels. Quasi-labels are noisier than our ideal benchmark, but the reason we use them is to check whether the potential available candidates our algorithm identified as promising for example would in fact be good directors. It could be that the focal board did not nominate a particular

director candidate because it relied on unobservables that would effectively make this individual a poor director despite observables suggesting otherwise. If this person nonetheless performed well on the board they ended up joining, the algorithm at least performed well to the extent that observable attributes affect director performance. Of course, it is still possible that due to the endogenous nature of the board-director match, the quasi-labels might be inflated, i.e. the performance of the available candidate may not be as high on the focal board. However, our results go both ways: nominated directors predicted to do poorly rank low compared to how other candidates would have performed, but we also find that nominated directors predicted to do well rank *high* compared to alternatives. The symmetry of our results provides reassurance that our quasi-labels are not systematically inflated due to the endogenous nature of the board-director match.

In sum, focusing on realistic potential candidates for each new board position, our algorithm is able to identify, with reasonable precision, those who will perform well and those who will not. These results suggest that our algorithm has the potential to improve on real world boards' nominating decisions. Importantly, this work is a first pass exercise to show the potential of machine learning in shedding light on the quality of boards' nominating decisions. A better algorithm and/or better data would likely predict future performance even more accurately.

4.4. Excluding Poorly Performing Firms

A possible concern with this analysis is that the relation between predicted performance and subsequent performance could occur only because of poorly performing firms. A poorly performing firm would likely be less attractive to a director, so it could be that only low ability directors are attracted to poorly performing firms, even if the firms are relatively large and otherwise prestigious. Because of their low ability, these directors would tend to do worse *ex post*.

For this reason, we repeat our analyses omitting firms that experience negative abnormal returns in the year prior to the election. Even without poorly performing

firms in the sample, the results are very similar to those reported above. For this reason, it does not appear that the relation between subsequent performance and predicted performance compared to alternative potential directors is driven by poorly performing firms with disgruntled shareholders.

4.5. Director Popularity or Performance?

An important interpretational issue is understanding exactly what the algorithm is predicting. The fiduciary responsibility of directors is to maximize shareholders' welfare, so choosing directors who will receive the most subsequent votes would seem to be a natural approach. One concern, however, is that many institutional shareholders decide on their votes through recommendations of shareholder services companies such as ISS. While in principle the goal of these services is to maximize shareholder welfare, it is possible that they instead follow mechanical rules and that our algorithm just suggest directors who will do well by these rules. ISS's influence is unlikely to drive our results for several reasons.

First, ISS introduced guidelines in the latter part of our training period. For example, guidelines to support proposals aimed at increasing female board representation were first introduced in 2010. However, our training sample covers data from 2000-2011. Less than 20% of appointments in our training set take place when ISS had those guidelines in place. Second, following Iliev and Lowry (2014) who argue that institutional investors with larger size of ownership vote independently from ISS recommendations, we repeat all our tests by focusing on a subsample of firms with larger-than-median (26%) ownership by the top-5 institutional owners. Our results (available upon request) remain very similar. Third, we compare the cumulative abnormal returns (CARs) around the announcement of director appointments in our test set for directors predicted to do well to those for directors predicted to do poorly.¹⁸ Table 5 reports the mean CARs

¹⁸ We collect announcement dates from *BoardEx*, *CapitalIQ* and *Lexis-Nexis*.

	N	Mean	Median
Directors in Decile 1 of predicted performance (excess votes)	292	-1.94%	-0.64%
Directors in Decile 10 of predicted performance (excess votes)	575	0.75%	0.34%
Difference in means (p-value)		0.0043	

TABLE 5: CUMULATIVE ABNORMAL RETURNS AROUND APPOINTMENT ANNOUNCEMENTS

Notes: This table reports the mean and median cumulative abnormal returns for directors predicted to do poorly and for directors predicted to do well. Directors predicted to do poorly (well) are directors in decile 1 (decile 10) of predicted performance (excess votes) as predicted by the *XGBoost* algorithm. The results are shown for appointments in the test set only. The cumulative abnormal returns reported are computed using a (-1; +1) window.

using a (-1; +1) window around announcements. The same pattern emerges using longer windows as well. Using our *XGBoost* algorithm to predict excess votes, we find that the mean CAR for directors predicted to do poorly (decile 1) in our test set is -1.94% whereas it is +0.75% for directors predicted to do well (decile 10). The difference is statistically significant at the 1% level. Directors predicted to be unpopular also tend to be viewed by the market as worse directors.

Finally, we train an *XGBoost* algorithm to predict a measure of firm profitability, *EBITDA/Total Assets*, three years post appointment. We then sort directors in our test set into deciles of predicted profitability. We report the actual profitability as well as the shareholder support in the first two rows of Table 6.¹⁹

		1	2	3	4	5	6	7	8	9	10	Decile 10 - 1 <i>p-value</i>
Algorithm trained on profitability	Average observed profitability	-0.498	-0.064	-0.017	0.017	0.078	0.083	0.113	0.114	0.144	0.205	0.0000
	Average observed shareholder support	0.942	0.946	0.956	0.937	0.957	0.961	0.953	0.954	0.960	0.961	0.0002
	Average observed excess votes	-0.0004	0.002	0.006	0.002	0.006	0.004	0.003	0.005	0.006	0.004	0.0668
Algorithm trained on excess votes	Average observed profitability	0.006	-0.017	0.008	0.037	0.052	0.058	0.057	0.083	0.087	0.112	0.0000
	Average observed excess votes	-0.012	-0.002	0.005	0.005	0.009	0.009	0.012	0.012	0.013	0.011	0.0000
Algorithm trained on total votes	Average observed profitability	-0.003	-0.032	-0.031	-0.018	0.024	0.029	0.058	0.075	0.086	0.100	0.0000
	Average observed shareholder support	0.920	0.937	0.946	0.948	0.950	0.957	0.957	0.966	0.972	0.977	0.0000

TABLE 6: COMPARING SHAREHOLDER SUPPORT MODELS WITH PROFITABILITY MODELS

Notes: This table reports the actual performance for each decile of *XGBoost*-predicted performance. *XGBoost* is trained to predict firm profitability three years after the director has been appointed (*EBITDA/Total Assets*), total votes as well as excess votes. The results are for our test set only (out-of-sample performance for directors appointed between 2012-2014).

¹⁹ The correlation of *EBITDA/Total Assets* with the shareholder support measure is 0.12 (p-value: 0.000).

The model trained to predict profitability in the subsequent period indeed does predict future profitability. The actual profits for the firms sorted into deciles based on expected profits increase monotonically, with average profits increasing with the model's expectation of profitability. Firms that nominated directors in the bottom decile of predicted performance have an average profitability of -49.8% and in the top decile is 20.5%. What is perhaps more surprising is that even though the model is trained to predict profitability, it also does reasonably well at predicting future shareholder support. Directors predicted to be in the bottom decile of profitability have shareholder support of 94% three years subsequent to the model's training, and directors predicted to be in the top decile have shareholder support of 96%. The difference between the two is statistically significantly different from zero at the 1% level. The model trained on profitability also does reasonably well at predicting *excess votes*. The average *excess votes* is -.0004 for directors in the bottom decile of predicted profitability and it is .004 for those in the top decile (the p-value of the difference is 6.68%).

These results suggest that the choice of training the algorithm on shareholder support in director elections is not crucial for the algorithm to be able to select high quality directors. When the model is trained using profitability instead, the pattern of predictions is similar. The algorithm predicts future subsequent support. Since this support is based on the market's perception of a director's contribution to quality, the results are similar when the algorithm is trained on profitability directly. In addition, for the algorithm trained on shareholder support that we discussed above, we consider whether it can also predict future profitability in addition to future shareholder support. We break the sample into deciles based on the algorithm's predictions of *excess votes* and *total votes*, and present average observed *excess votes*, *total votes* as well as the average profitability for each decile. We present these averages in the bottom four rows of Table 6.

As discussed above, *XGBoost* is successful in predicting future shareholder support (i.e. total votes) and excess votes: average shareholder support in the lowest decile is 92% (-1.2% for excess votes), compared to 97.7% in the top decile (1.1% for excess votes). In addition, it also predicts future profitability. Firms that nominated directors in the bottom decile of predicted shareholder support have an average profitability of -0.3%, whereas firms that nominated directors in the top decile of predicted shareholder support have an average profitability of 10%. When *XGBoost* predicts excess votes, the average profitability of firms in the bottom decile is .6% and it is 11.2% for the top decile. This finding suggests that nominating directors on the recommendation of an algorithm trained to predict shareholder votes would not come at the expense of poor firm performance.²⁰

5. Characteristics that Affect Director Performance

The machine learning models appear to be able to predict which directors are likely to receive more votes than average in subsequent elections. These excess votes presumably reflect shareholder satisfaction with individual director performance, which is a market-based measure of director performance.

One of the differences with traditional econometric modeling is that the machine learning algorithms do not provide a formula that can be used to infer the influence of any particular independent variable on performance. To understand which characteristics affect director performance, we consider the predictions from the machine learning models and evaluate the extent to which director and firm characteristics are associated with high and low predicted performance.

5.1. Univariate Comparisons

²⁰ This result alleviates concerns related to the omitted payoff bias articulated in Kleinberg et al. (2017), which in our setting refers to the concern that the decision-maker could have alternative objectives other than satisfying shareholders when making the nominating decision.

Table 7 provides some guidance about which director features are valued by the

	Mean		Difference p-value
	Bottom decile of predicted performance	Top decile of predicted performance	
Director level			
Age	56.3	57.0	0.083
Audit committee	0.236	0.818	0.000
Audit committee chair	0.039	0.077	0.001
Background academic	0.060	0.049	0.330
Background finance	0.190	0.122	0.000
Background lawyer	0.026	0.017	0.233
Background manager	0.335	0.318	0.471
Background marketing	0.084	0.026	0.000
Background military	0.010	0.006	0.405
Background politician	0.029	0.011	0.008
Background science	0.040	0.011	0.000
Background technology	0.021	0.007	0.021
Busy	0.520	0.120	0.000
Chairman	0.098	0.001	0.000
Compensation committee	0.624	0.059	0.000
Compensation committee chair	0.175	0.024	0.000
Foreign	0.156	0.088	0.005
Governance chair	0.045	0.011	0.000
Governance committee	0.168	0.122	0.008
International work experience	0.109	0.037	0.000
Male	0.897	0.746	0.000
Network size	1540	1327	0.000
Nomination chair	0.004	0.001	0.318
Nomination committee	0.023	0.011	0.057
Number of qualifications	2.208	2.282	0.180
Total current number of boards sitting on	2.848	1.545	0.000
Total number of listed boards sat on	5.814	2.289	0.000
Ivy league	0.217	0.109	0.000
MBA	0.466	0.410	0.064
Nb previous jobs same FF48 industry	0.105	0.037	0.000
Nb previous directorships same FF48 industry	0.342	0.037	0.000
Board level			
Gender ratio	0.105	0.153	0.000
Nationality mix	0.128	0.084	0.000
Board attrition	0.102	0.054	0.000
Average tenure of incumbent directors	3.443	9.731	0.000
Average tot. nb of boards incumbent directors sit on	1.672	1.809	0.000
Board size	8.5	10.2	0.000
CEO SOX certified	0.539	0.995	0.000
Chairman is CEO	0.357	0.496	0.001
Chairman is CEO with tenure ≥ 5	0.600	0.983	0.000
Indep. directors compensation over CEO tot. compensation	0.912	1.172	0.280
Mean past voting shareholder support	-0.012	0.011	0.000
Number of female directors	1.007	1.611	0.000
Incumbent directors with finance background	0.117	0.221	0.000
Busy incumbent directors	0.173	0.210	0.000
Average age of incumbent directors	57.5	63.0	0.000
Average network size of incumbent directors	1239	1347	0.007

Firm level			
Dividend payer	0.298	0.630	0.000
Excess returns 12 months leading up to appointment	0.028	-0.018	0.126
Firm age	10	30	0.000
Hoberg-Phillips product market fluidity	7.446	6.237	0.000
Institutional ownership %	0.586	0.711	0.000
Largest 10 institutional shareholders %	0.367	0.421	0.000
Largest 5 institutional shareholders %	0.275	0.303	0.001
Largest institutional shareholder %	0.106	0.102	0.492
Leverage	0.266	0.191	0.000
Log (number of institutional blockholders)	1.010	1.250	0.000
Log (number of institutional owners)	4.971	5.279	0.000
Ownership by blockholders %	0.193	0.226	0.002
ROE	-0.110	0.194	0.353
Stock returns prior 12 months	0.158	0.116	0.188
Total assets	17600	30435	0.087
Number of analysts	8.4	12.0	0.000
Short interest (%)	0.036	0.053	0.000
Peter & Taylor Total Q	4.291	0.990	0.000

TABLE 7: TOP VS. BOTTOM DECILE OF PREDICTED PERFORMANCE

Notes: This table reports the mean of firm and director level features for directors in the bottom decile of predicted excess votes and compares it to the mean for directors in the top decile of predicted excess votes. These results are for directors in our test set. Because we do not need the actual vote outcomes for this exercise but only the predictions, this test set covers appointments up to 2016. The algorithm used to predict performance is XGBoost.

algorithm in its assessment of directors. This table reports the averages of a number of characteristics of potential directors, boards, and firms that are associated with low and high expected future voting.

In particular, it presents the means of these characteristics for the bottom and top deciles of predicted shareholder support predicted by the *XGBoost* model.

Table 7 indicates that there are notable differences between directors in the top and bottom deciles. In particular, directors in the bottom decile are more likely to be male, sit on more current boards, have sat on more boards in the past, have received lower shareholder support in previous elections for other boards they sat on, and have a larger network. These differences suggest that male directors who are on a number of boards tend to be less desirable directors, either because they are too busy to do a good job or because they are less likely to monitor the CEO.²¹

²¹ Fich and Shivdasani (2006) present evidence suggesting that a director being overly busy can meaningfully affect their monitoring of management.

Board-level variables that affect predicted excess votes likely reflect perceptions of the quality of governance in a particular firm. Note that the outcome variable presented is the *excess votes*, which is adjusted for the average vote in the slate, and therefore, some of the statistics are harder to interpret. For instance, the average tenure of incumbent board members is about three years for directors in the bottom decile of the predicted performance, whereas it is about ten years for those in decile ten. This pattern occurs because a new director is more likely to receive more votes relative to other directors up for reelection if the others have been there forever. In unreported results where the top and bottom deciles refer to unadjusted (total) votes, we see that longer average director tenure, which is likely to reflect an entrenched board, is associated with lower predicted shareholder support.

Firm level variables affecting voting tend to reflect the performance of the firm, with better performance leading to higher predicted shareholder support. While prior 12-month stock returns for the bottom predicted decile of shareholder support are not different from that for the top decile of predicted shareholder support, average ROE is significantly larger for the top decile.

5.2. Multivariate Comparisons

Because director and firm characteristics are not independent from one another, we estimate regressions of predicted performance. As independent variables, we include both firm and director variables. The coefficients reflect the characteristics that *XGBoost* tends to associate with higher performance. We report estimates of these regressions in Table 8. Director variables related to predicted subsequent shareholder support are gender, a dummy variable that indicates whether the director is “busy” and the number of listed boards a director serves on. In particular, our algorithm suggests that male directors and directors who are on a number of boards (“busy” directors) tend to be less popular with shareholders.

Dependent variable: predicted performance	(1)	(2)	(3)	(4)
Busy	-0.006*** (-24.332)	-0.005*** (-13.183)	-0.005*** (-12.230)	-0.005*** (-12.087)
Male	-0.001*** (-4.623)	-0.001 (-1.398)	-0.001 (-1.603)	-0.001* (-1.688)
Age		-0.000** (-2.001)	-0.000** (-2.079)	-0.000** (-2.242)
MBA		0.000 (1.074)	0.000 (1.108)	0.000 (1.150)
Ivy league		-0.001** (-2.555)	-0.001* (-1.869)	-0.001* (-1.864)
Background lawyer			-0.002 (-1.521)	-0.001 (-1.394)
Background academic			0.000 (0.180)	0.000 (0.134)
Background finance			-0.001 (-1.344)	-0.001 (-1.568)
Network size			-0.000*** (-2.838)	-0.000*** (-2.691)
Ln (Assets)	0.001*** (9.054)	0.000 (0.276)	0.000 (0.016)	0.000 (0.160)
ROA	0.001*** (4.280)	0.000 (0.024)	0.000 (0.156)	0.000 (0.124)
Board size	-0.000*** (-3.303)	-0.000** (-2.027)	-0.000* (-1.751)	-0.000* (-1.843)
Average nb independent directors	0.009*** (20.814)	0.006*** (3.055)	0.006*** (2.906)	0.005** (2.529)
Chairman duality		0.001*** (3.399)	0.001*** (3.481)	0.001*** (3.319)
Excess returns 12 months leading up to appointment		0.000 (1.049)	0.000 (1.058)	0.000 (1.156)
Number of female directors			0.000 (0.172)	0.000 (0.554)
Average tenure of incumbent directors		0.000*** (6.441)	0.000*** (6.099)	0.000*** (4.907)
Log (number of institutional owners)		0.001** (2.155)	0.001** (2.431)	0.001* (1.798)
Compensation committee chair				-0.002* (-1.803)
Audit committee chair				0.002** (2.524)
Governance committee chair				-0.002 (-1.457)
Nomination committee chair				-0.002 (-0.599)
Firm Age				0.000*** (2.925)
Constant	-0.002*** (-3.762)	0.003 (1.053)	0.003 (1.128)	0.005* (1.867)
Observations	7,738	1,893	1,883	1,883
R-squared	0.153	0.131	0.136	0.146

t-statistics in parentheses

*** p<0.01, ** p<0.05, * p<0.1

TABLE 8: THE DETERMINANTS OF PREDICTIONS: OLS REGRESSIONS

Notes: This table reports the results from OLS regression models of the predicted excess votes in our test set on some firm level and director level features. Because we do not need the actual vote outcomes for this exercise but only the predictions, this test set covers appointments up to 2016. The algorithm used to generate the predictions is *XGBoost*.

This pattern could reflect the commonly stated concern of shareholders that directors are too often the same people (almost always men), are on many boards but do not monitor to the extent that shareholders would like (see for example Biggs (1996)). Consistently, network size has a significantly negative coefficient as well.

Board level variables that are significantly related to the predicted shareholder support are the size of the board, the average tenure of incumbent board members, and the average number of independent directors. These variables again are likely to reflect the independence of the board from management. Firm-level variables that appear to be associated with subsequent performance are size (total assets), operating performance, and whether the firm pays dividends. A word of caution in interpreting these coefficients: the R^2 is fairly low (below 20%), which speaks to the importance of feature interactions and non-linearities that *XGBoost* relies on to generate its predictions of subsequent performance.²²

5.3. Overvalued Director Characteristics

The algorithm's predictions also help identify the individual director features that tend to be overvalued or undervalued by firms when they select new directors. We identify directors who were nominated but are predictably of low quality and compare them to those directors the algorithm would have preferred for that specific board position. The patterns of discrepancies between these two groups recognize the types of directors that tend to be overvalued in the nomination process. In other words, the algorithm provides a diagnostic tool that can help evaluate the way in which directors are chosen.

In Table 9, we report characteristics of directors who were nominated, but whom the algorithm predicted would do poorly (and subsequently did poorly). Compared to promising candidates as identified by our algorithms, predictably unpopular directors are more likely to be male, have fewer degrees post

²² Kleinberg et al. (2017) make a similar argument when they report results of linear projections of predicted crime rates.

undergraduate, a larger professional network, more current and past directorships, and a background in finance. This comparison is for each new board seat, holding committee assignments constant for nominated directors and candidates. These are averages across all new board positions.

	Hired directors with predicted and observed low shareholder support	Promising candidates for this board position	Difference <i>p-value</i>
	Mean	Mean	
Male	0.984	0.835	0.000
Number of qualifications	2.1	2.4	0.000
Ivy League	0.29	0.26	0.523
MBA	0.57	0.38	0.000
Network size	1673	1428	0.000
Total number of listed boards sat on	6.4	2.3	0.000
Total number of unlisted boards sat on	11.0	2.7	0.000
Total current number of boards sitting on	3.1	1.5	0.000
Number previous jobs same industry	0.11	0.08	0.223
Number previous directorships same industry	0.26	0.07	0.000
Busy	0.64	0.10	0.000
Director age	54.1	54.6	0.353
Background academic	0.021	0.000	0.001
Background finance	0.094	0.046	0.002
International work experience	0.130	0.018	0.000

TABLE 9: OVERVALUED DIRECTOR CHARACTERISTICS

Notes: This table reports the mean of director features for directors in our test set (out of sample predictions) whom our XGBoost algorithm predicted would be in the bottom decile of performance and indeed ended up in the bottom decile of actual performance (predictably unpopular directors) and compares it to the mean for potential candidates the board could have nominated instead, whom our XGBoost algorithm predicted would be in the top decile.

These results highlight the features that are likely overrated by management when nominating directors. They are consistent with the view that directors tend to come from an “old boys club”, in which men who have sat on a lot of boards are chosen to be directors, even if they received poor shareholder support at the firms on whose boards they serve. The underlying reason for this pattern, however, is not clear. As suggested by the literature on boards going back to Smith (1776) and Berle and Means (1932), managers and existing directors could implicitly collude to nominate new directors unlikely to rock the boat and upset the rents managers

and existing directors receive from their current positions. Alternatively, a long literature in psychology dating to Meehl (1954) and highlighted in Kahneman (2011) has found that even simple algorithms can outperform interviews by trained professionals at predicting subsequent performance in a number of contexts. It is possible that managers and boards could be attempting to find value-maximizing directors but because of behavioral biases, could underperform the algorithms we present. Understanding why firm-selected directors differ from algorithm-selected directors is likely to be an important topic of future research.

6. Summary and Discussion

We present a machine-learning approach to selecting the directors of publicly traded companies. In developing the machine learning algorithms, we contribute to our understanding of governance, specifically boards of directors, in at least four ways. First, we evaluate whether it is possible to construct an algorithm that accurately forecasts whether a particular individual will be successful as a director in a particular firm. Second, we compare alternative approaches to forecasting director performance; in particular, how traditional econometric approaches compare to newer machine learning techniques. Third, there is no consensus in the literature on which metric to use for evaluating director performance. We provide evidence that director popularity is related to their expected value and therefore shareholder support is a reasonable proxy for their performance. Finally, we use the selections from the algorithms as benchmarks to understand the process through which directors are actually chosen and identify the types of individuals who are more likely to be chosen as directors *counter* to the interests of shareholders.

There are a number of methodological issues we must address before we can construct such an algorithm. We must be able to measure the performance of a director to predict which potential directors will be of highest quality. Measurement of directors' performance is complicated by the fact that most directors' actions

occur in the privacy of the boardroom where they are not observable to an outside observer. In addition, most of what directors do occurs within the structure of the board, so we cannot isolate their individual contributions. Our approach is based on the fraction of votes a director receives in shareholder elections. This vote, which is shown to be informative about directors' quality in the prior literature, reflects the support the director personally has from the shareholders and should incorporate all publicly available information about the director's performance. In addition, predicted future votes are positively related to CARs around the announcements of director appointments.

Using publicly available data on firm, board, and director characteristics, our *XGBoost* algorithm can fairly accurately predict the success of directors, and in particular, can identify which directors are likely to be unpopular with shareholders. In comparison to the machine-learning models, standard econometric models fit the data poorly out of sample. Specifically, the observed performance of individual directors is not related to the predictions of performance of an OLS model. The fact that the machine learning models dramatically outperform econometric approaches is consistent with the arguments of Athey and Imbens (2017) and Mullainathan and Spiess (2017): machine learning is a valuable approach for prediction problems in social sciences.²³

While we can observe the fraction of support an existing director has from shareholders, we cannot observe the votes a potential director who was not chosen would have received, nor whether a potential director for a firm would have been willing to accept the directorship. We address this issue by constructing a pool of potential directors from those who around that time accept a directorship at a smaller nearby company, so presumably would have been attracted to a directorship at a larger, neighboring company. To evaluate the performance of our algorithm,

²³ Current efforts are directed towards endowing machine-learning algorithms with an understanding of causal effects. Research on that front is still very much in its infancy.

we use the fraction of votes he received at the company where he was a director as our measure of this potential director's performance.

The differences between the directors suggested by the algorithm and those actually selected by firms allow us to assess the features that are overrated in the director nomination process. Comparing predictably unpopular directors to promising candidates suggested by the algorithm, it appears that firms choose directors who are much more likely to be male, have a large network, have a lot of board experience, currently serve on more boards, and have a finance background.

In a sense, the algorithm is saying exactly what institutional shareholders have been saying for a long time: that directors who are not old friends of management and come from different backgrounds are more likely to monitor management. In addition, less connected directors potentially provide different and potentially more useful opinions about policy. For example, TIAA-CREF (now TIAA) has had a corporate governance policy aimed in large part at diversifying boards of directors since the 1990s for this reason (see Biggs (1996) and Carleton et al. (1998)).²⁴

Our finding on the predictability of which directors will or will not be popular with shareholders has important implications for corporate governance. Observers since Smith (1776) and Berle and Means (1932) have been concerned about whether managers intentionally select boards that maximize their own interests rather than those of the shareholders. In addition, a psychology literature started by Meehl (1954) has found that because of behavioral biases, even simple algorithms can outperform humans in deciding on personnel decisions. It is easy to imagine that a machine learning algorithm, which is more sophisticated than the algorithms relied on by psychologists, would allow firms to improve their selection process.

²⁴ Similarly, Glenn Kelman, the CEO of RedFin, recently wrote: "Redfin has recently completed a search for new board directors, [...] and we had to change our process, soliciting many different sources for candidates rather than relying exclusively on board members' connections. If you don't pay attention to diversity, you'll end up hiring people who are nearest at hand, who have had similar jobs for decades before. This is how society replicates itself from generation to generation, in a process that seems completely innocuous to those who aren't the ones shut out." <https://www.redfin.com/blog/2016/11/how-to-triple-the-number-of-women-appointed-to-boards-in-three-years.html>

A natural question concerns the applicability of algorithms such as the ones we developed in practice. The algorithms we present should be treated as “first pass” approaches; presumably more sophisticated models would predict director performance even better than the ones presented in this paper. In addition, our algorithms rely on publicly available data; if one had more detailed private data on director backgrounds, performance, etc., one could improve the algorithm’s fit as well. If algorithms such as these are used in practice in the future as we suspect they will be, practitioners will undoubtedly have access to much better data than we have and should be able to predict director performance more accurately than we do in this paper. An important benefit of algorithms is that they are not prone to the agency conflicts that occur when boards and CEOs together select new directors.

Algorithmic bias is a concern of growing importance and algorithms are only as impartial as the data that feed them. If the data is generated by human decisions, machine learning algorithms can generate bias amplification (see Zhao et al., 2017). As Miller (2018) argues however, the perils of human bias are arguably worse than the perils of algorithmic bias. An important feature of our application is that the decision maker and the evaluator are separate entities: the board decides on the identity of the new director while shareholders vote. If we assume that the set of biases and incentives are independent between investors who vote (generate the left-hand side variable in our model) and board members who select new directors (generate the right hand side variables in our model), then we believe our algorithm is not as prone to propagating biases.

Institutional investors are likely to find this independence from agency conflicts particularly appealing and are likely to use their influence to encourage boards to rely on an algorithm such as the one presented here for director selections in the future. An important advantage of an algorithm over the way in which directors have been chosen historically is that algorithms do not allow for judgment on the part of directors and current management. Rivera (2012) studies the hiring practices

of top investment banks, consulting and law firms and concludes that recruiters value personal fit which is not necessarily a function of expected performance. In the context of lower skill workers, Hoffman et al. (2017) find that managers who hire against test recommendations end up with worse average hires. Cowgill (2018) shows that in the context of hiring at a software company, the job-screening algorithm prefers “nontraditional” candidates. Our results suggest that the same idea applies to the nominating of corporate directors. Including algorithmic input to limit discretion and reliance on soft information in these decisions could help minimize agency problems, and thus lead to better directors than the current process. On the other hand, if the algorithm omits attributes of potential directors that are valuable to management, such as specialized knowledge of an industry or government connections, then it potentially could lead to suboptimal solutions. This is why we advocate for tools built on algorithms as decision aids, not substitutes for human judgement. Humans and machines both have limits and make different kinds of mistakes. Achieving the right balance in the division of labor between humans and machines to take advantage of their relative strengths is key.²⁵

In this paper, we use 21st century technology to confirm an observation that dates back over two hundred years: the board selection process leads to directors who often are not the best choices to serve shareholders’ interests. This technology can, however, in addition to confirming this observation, provides us with the tools to change it. By providing a prediction of performance for *any* potential candidate, a machine-learning algorithm could expand the set of potential directors and identify individuals with the skills necessary to become successful directors, who would have otherwise been overlooked. We expect that in the not too distant future, machine-learning techniques will fundamentally change the way corporate governance structures are chosen, and that shareholders will be the beneficiaries.

²⁵ The issues around the consequences of AI-based decisions are exposed in grounded discussions in Agrawal, Gans and Goldfarb (2018)

References

- Adams, R. B (2017) Boards and the Directors Who Sit on Them. Chapter 6 of *Handbook of the Economics of Corporate Governance*, edited by B. E. Hermalin and M. S. Weisbach, Elsevier.
- Adams, R., B. Hermalin and M. Weisbach (2010) The Role of Boards of Directors in Corporate Governance: A Conceptual Framework and Survey. *Journal of Economic Literature* 48, 58–107.
- Alexander, C., M. Chen, D. Seppi, and C. Spatt (2010) Interim News and the Role of Proxy Voting Advice. *Review of Financial Studies* 23: 4419-4454.
- Aggarwal, R., S. Dahiya and N. Prabhala (2017) The Power of Shareholder Votes: Evidence from Uncontested Director Elections. *Georgetown McDonough School of Business Research Paper*.
- Aggarwal, R., I. Erel, and L. Starks (2016) Influence of Public Opinion on Investor Voting and Proxy Advisors, Working Paper, Ohio State University.
- Agrawal, A., J. Gans and A. Goldfarb (2018) Prediction Machines. *Harvard Business Review Press*, Boston, Massachusetts.
- Athey, S. and G.W. Imbens (2017) The State of Applied Econometrics: Causality and Policy Evaluation, *Journal of Economic Perspectives*, 31, 3-32.
- Biggs, John (1996) Corporate Governance Assessment: A TIAA-CREF Initiative, *Directors Monthly*, 20 (10) 1-8.
- Cai, J., J. Garner and R. Walkling (2009) Electing Directors. *The Journal of Finance*, 64(5): 2389-2421.
- Cai, J., T. Nguyen, and R. Walkling (2017) Director Appointments – It is Who You Know, Drexel University Working Paper.
- Carleton, Willard T., James M. Nelson and Michael S. Weisbach (1998) The Influence of Institutions on Corporate Governance through Private Negotiations: Evidence from TIAA-CREF, *The Journal of Finance*, 53, 1335-1362.
- Chen, T. and C. Guestrin (2016) XGBoost: A Scalable Tree Boosting System. KDD '16 Proceedings of the 22nd ACM SIGKDD International Conference on Knowledge Discovery and Data Mining: 785-794.
- Coles, J., N. Daniel and L. Naveen (2008) Boards: Does One Size Fit All? *Journal of Financial Economics*, 87, 329-356.
- Coles, J., N. Daniel and L. Naveen (2015) Board Groupthink. *Working Paper*.
- Cowgill, B. (2018) Automating Judgement and Decision-making: Theory and Evidence from Resumé Screening. *Working Paper*.
- Daines, R., I. Gow, and D. Larcker (2010) Rating the ratings: How Good are Commercial Governance Ratings? *Journal of Financial Economics* 98: 439-461.
- Ertimur, Y. F. Ferri, and D. Oesch (2013) Understanding Uncontested Director Elections. *Management Science*, forthcoming.
- Fich, E. and A. Shivdasani (2006) Are Busy Boards Effective Monitors? *The Journal of Finance* 61: 689-724.
- Field, L., M. Souther, and A. Yore (2017) Does diversity pay in the boardroom? University of Delaware Working Paper.
- Fischer, P., J. Gramlich, B. Miller and H. White (2009) Investor Perceptions of Board Performance: Evidence from Uncontested Director Elections. *Journal of Accounting and Economics* 48: 172–189.
- Hart O. and L. Zingales (2017) Companies Should Maximize Shareholder Welfare Not Market Value. *Journal of Law, Finance, and Accounting*, 2: 247–274.
- Hastie, T., R. Tibsharani and M. Wainwright (2015) Statistical Learning with Sparsity: The Lasso and Generalizations. *Chapman and Hall/CRC*.
- Hermalin, B. E., and M. S. Weisbach (1998) Endogenously Chosen Boards of Directors and Their Monitoring of the CEO. *American Economic Review*, 88(1): 96–118.

Hermalin, B. E., and M. S. Weisbach (2003) Boards of Directors as an Endogenously Determined Institution: A Survey of the Economic Literature. *Federal Reserve Bank of New York Economic Policy Review*, 9(1): 7–26.

Hoberg, G. and G. Phillips (2010) Product Market Synergies and Competition in Mergers and Acquisitions: A Text-Based Analysis. *Review of Financial Studies* 23 (10), 3773-3811.

Hoberg, G. and G. Phillips (2016) Text-Based Network Industries and Endogenous Product Differentiation. *Journal of Political Economy* 124 (5) 1423-1465.

Hoffman, M., L. B. Kahn and D. Li (2017) Discretion in Hiring. *The Quarterly Journal of Economics*. qjx042, <https://doi.org/10.1093/qje/qjx042>.

Iliev, P., K. Lins, D. Miller and L. Roth (2015) Shareholder Voting and Corporate Governance Around the World. *The Review of Financial Studies* 28(8): 2167–2202.

Iliev, P. and M. Lowry (2014) Are Mutual Funds Active Voters? *Review of Financial Studies* 28: 446-485.

Kahneman, D. (2011) *Thinking, Fast and Slow*, Farrar, Strauss and Giroux: New York.

Kleinberg, J., H. Lakkaraju, J. Leskovec, J. Ludwig, S. Mullainathan (2017) Human Decisions and Machine Predictions. *The Quarterly Journal of Economics* 133 (1) 237–293.

Kleinberg J., Liang A. and S. Mullainathan (2017) The Theory Is Predictive, but Is It Complete? An Application to Human Perception of Randomness. *Working Paper*.

Kleinberg, J., J. Ludwig, S. Mullainathan and Z. Obermeyer (2015) Prediction Policy Problems. *American Economic Review* 105(5): 491–495.

Kramarz, F. and D. Thesmar (2013) Social Networks in the Boardroom. *Journal of the European Economic Association* 11(4): 780-807.

Larcker, D., A. McCall, and G. Ormazabal (2015) Outsourcing Shareholder Voting to Proxy Advisory Firms. *Journal of Law and Economics* 58, 173-204.

Linck, J. J. Netter, and T. Yang (2009) The effects and unintended consequences of the Sarbanes-Oxley Act on the supply and demand for directors, *Review of Financial Studies* 8, 3287–3328.

Malenko, N., and Y. Shen (2016) The Role of Proxy Advisory Firms: Evidence from a Regression-Discontinuity Design, *The Review of Financial Studies* 29: 3394–3427.

Masulis, R. and S. Mobbs (2014) Independent Director Incentives: Where do Talented Directors Spend their Limited Time and Energy, *Journal of Financial Economics* 111, 406-429.

Meehl, P. E. (1954) *Clinical vs. Statistical Prediction: A Theoretical Analysis and a Review of the Evidence*, University of Minnesota Press: Minneapolis.

Miller, A. (2018) Want Less-Biased Decisions? Use Algorithms. *Harvard Business Review*.

Mitchell, T. (1997) *Machine Learning*. McGraw Hill.

Mullainathan, S. and J. Spiess (2017) Machine learning: An Applied Econometric Approach, *Journal of Economic Perspectives*, 31, 4: 87-106.

Pearl J. and D. Mackensie (2018) *The Book of Why*. Basic Books.

Rivera, L.(2012) Hiring as Cultural Matching: The Case of Elite Professional Service Firms, *American Sociological Review*, 77: 999-1022.

Shivdasani, A. and D. Yermack (1999) CEO Involvement in the Selection of New Board Members: An Empirical Analysis, *The Journal of Finance*, 54, 1829-1853.

Shmueli, G. (2010) To Explain or to Predict? *Statistical Science* 25(3): 289-310.

Smith, A. (1776) *An Inquiry into the Nature and Causes of the Wealth of Nations*, Indianapolis, Liberty Press.

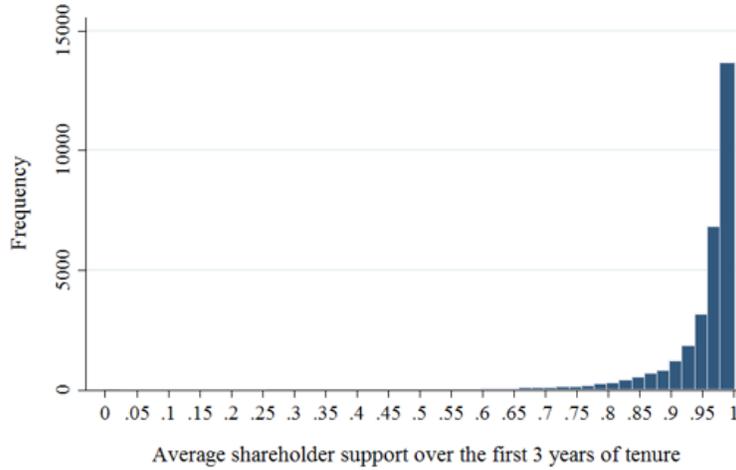
Yermack, D. (1996) Higher Market Valuation of Firms with a Small Board of Directors, *Journal of Financial Economics* 40: 185-211.

Zhao Jieyu, T. Wang, M. Yatskar, V. Ordonez, K. Chang (2017) Men Also Like Shopping: Reducing Gender Bias Amplification using Corpus-level Constraints, *EMNLP* 2017.

For Online Publication

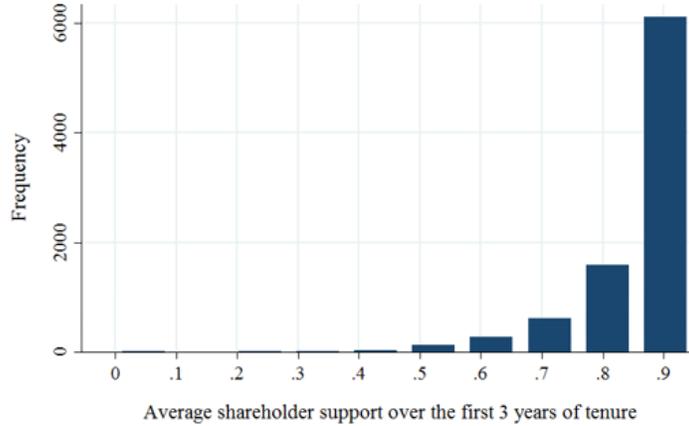
VOTES DISTRIBUTION

Shareholder Support: Fraction of Votes “For”



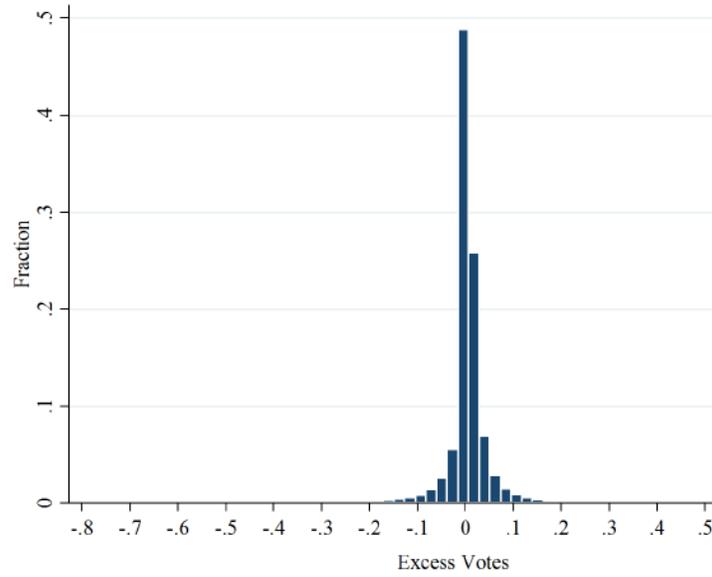
This figure shows the distribution of average shareholder support, defined as the fraction of votes in favor of a given director over all votes cast for the director’s reelection within three years of her tenure. The data is from ISS Voting Analytics.

Distribution of Bad Outcomes: Fraction of Votes “For” Below 95%



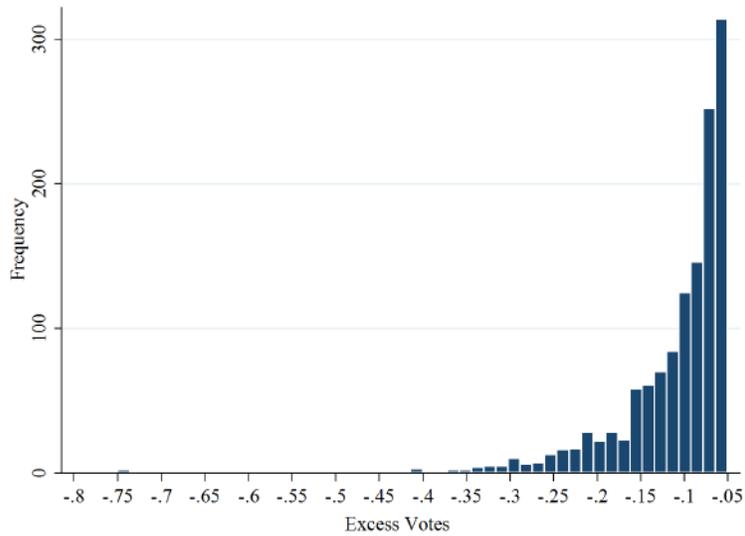
This figure shows the distribution of average shareholder support for values under its mean value of 95%. Shareholder support is defined as the fraction of votes in favor of a given director over all votes cast for the director’s reelection within three years of her tenure. The data is from ISS Voting Analytics.

Excess Votes: Fraction of Votes “For” Minus the Slate’s Average



This figure shows the distribution of *excess votes* for our sample. To compute *excess votes*, we compute the fraction of votes in favor of a given director over all votes cast for the director. Next, we subtract the average of that variable for the slate of directors up for reelection that year on the focal board. Finally, we take the average of this relative vote measure over the first three years of the new director’s tenure. The data is from ISS Voting Analytics.

Distribution of Bad Outcomes: Excess Votes below -5%



This figure shows the distribution of *excess votes* below -5%.

OLS MODEL

This table reports coefficients from an OLS regression of excess votes on various director, firm, and board characteristics. OLS model also includes firm fixed effects. Excess vote is defined as the average observed level of shareholder support over the first three years of a new director's tenure, minus the average vote for all directors in the same slate. The regression sample contains director appointments between 2000-2011.

Dependent Variables: Excess Votes	
Compensation committee chair	-0.003 <i>(-1.281)</i>
Audit committee chair	0.006*** <i>(2.975)</i>
Governance committee chair	0.003 <i>(1.338)</i>
Nomination committee chair	0.002 <i>(0.399)</i>
Nb previous jobs same FF48 industry	-0.002 <i>(-1.117)</i>
Background finance	0.002 <i>(1.341)</i>
Background law	-0.006** <i>(-2.320)</i>
MBA	0.001 <i>(1.229)</i>
Ivy league	-0.001 <i>(-0.615)</i>
Male	0.001 <i>(0.609)</i>
Age (director)	0.000 <i>(-0.068)</i>
Number of qualifications	0.000 <i>(0.133)</i>
Ln (Assets)	0.003** <i>(2.323)</i>
Leverage	-0.007 <i>(-1.285)</i>
M/B	0.000 <i>(0.185)</i>
Largest 5 institutional shareholders %	0.012 <i>(1.553)</i>
ROA	0.000 <i>(0.078)</i>
Product market fluidity	0.000 <i>(-0.486)</i>
12-month return	0.000 <i>(-0.452)</i>
Dividend payer	0.003 <i>(1.147)</i>
Board size	0.000 <i>(0.375)</i>
Number of female directors	0.000 <i>(0.371)</i>
Average nb independent directors	-0.009 <i>(-1.232)</i>
Average age	0.000 <i>(0.774)</i>
Constant	-0.026* <i>(-1.650)</i>
Observations	10,601
Number of firms	2,820
R-squared	0.005

t-statistics in parentheses

*** p<0.01, ** p<0.05, * p<0.1

ALGORITHMS USED TO PREDICT PERFORMANCE: SOME DETAILS

A.2.1. Less is More: The Case for *Lasso* and *Ridge*

Lasso and *ridge* are both linear models that use a regularization term to achieve a balance between bias and variance. They do so by minimizing a loss function that includes in-sample fit and a penalty term that favors simple models, thereby reducing variance. Prediction accuracy is thus improved by setting some coefficients to zero and shrinking others. To achieve this goal, lasso and ridge combine the minimization of the sum of the squared errors with the norm of parameters. The lasso estimator solves the problem:

$$\min_{\beta} \sum_{j=1}^k (y_i - x_i\beta)^2 + \lambda \cdot \|\beta\|_1$$

where $\|\beta\|_1$ is the ℓ_1 -norm (least absolute deviation). The penalty weight (λ) on the sum of the absolute values of coefficients is set using the default parameter in scikit-learn²⁶.

Ridge is similar to *lasso* except that the bound on the parameter estimates is the ℓ_2 -norm (least squares), therefore shrinking estimates smoothly towards zero, as opposed to setting some estimates to zero as Lasso does.²⁷

A.2.2. Gradient Boosting Trees

Gradient Boosting Trees are related to random forests. A decision tree is the basic building block of random forests. A decision tree defines a tree-shape flow graph to support decisions. An instance is classified by starting from the root of the tree, testing the feature specified by the node, moving down the branch corresponding to the feature value in the given instance.

A key difference between decision tree learning and Ridge and Lasso regression lies in the fact that there is no explicit objective function that a decision tree optimizes. Instead, the learning process is a greedy recursive algorithm that finds the best feature to split the current data based on a criterion. In our paper, we use a decision tree regressor

²⁶ <http://scikit-learn.org/stable/>

²⁷ For a detailed discussion of sparse estimators, we refer interested readers to Hastie, Tibshirani and Wainwright (2015).

where the criterion aims to minimize the mean squared error in each branch. Refer to Mitchell (1997) for more details on decision tree learning.

Random forest is an ensemble method based on decision trees. The main intuition is that a single decision tree can be noisy but is able to function as a weak learner. An ensemble of weak learners makes a strong learner. To train a random forest regressor, a number of decision tree regressors are fitted by randomly sampling data from the training instances with replacement and also randomly sampling a subset of features. The average values of all decision tree regressors is used to predict the value of an instance.

Gradient boosting tree is another ensemble method based on decision trees. It differs from random forests in two aspects:

1. Boosting. To predict the value of an instance, gradient boosting trees uses K additive functions instead of computing the average:

$$\hat{y}_i = \sum_{k=1}^K f_k(x_i),$$

where f_k is a decision tree regressor. In other words, in boosting, each additional decision tree attempts to fit the residual error, whereas each decision tree in random forest attempts to fit the target value y directly.

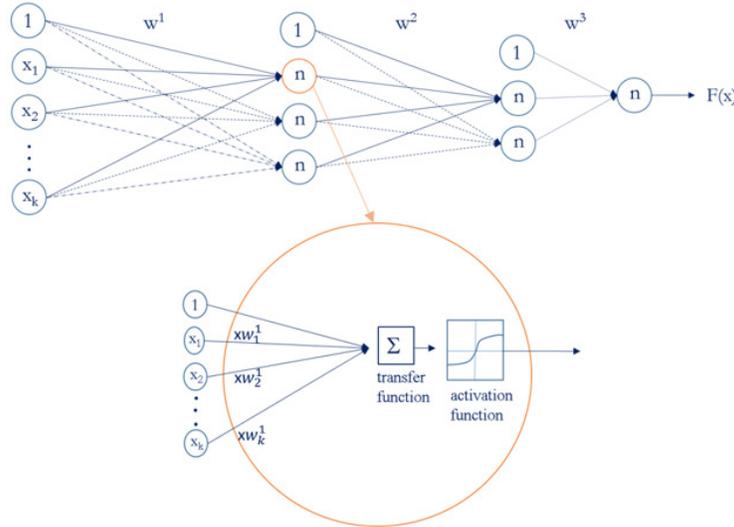
2. Regularized objectives. The split in a decision tree regressor of gradient boosting trees optimizes a regularized global objective that balances the predictive performance and the complexity of decision tree regressors. The loss function is formulated as:

$$L = \sum_i l(\hat{y}_i, y_i) + \sum_k \Omega(f_k),$$

where l refers to a differentiable loss function that measures the difference between the predicted value and the target value (in our case, it is simply squared loss), $\Omega(f_k) = \gamma T + \frac{1}{2} \lambda \|w\|^2$ and measures the complexity of a tree, T refers to the number of leaves in the tree and w refers to the score at a leaf. γ and λ are parameters to control how these two complexity measures are weighted in the final objective function. The name gradient boosting trees arise from the fact that a gradient will be computed in the

algorithm to optimize the above objective function. Please refer to Chen et al, 2016 for a detailed discussion.

A.2.3. Neural Networks



The figure above depicts the structure of a basic neural network with two hidden layers. Neurons x_i are input neurons connected to the next layer of neurons by synapses which carry weights w^l . Each synapse carries its own weight. An activation function (usually a sigmoid to allow for non-linear patterns) is embedded in each neuron in the hidden layers to evaluate its inputs. The set of weights carried by the synapses that reach a neuron are fed into its activation function, which will determine whether that neuron is activated. If activated, it then triggers the next layer of neurons with the value it was assigned, with weight w^2 (again with each synapse carrying its own weight).

A FRAMEWORK TO ASSESS ALGORITHMS' PREDICTIONS

Following Kleinberg et al. (2017), we develop a framework to understand the issues faced when assessing the prediction accuracy of our algorithms. Suppose that the true data generating process is given by $\mathcal{Y} = \mathcal{F}(\mathcal{W}, \mathcal{Z})$, where \mathcal{W} and \mathcal{Y} are operationalized by W , our vector of inputs and Y , our outcome variable (i.e., director

performance). Z represents a set of features that affect director performance and that are observable by the board but not by the algorithm. An example of such a feature would be idiosyncratic knowledge of the firm or its industry that would make a potential director more valuable.

In addition, there are features B that do *not* affect director performance and are unobservable to the algorithm, but could nonetheless affect boards' nominating decisions. Examples of such features could be a candidate's political views, or the neighborhood where he grew up. The board's preferences for certain features in B could be conscious or even could represent an implicit bias of which they are unaware of. The important point is that these attributes of a potential director can influence boards' decisions even though they are uncorrelated with performance.

\mathcal{F} is operationalized by a functional form f . For the purpose of predictive modeling, we are interested in finding a function that closely matches the function f in out-of-sample data. Compared to classic causal hypothesis testing, we do not make strong assumptions about the structure of \mathcal{F} and thus do not focus on examining the estimated parameters and claim that these parameters match f . In other words, our algorithm seeks a functional form that maps features W into predictions $\hat{f}(W)$ that generalize well on out-of-sample data (Shmueli, 2010).

A director is characterized by \vec{x} , composed of three vectors of features and outcome y :

$$\vec{x} = \begin{bmatrix} W \\ Z \\ B \end{bmatrix}$$

Note that x may include not only director characteristics but also firm and board characteristics so that both the board and the algorithm try to assess a director's future performance on a specific board.

For the purpose of the model, we shrink the dimension of \vec{x} to a vector with three unidimensional characteristics w , z and b . In addition, we make the assumption that the sum of w and z is distributed between 0 and 1 and that their sum equals y on average:

$$E[Y = y|W = w, Z = z] = E[y|w, z] = w + z$$

Each board j has a payoff function π_j that is a function of the director's performance as well as of the director's characteristics as defined by \vec{x} . For each director (x, y) in the candidate pool \mathcal{D} of size k , the board's payoff is characterized as:

$$\pi_j(x, y) = \underbrace{u_j y}_{\text{benefits from director's performance}} + \underbrace{v_j g_j(x)}_{\text{benefits from hiring director with characteristics } x}$$

$g_j(x)$ is a board specific function that maps directors' characteristics into a score. We can think of $g_j(x)$ as a measure of the utility the board derives from nominating a director with specific characteristics; for example, they could derive private benefits from nominating someone from their own network. The variables u_j and v_j are the weights that board j puts on director performance and on the benefits it derives from nominating a director with certain features, respectively.

We assume that board j chooses a nominating rule h_j such that it maximizes its expected payoff.

$$h_j \in \{0,1\}^k \text{ and } \|h_j\|_0 = 1$$

$$\Pi_j(h_j) = \sum_{i \in \mathcal{D}} h_{j,i} E[\pi_j(x_i, y_i)]$$

The nominating rule h_j depends on $k_j(x)$, the board's *assessment* of future performance for a director with characteristics x . For a given $g_j(x)$, the board chooses the director with the highest $k_j(x)$. We do not observe boards' relative weights on director performance, u_j , and their own preferences for directors with particular characteristics, v_j . In a world of perfect corporate governance, boards are only concerned with their mandate (i.e. representing shareholders' interests) and $v_j = 0$.

We set $v_j = 0$ not because we believe in a world of perfect governance but because our question is: can an algorithm identify a director x'' with better performance than director x' nominated by board j , whom the board will like at least equally well? In other words, conditional on $g_j(x'') \geq g_j(x')$, can an algorithm recommend a nominating rule α that produces a higher payoff than the baseline: the outcome of board j 's actual nominating decision?

The difference in the expected payoffs between the two nominating rules α_j and h_j is:

$$\begin{aligned}\Pi_j(\alpha_j) - \Pi_j(h_j) &= \sum_{i \in \mathcal{D}} \alpha_{j,i} E[\pi_j(x_i, y_i)] - \sum_{i \in \mathcal{D}} h_{j,i} E[\pi_j(x_i, y_i)] \\ &= \underbrace{E[y|\alpha]}_{\text{missing label}} - \underbrace{E[y|h]}_{\text{observed label}}\end{aligned}$$

We do not observe the performance of directors who would be nominated under the alternative nominating rule produced by the algorithm. As discussed in Kleinberg et al. (2017), missing labels are often dealt with in the machine learning literature by various imputation procedures. However, this approach would assume that if a director shares the same set of observable feature values, w , as the nominated director, their performance would be identical. This is the equivalent of assuming that unobservables, z , play no role in nominating decisions. For a given w , the imputation error would therefore be:

$$\begin{aligned}E[y|\alpha, w] - E[y|h, w] &= E[w + z|\alpha, w] - E[w + z|h, w] \\ &= E[w|\alpha, w] - E[w|h, w] + E[z|\alpha, w] - E[z|h, w] \\ &= E[z|\alpha, w] - E[z|h, w]\end{aligned}$$

This imputation error points up the *selective labels problem* as described by Kleinberg et al. (2017). In our setting, it refers to the possibility that directors who were nominated, although they might share the same exact observable features as other directors not nominated, might differ in terms of unobservables. These unobservables could lead to different average outcomes for nominated vs. not nominated, even if both are identical on the basis of observable characteristics.

We exploit the design of our pool of candidate directors for each board seat in order to compare the performance of our algorithm to board decisions. We consider directors who joined the board of a neighboring company around the same time. These directors were available to join a board at that time and willing to travel to that specific location for board meetings. Furthermore, to alleviate concerns related to the ability of a particular firm to attract promising directors, we restrict the pool of potential candidates to directors who joined a *smaller* neighboring company around the same time, since the prestige of being a director tends to increase with company size (see Masulis and Mobbs, 2014). In addition, we note that there is on average very little variation in shareholder

support for individual director performance across the different boards they join during our sample period. Therefore, although we do not have labels for nominees generated by the algorithm's nominating rule, $E[y|\alpha]$, we observe their *quasi-label*: their performance on the smaller neighboring board they joined around the same time.

We are interested in evaluating the quality of boards' nominating decisions. Our approach is to contrast those decisions to an alternative nominating rule that our algorithm would have chosen. For example, using the notation introduced in this section, if the algorithm predicted a director with characteristics x' would perform very poorly and there were 150 other candidates the algorithm predicted would do better, there are effectively 150 alternative nominating rules α that would yield a higher payoff in terms of benefits derived from director performance. To allow boards to use unobservables to make their nominating decisions, we add the assumption that among those 150 alternative nominees, there exists at least one director with characteristics x'' such that $g_j(x'') \geq g_j(x')$. When we analyze the quasi-labels of those potential candidates, we explore whether they indeed do much better on average than director x' when x' was predicted to do poorly, and worse when x' was predicted to do well.

There are two, not mutually exclusive, reasons why the selections of the algorithm could outperform the actual directors selected by firms: first, the algorithm actually attempts to choose value maximizing directors while actual boards do not ($u_j = 0$), and second, the machine learning approach outperforms the choices firms would have made even if they were attempting to maximize value. In other words, boards are "mispredicting" future performance, i.e. the technology $k_j(x)$ they use to assess the future performance of candidates is inapt. Results related to chosen directors who were predictably unpopular would suggest that boards put disproportionate weight on v_j .

DATA DEFINITIONS

A.4.1. Individual Director Features

Source: BoardEx except if stated otherwise
(as of when the director joins the board)

Variable

Age
Audit chair
Audit member
Avg. time on the board

Background academic
Background CEO

Background finance

Background hr

Background law

Background manager

Background marketing

Background military

Background politician

Background science

Background technology
Bonus
Busy
CEO
Chairman
Compensation chair
Compensation committee

Definition

Director age
Equals to one if director is chair of the audit committee
Equals to one if director is a member of the audit committee
The average time that a director sits on the board of quoted companies
Dichotomous variable equal to (*henceforth "Equals to"*) one if job history includes in title one of the following: "professor" "academic" "lecturer" "teacher" "instructor" "faculty" "fellow" "dean" "teaching"
Equals to one if job history includes CEO title
Equals to one if job history includes in title one of the following: "underwriter" "investment" "broker" "banker" "banking" "economist" "finance" "treasure" "audit" "cfo" "financial" "controller" "accounting" "accountant" "actuary" "floor trader" "equity" "general partner" "market maker" "hedge fund"
Equals to one if job history includes in title one of the following: "hr" "recruitment" "human resource"
Equals to one if job history includes in title one of the following: "lawyer" "legal" "attorney" "judge" "judicial"
Equals to one if job history includes in title one of the following: "manager" "vp" "president" "director" "administrator" "administrative" "executive" "coo" "chief operating" "operation" "secretary" "founder" "clerk" "division md" "employee" "associate" "head of division"
Equals to one if job history includes in title one of the following: "marketing" "publisher" "mktg" "sales" "brand manager" "regional manager" "communication" "merchandising" "comms" "distribution" "media"
Equals to one if job history includes in title one of the following: "captain" "soldier" "lieutenant" "admiral" "military" "commanding" "commander" "commandant" "infantry" "veteran" "sergeant" "army"
Equals to one if job history includes in title one of the following: "politician" "senator" "political" "deputy" "governor"
Equals to one if job history includes in title one of the following: "researcher" "medical" "doctor" "scientist" "physician" "engineer" "biologist" "geologist" "physicist" "metallurgist" "science" "scientific" "pharmacist"
Equals to one if job history includes in title one of the following: "technology" "software" "programmer" "it" "chief information officer" "database" "system administrator" "developer"
Annual bonus payments (in thousands)
Equals to one if directors sits on three or more boards
Equals to one if director is the company's CEO
Equals to one if director is chairman of the board
Equals to one if director is chair of the compensation committee
Equals to one if director is a member of the compensation committee

Employer contribution
Equity linked remuneration ratio

Employers Defined Retirement/Pension Contribution
Equity Linked Compensation as a proportion of total compensation for the

Foreign	individual based on the closing stock price of the last annual report
GenBBB	Equals to one if director's nationality is not American
GenDepBB	Equals to one if director was born between 1946 and 1964
Gender	Equals to one if director was born in or before 1926
GenMature	Equals to one if director is male
GenX	Equals to one if director was born between 1927 and 1945
GenY	Equals to one if director was born between 1965 and 1980
Governance chair	Equals to one if director was born in 1981 or after
Governance member	Equals to one if director is chair of the governance committee
	Equals to one if director is a member of the governance committee
HistInternational	Equals to one if job history includes a position outside the United States
Independent	Equals to one if director is not an executive director
Lead independent director	Equals to one if director is lead independent director
Mean past voting outcome	Average shareholder support during the first three years of tenure for previous board positions (starting in 2002). Source: ISS Voting Analytics
Mean_support_3yrs	Average shareholder support over the first three years of tenure. Source: ISS Voting Analytics
Network size	Network size of director (number of overlaps through employment, other activities, and education)
Nomination chair	Equals to one if director is chair of the nomination committee
Nomination member	Equals to one if director is a member of the nomination committee
Number connections	Number of established connections to incumbent board members prior to joining the board
Number qualifications	Number of qualifications at undergraduate level and above
Other chair	Equals to one if director is chair of a committee other than compensation, audit, governance or nomination
Other member	Equals to one if director is a member of a committee other than compensation, audit, governance or nomination
Other compensation	Value of annual ad hoc cash payments such as relocation or fringe benefits awarded during last reporting period (in thousands)
Perf to total compensation	Performance to total - Ratio of Value of LTIPs Held to Total Compensation
Salary	Base annual pay in cash (in thousands)
Timeretirement	Time to retirement (assumed to be 70 years old)
Tot Current Nb Listed Boards sitting on	The number of Boards of publicly listed companies that an individual serves on
Tot Current Nb Other Boards sitting on	The number of Boards for organizations other than publicly listed or private companies that an individual serves on
Tot Current Nb Unlisted Boards sitting on	The number of Boards of private companies that an individual serves on
Tot Nb Listed Boards sat on	The number of Boards of publicly listed companies that an individual has served on
Tot Nb Other Boards sat on	The number of Boards for organizations other than publicly listed or private companies that an individual has served on
Tot Nb unlisted Boards sat on	The number of Boards of private companies that an individual has served on
Total Compensation	Salary + Bonus
Total director compensation	Salary plus Bonus plus Other Compensation plus Employers Defined Retirement/Pension Contribution
Total equity linked wealth	A valuation of total wealth at the end of the period for the individual based on the closing stock price of the last annual report
Value of shares held	Value of shares held at the end of the reporting period for the individual based on the closing stock price of the annual report

A.4.2. Board-level features

Source: BoardEx except if stated otherwise
(as of when the director joins the board)

Variable

Attrition rate
Average age
Average nb independent directors

Average nb qualifications

Average network size
Average tenure

Average tenure of incumbent directors

Avg tot current nb listed boards

Avg tot nb listed boards sat on
Board Pay Slice - salary
Board Pay Slice - total
Board size

BOSS
CEO bonus
CEO salary
CEO total compensation
Chairman duality
Count Female
Gender ratio
Nationality Mix
Nb independent
Stdev age

Stdev current listed board

Stdev listed board sat on

Stdev number qualifications
Stdev Time in Company
Stdev Time on Board
Succession Factor
Tot indep comp

Tot indep comp scaled

Definition

Number of Directors that have left a role as a proportion of average number of Directors for the preceding reporting period
Average age of directors on the board
Fraction of non executive directors on the board
Average number of qualifications at undergraduate level and above of directors on the board
Average network size of directors on the board (number of overlaps through employment, other activities, and education)
Average board tenure of directors on the board
Average time in company for executive and non-executive directors on the board
The average number of boards of publicly listed companies directors currently serve on
The average number of boards of publicly listed companies directors have served on
Tot indep comp/ CEO salary
Tot indep comp/ CEO total compensation
Number of directors on the board
Dichotomous variable equal to one if the CEO is also the chairman of the board and the President
CEO's bonus
CEO's salary
CEO total compensation (salary plus bonus)
Dichotomous variable equal to one if the CEO is chairman of the board
Number of women on the board
The proportion of male directors
Proportion of Directors from different countries
Number of independent directors
Standard deviation of directors' age
Standard deviation of the number of listed boards each director currently serves on
Standard deviation of the number of quoted boards sat on for all directors on the board
Standard deviation of the number of qualifications at undergraduate level and above for all directors on the board
Standard deviation of time in the company for all directors on the board
Standard deviation of time on board for all directors on the board
Measurement of the Clustering of Directors around retirement age
Sum of all independent directors' total compensation
Sum of all independent directors' total compensation divided by the number of independent directors

A.4.3. Firm level features

Source: Compustat /CRSP except if stated otherwise
(as of when the director joins the board)

<u>Variable</u>	<u>Definition</u>
Current assets	current assets - Total
Acquisitions	acquisitions -
Auditor	Dichotomous variable for each auditing firm
CAPX	capital expenditures - Equals to one if the CEO is exempt from filing Certification Documents as required under section 302 of the Sarbanes-Oxley Act of 2002
CEOSO1	Equals to one if the CEO is exempt from these filing Certification Documents
CFOSO1	Equals to one if the CFO has not filed Certification Documents as required under section 302 of the Sarbanes-Oxley Act of 2002
CEOSO2	Equals to one if the CEO has not filed these Certification Documents
CFOSO2	Equals to one if the CFO has not filed these Certification Documents
CEOSO3	Equals to one if the CEO has filed Certification Documents as required under section 302 of the Sarbanes-Oxley Act of 2002
CFOSO3	Equals to one if the CFO has filed these Certification Documents
Equity (ordinary)	ordinary equity - Total
Cash	cash -
Cash and ST investments	cash and short term investments -
COGS	cost of good sold -
Shares outstanding	common shares outstanding -
Dividend payer	dichotomous variable equal to 1 if the total amount of dividends to ordinary equity > 0
LT debt	long term debt - Total - Source : Compustat
Depreciation	depreciation and amortization -
Dividends	total amount of dividends to ordinary equity
EBIT	Earnings Before Interest and Taxes
EBITDA	Earnings Before Interest
Firm age	time since IPO or first occurrence on CRSP
Inventories	Inventories - Total
Current liabilities	Current liabilities - Total
Leverage	Total long term debt / total assets
Ln (nb institutional blocks)	Logarithm of one plus the number of institutional blockholders.
Ln (nb institutional owners)	Logarithm of one plus the number of institutional investors.
M/B	(common shares outstanding * stock price)/ ordinary equity
Minority interest	Minority interest
Mkt value	Market value
NI	Net income
Price (calendar)	Price Close - Annual - Calendar
Price (fiscal)	Price Close - Annual - Fiscal
Product market fluidity	Product market fluidity. Hoberg and Phillips
Profitability	ebitda/total assets
Block ownership %	Fraction owned by blockholders.
Institutional ownership %	Fraction owned by institutional investors.
Largest inst. shareholder %	Fraction owned by largest institutional investor.
Largest 10 inst. shrhlders %	Fraction owned by top ten institutional investors.
Largest 5 inst. shrhlders %	Fraction owned by top five institutional investors.
Retained earnings	Retained earnings
Retained earnings (restated)	Retained earnings restatements
12-month return	Cumulative stock return in the twelve months leading up to the appointment.

Revenue	Revenue - Total
ROA	Net income / total assets
ROE	Net income / ordinary equity
Sales	Net sales - Total
Equity (total)	Stockholders' equity - Total
Settlements	Settlement (Litigation/Insurance) After-tax
Total Assets	Total assets -
Working capital	Working capital
Extraordinary items	Extraordinary items
R&D	R&D expenses

A.4.4. Industry and market level features

*Source: Compustat /CRSP except if stated otherwise
(as of when the director joins the board)*

<u>Variable</u>	<u>Definition</u>
Excess returns 12-month leading up to appointment	cumulative stock return in the twelve months leading up to the appointment minus cumulative returns on the S&P500 in the twelve months leading up to the appointment
Industry ROA	return on assets of firms with same 3-digit SIC code
Mkt12	cumulative returns on the S&P500 in the twelve months leading up to the appointment
Tnic3*	3-digit, text-base industry classifications from Hoberg and Phillips (2010, 2016)