Does Board Diversity Influence a Firm's Innovation?

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Master Thesis

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Abstract

This study examines the relationship between board diversity, specifically in terms of age and gender diversity, and firm innovation measured via R&D investments, across North American listed firms and with special focus on the high technology sector. A contribution to the existing corporate governance literature is achieved by examining these relationships across all industries and then isolating and comparing the effects between high-tech firms and firms from all other industries. The study's findings show that while gender diversity positively influences a firm's commitment to R&D investments across all industries, this impact appears less significant within high-tech firms when compared to the rest of the industries. Age diversity, however, does not show a potential impact on R&D investment decisions in either tech or non-tech firms. These findings challenge the 'one-size-fits-all' approach to board diversity, suggesting that diverse aspects of board composition may influence innovation differently across industries and maybe regions. Despite its cross-sectional design and a focus on North American firms, this research can have important implications for business leaders, policymakers, and academic researchers by providing new insights into board diversity's role in driving innovation. Future research should consider temporal dynamics and replicate the study in various geographic settings, considering other forms of diversity.

1. Introduction

Due to globalization and technological advancements, firms are under pressure to enhance their competitive advantage, with innovation being acknowledged as the primary driver of a firm's long-term growth (Canil *et al.*, 2021). Identifying the factors that contribute to innovation has become more difficult and it is an area of increasing interest for economists (Phan and Yu, 2022). There are various factors that can impact a firm's ability to innovate, yet an important one that has gained a lot of interest in recent years is board diversity (Phan and Yu, 2022; Tsui *et al.*, 2022; Ain *et al.*, 2021).

The purpose of this study is to examine the relationship between board diversity and a firm's commitment to invest in innovation activities. More specifically, the following is the main research question:

RQ: Does board diversity, in terms of age and gender, influence the allocation of resources towards innovation activities in North American listed firms? Is this influence stronger in the North American high-tech industry?

Board diversity and its impact on several aspects of a firm has become the subject of growing attention in literature in line with the rising significance of diversity in recent times. Board diversity usually refers to the presence of directors with different characteristics (e.g., gender), backgrounds, and experiences, with numerous studies showing that there is a positive link between board diversity and numerous measures of corporate performance, such as financial performance (e.g., Dezsö and Ross, 2012; Carter *et al.*, 2003; Chapple and Humphrey, 2013), and social responsibility (e.g., Boulouta, 2012).

On top of that, it has been argued that board diversity may create an environment that fosters creativity, enables better decision-making and results in greater management on risks of innovation (Midavaine *et al.* 2016; Deore *et al.* 2021). All those elements can play a significant role in enabling innovation in firms that are trying to keep up with a dynamic and rapidly changing environment. In a diverse board, the different voices can bring a symphony of perspectives and ideas to the table and enforce the need for further innovation. Furthermore, a diverse board can assist organizations to better comprehend diverse markets and customers, leading to more innovative products and services (Mothe and Nguyen-Thi, 2021).

Nonetheless, many argue that the relationship between board diversity and innovation can be more complex and depend on a variety of factors, some of which can have adverse effects. According to Midavaine *et al.* (2016), diversity in groups may lead to the creation of subgroups resulting in conflicts. In addition, there can be inherent factors that limit diversity, such as a requirement for the directors to have enough technical or other expertise to be able to serve and understand the complexity of the operations of a certain firm.

Therefore, additional research that examines the relationship between board diversity and innovation is needed. This study focuses on this relationship in the technology industry in the region of North America. This will be achieved by focusing on gender and age diversity and looking at the variations in a firm's commitment to invest its assets in innovation. The latter will be achieved by specifically looking at the variations in the ratio of research and development expenses to total assets between firms in the high-tech industry when compared to the rest of the firms.

The North America region has been selected due to its high concentration of both listed firms in general and highly advanced technological firms (defined as the ones from with a SIC code of 737). Analytically, a total of 1,745 firms (6,219 firm year observations) from different industries are included in the sample of which 324 are considered as high-tech ones (969 firm year observations). In addition, the North America region is at the forefront of all the diversity advancements in recent years and in this setting the effect between board diversity and innovation can be clearer and more visible.

The relationship is examined through an Ordinary Least Squares (OLS) regression model in which a wide-ranging dataset of North American firms across various industries is applied and allows for ascertaining the relationships between the variables. The study's results contradicted some of the initial hypotheses. More specifically, no evidence is found supporting that any type of the examined board diversity proxies has a stronger effect on high-tech firms than firms in other industries. Additionally, board age diversity seems to be a weak predictor of a firm’s innovation activities as no evidence is found to support otherwise. On the other hand, strong statistically significant evidence indicates that gender diversity on boards correlates positively with R&D intensity. The latter is valid for non-tech firms at all levels of gender diversity and for tech firms when male and female directors are represented almost equally at the board.

Finally, this study advances the corporate governance literature by focusing on the effect between board diversity and innovation instead of firm performance which is examined thoroughly in the existing literature (e.g., Dezsö and Ross, 2012; Carter *et al.*, 2003; Chapple and Humphrey, 2013). Moreover, it delivers nuanced insights into the interplay between the relationships. By examining both gender and age diversity, this study widens the lens through which board diversity's impact on innovation is viewed. Interestingly, it highlights that the effect of board diversity on firm innovation is not uniform across industries, calling into question the one-size-fits-all approach to diversity. This nuanced understanding can assist firms, investors, and policymakers in designing more effective corporate governance structures and strategies. However, the study acknowledges its limitations, primarily being its cross-sectional design and North American focus, which may affect the generalizability of the results. Therefore, future research is encouraged to utilize longitudinal designs and explore this relationship in various geographic contexts, which can potentially add rich, temporally, and culturally diverse insights into this interesting domain of corporate governance and innovation.

2. Literature review

2.1 Firm innovation

In recent years, people are constantly overwhelmed by new and innovative products and services on almost all facets of human life, such as technology, food, or medicine (Blok, 2021). This process of developing new knowledge to create new, or better products and more cost-effective solutions is called innovation (O’Sullivan, 2000). Innovation, in general, can bring numerous benefits to society (e.g., increased productivity, solutions to existing problems or consumers' needs, etc.) and it usually occurs at a firm level (Restrepo-Morales *et al.*, 2019). Consequently, the role of innovation as the key to a firm's economic development, growth and performance is researched and highlighted in many studies (e.g., Dezsö and Ross, 2012; Cohen and Klepper, 1996; Zahra and Covin, 1995; Restrepo-Morales *et al.*, 2019). Therefore, innovation is considered to be a significant factor in ensuring the long-term growth of any firm.

Firm innovation requires commitment and investment of firm resources in the long term which in turn comes with corporate risk taking. As with any other type of investment, allocating resources to firm innovation contains certain inherent risks due to the uncertain nature of the potential returns (Chindasombatcharoen *et al.*, 2022). This is also indicated in the research of Restrepo-Morales *et al.* (2019), where it is shown that resource limitations (e.g., human capital) and/or financial constraints, especially in small or medium sized companies (SMEs), can often lead to their failure due to the risks involved.

2.2 Board roles and impact on innovation

One of the most important internal corporate governance mechanisms, that is also tasked to decide on a firm's investment strategy and the bearing of corporate risk, is the board of directors ("BOD") (Chindasombatcharoen *et al.*, 2022). The board of directors is also the end responsible for the innovation investments that could impact the competitiveness of the firm in the long run (Sila *et al.*, 2016). According to agency theory, fostering firm innovation requires a strong board of directors due to the risks involved, as aforementioned (Makkonen, 2022). Additionally, risk averse executives may attempt to limit investments in research and development or other innovative activities potentially hampering the firm's future thus making the board's role in monitoring the behavior of executives even more crucial (Makkonen, 2022).

The board of directors acts as a group or a team of individuals that takes decisions around the strategy of a firm. As in any team, the more diverse the input of each member the more it acts in favor of the quality of the decision taken (Van Knippenberg and Schippers, 2007). A board member's input is influenced by that member's characteristics and background (Cramton and Hinds, 2005) and according to the upper echelons theory, those characteristics may explain the differences in the strategic decisions taken by the firm (Hambrick and Mason, 1984 and Hambrick, 2007).

There is a broad body of literature examining the effect that board's and board members' characteristics have on firm performance but studies on their impact on firm innovation was limited until recent years (Phan and Yu, 2022). For instance, Tseng *et al.* (2013) discover a positive correlation between the size of the board and the ability to innovate. Similarly, Dong and Gou (2010) uncover evidence indicating that the presence of independent outside directors and director ownership contributes to superior investment in innovation. However, these studies generally treat directors as a homogeneous group and do not consider their personal attributes, such as ethnicity, gender, and qualifications (Phan and Yu, 2022). Instead, Galia and Zenou (2012) produced one of the first papers examining the direct relationship between aspects of board member's characteristics, and therefore diversity, (i.e., gender and age) and different types of innovation (i.e., product, process, organizational and marketing innovation) in French firms. The results of this research showcased evidence of a relationship between board diversity and all types of innovation except process innovation (i.e., the implementation of a new or significantly improved production or delivery method).

After the above research, several researchers attempt to examine the relationship of various aspects of the board member's characteristics such as age, gender, education, ethnicity, and experience with a firm's innovation. For instance, Galia *et al.* (2015) further contributes to the literature of the topic by examining the link between a board member's gender, age, and independence (i.e., proportion of employee directors) and environmental innovation. The results are consistent with Galia and Zenou (2012) regarding gender and age but indicate a negative relationship between employee directors and environmental innovation. Additionally, Midavaine *et al.* (2016) examine whether information-based diversity such as education and experience (i.e., tenure) and person-based diversity (i.e., age and gender) can have an impact on a company's R&D investment. The results are consistent with those of prior research in terms of the person-based diversity and its impact on R&D investment, also playing a moderating role in the information-based diversity strengthening the effects found. Finally, Mothe and Nguyen-Thi (2021) in their research examine whether age diversity, under different HR practices, impacts technological innovation while controlling for other diversity aspects such as ethnicity and gender. The results for age and gender diversity are consistent with the findings but no significant relationship is found regarding the ethnic or nationality diversity and innovation.

Finally, as the above research papers indicate, person-based diversity characteristics are shown to have a significant effect on a firm's commitment to invest in innovation. Therefore, it is argued that examining both gender and age diversity on boards of directors can provide significant insights around the variations of innovative activities undertaken by firms. Moreover, drawing from the upper echelons theory (Hambrick and Mason, 1984; Hambrick, 2007), the variations in these characteristics might account for the disparities in innovative efforts or risk-taking investments among firms or among firms in different industries.

2.3 Gender Diversity

The work behavior of individuals can vary depending on their gender, especially when it boils down to managing risk (Tsui *et al.*, 2022). Wei (2007) claims that different gender can have different risk tolerance levels with women usually seen as more risk-averse than men which in turn can impact a firm's financial decisions. Jianakoplos and Bernasek (1998) claim that this trait is also visible when taking into consideration investment decisions. However, Adams and Funk (2012) found that female directors show increased sensitivity when it comes to issues with social and environmental complications and can be more risk-seeking than their male counterparts. Therefore, since investments in innovation contain risks, it is expected that gender diversity may have a moderating effect on managing those risks. Finally, as shown by Post and Byron (2015), gender differences can impact a firm's performance and a board's decision-making process thus also affecting investment decisions.

The percentage with which women are represented in the board of directors is a measurement of gender diversity (Marinova *et al.* 2015 and Byoun *et al.* 2016). This percentage has significantly increased over the years, since women are receiving the necessary education to perform those roles (Phan and Yu, 2022). Since the qualifications of female directors is confirmed, the gender diversity may be a key element of board diversity (Hafsi and Turgut, 2013). This is highlighted also by the fact that many national governments are imposing relevant legislations to enforce gender quotas to achieve better representation and greater diversity in boards (Tsui *et al.*, 2022).

Existing literature on gender diversity shows that gender diversity can have a positive impact on firm or corporate innovation by bringing additional expertise and enforcing better and more broad examination of complex issues and problems (Ain *et al.*, 2021). This is also supported by the research of Galia and Zenou (2012) which claims that gender diversity can increase quality of decision making by bringing new and innovative ideas and options.

2.4 Age diversity

Another personal characteristic of board members and an aspect of diversity is age. The relationship between age diversity and innovation has been analyzed via various theoretical lenses as Mothe and Nguyen-Thi (2021) highlight in their research which indicates that the process of technological innovation is a complex and societal endeavor that involves the active participation and interactions of individuals spanning different generations. This dynamic interplay among generations can present challenges in terms of transferring knowledge and fostering intergenerational cohesion (Mothe and Nguyen-Thi, 2021). Consequently, the effective management of age diversity has become increasingly crucial in supporting such innovative processes.

The effort to develop both theoretical and empirical frameworks aimed at understanding the relationship between age diversity and company performance, including aspects such as labor productivity and innovation is increasing over the years. However, the findings from these studies vary and are inconclusive (Van Knippenberg and Schippers, 2007). For instance, Barker and Mueller (2002) argue that older directors tend to be more risk-averse and they put value on career and financial security rather than the interest of the shareholders. This phenomenon may cause conflict among younger members of the board who may be more ambitious and thinking of future opportunities. Furthermore, older directors are more intolerant in investments that are far away in the future as they are closer to retirement and thus, prefer investments that produce results in the short-term (Chindasombatcharoen *et al.*, 2022).

On the other hand, Drees and Heugens (2013) argue that older directors are more experienced due to longer tenures and can bring better market knowledge and effective problem-solving skills. Thus, a broader range of age and perspectives is necessary for the firm to deal with the variety of stakeholders’ expectations which may lead to increased innovation (Bear *et al.*, 2010).

2.5 Regional and industry focus

The relationship between gender and age diversity has been examined in various regional and industry settings. For example, Phan and Yu (2022), examined the associations between institutional ownership, board diversity, and corporate innovation in companies listed in the United States. In this research, it is argued that firms with more female directors, a strong presence of an audit committee, or a significant representation of ethnic minority directors on their board exhibit a notable and favorable influence on innovation. This influence is observed in terms of increased investments in research and development (R&D) as well as a higher number of patents generated. Additionally, Azzam (2022) primarily focuses on investigating the connection between board gender diversity and investments in research and development (R&D) within the context of the United Kingdom. This study delves into the examination of how the relationship between board gender diversity and R&D investments is influenced by the tenure of female directors on the board. The results of this research reveal a positive association between board gender diversity and the intensity of research and development (R&D) activities.

In terms of industry setting, Yu *et al.* (2020) indicated that examining innovation performance of a firm in the high-tech industry can be beneficial for evaluating the quality of innovation as well as assisting in deciding on innovation-related policies. Moreover, Tsui *et al.* (2022) tested the industry specific innovation relationship between a firm’s corporate governance, performance, and R&D investments and the board gender diversity in the healthcare industry. Their findings indicate that the selection of gender for positions such as board chair and CEO has a greater impact on company performance compared to solely increasing the proportion of women on corporate boards. Both studies provide indications that the industry setting can influence the examined relationship.

2.6 Hypotheses development

Overall, the existing literature suggests that both gender and age diversity in boards can be an important driver of firm innovation and further examination of this relationships can provide significant insights in explaining the variations in innovation activities undertaken by firms (Azzam, 2022; Ain *et al.*, 2021; Tsui *et al.*, 2022). According to Galia & Zenou (2012), female directors can bring unique experiences, wider perspectives, knowledge, and skills that can stimulate innovation activities and make a positive contribution to a company's research and development (R&D) investments. Previous research suggests that women excel in comprehending customer needs, thus providing firms with avenues and possibilities to meet those needs effectively (Galia & Zenou, 2012; Gonzales-Bustos *et al.*, 2020). Conversely, many previous studies indicate that female directors play a more effective monitoring role over managers (e.g., Gul *et al.*, 2011; Srinidhi *et al.*, 2011; Terjesen *et al.*, 2009). As a result, intense board monitoring may lead CEOs to become risk-averse and less willing to invest in long-term and high-risk initiatives like research and development projects (Cheng, 2004; Garg, 2013). Consistent with this perspective, Almor *et al.* (2022) identify a negative relationship between board gender diversity and R&D investments.

Regarding age diversity, one group of studies presents both positive and negative effects to firm innovation. Zajac *et al.* (1991) provide evidence that diversity in employees' age is positively correlated with technological innovations in internal corporate joint ventures. Backes-Gellner and Veen (2013) also demonstrate that increasing age diversity can have a positive impact on a firm’s productivity, specifically when employees are engaged in more creative rather than routine tasks. A second group of studies does not find a significant or conclusive relationship between age diversity and innovative behavior. Van der Vegt and

Janssen (2003), McGuirk and Jordan (2012), and Faems and Subramanian (2013) do not uncover a direct link between age diversity and innovative behavior.

Therefore, while prior research has examined board diversity and innovation within different countries such as the United States or the United Kingdom, this study narrows its focus on North America, an economically integrated region with a strong technology sector. This focus on a single, cohesive region allows the minimization of the potential influence of diverse regional economic, cultural, and legislative factors that could impact the results. Additionally, the focus on the high-tech technology industry, that is on the forefront of innovation the last decade and can provide significant insights in terms of innovation performance (Yu *et al.*, 2020) and may lead to more significant effects in the tested relationship than the ones that can be evidenced in other industries.

Therefore, based on the above arguments the following four hypotheses emerge:

- H1: Listed firms in North America, with a more age diversified board of directors, allocate more resources towards research and development.
- H2: Listed firms in North America, with a more gender diversified board of directors, allocate more resources towards research and development.
- H3: High-tech firms in North America, with a more age diversified board of directors, allocate more resources towards research and development than listed firms in other industries.
- H4: High-tech firms in North America, with a more gender diversified board of directors allocate more resources towards research and development than listed firms in other industries.

3. Methodology

3.1 Data sample

The analysis of this research employs data from two different sources. The Wharton Research Data Services ("WRDS") is used to access the databases in these sources. To obtain data on directors' personal characteristics, such as gender and age, the BoardEx database is used since it covers more than 20,000 publicly listed companies in 101 countries (Griffin *et al.*, 2021). More specifically, the BoardEx – North America database is used since the focus is on listed companies in the region of North America. To obtain data on the firms' financial characteristics, this research relies on the Compustat North America database which provides more than 300 annual and 100 quarterly financial statements for publicly listed companies.

The period of the data sample covers 6 years and extends from 2016 to 2021 to accommodate for more up to date and complete information. Three different datasets are created and used in this study:

- *All-Firms* dataset: this dataset contains the information for all the identified listed firms in the region of North America (firms that contain N/A or duplicate values and / or missing necessary information on the variables used in the analysis are excluded from the dataset). Moreover, all firms that contain less than five board members are excluded from the dataset as the Blau Index used as a proxy for the board age diversity assumes that there are at least five age categories. If firms with less than five board members are not excluded, the results of the Blau Index can be inaccurate. The dataset contains 6,219 firm-year observations for 1,745 different firms.

- *Tech-firms* dataset: this is a subset of the *All-Firms* dataset and includes only high-tech firms based under the SIC code of 737 “Computer Programming, Data Processing, and other Computer Related Services” (SICCODE, 2023). Some of the most technologically advanced companies in the world are classified under this Sic code, such as Apple, Amazon, SAP, Oracle, etc. (SICCODE, 2023). The dataset contains 969 firm-year observations for 324 different firms.
- *NTech-firms* dataset: this is a subset of the *All-Firms* dataset and excludes all the firms identified in the *Tech-firms* dataset. The dataset contains 5,250 firm-year observations for 1,421 different firms.

3.2 Research design

This research uses OLS (Ordinary Least Squared) regression analysis to estimate the effect of board age and gender diversity on firm innovation. OLS regression analysis is widely used in relevant prior research either as baseline or to fully examine the effect of board diversity and firm innovation in different settings (e.g., Ain *et al.*, 2021; Mothe and Nguyen-Thi, 2021, Canil *et al.*, 2021). The equation of the analysis is the following,

$$RNDTA = \beta_0 + \beta_1 Age.diversity_{jit} + \beta_2 Gender.diversity_{jit} + \sum \beta_j\, CV_{jit} + YearFixedEffects + \varepsilon_{it} \quad (Eq.1)$$

where *RNDTA* is the dependent variable and a proxy for firm innovation, *Age.diversity* is the first independent variable as a proxy for board age diversity, *Gender.diversity* is the second independent variable as a proxy for board gender diversity, *CV* represents the set of control variables and *YearFixedEffects* is the dummy variable used to control for year fixed effects in the analysis. Further explanation of the variables is provided below, and short definitions can be found in Table 8 of appendix A.

The *(Eq.1)* is run three times, one of for each of the datasets to test the four hypotheses as follows:

- By regressing the *All-Firms* dataset, H1 and H2 hypotheses are tested. If positive and statistically significant β_1 and β_2 coefficients are found, then the respective hypotheses are supported.
- By regressing the *Tech-Firms* and *NTech-Firms* datasets, H3 and H4 hypotheses are tested. If higher positive and statistically significant β_1 and β_2 coefficients in the *Tech-Firms* dataset than the ones of the *NTech-Firms* are found, then the respective hypotheses are supported.

The use of the three different datasets instead of an industry interaction term is selected to better isolate the industry impact while avoiding any potential noise from the presence of the technology firms in the results for H1 and H2.

3.2.1 Key variables

3.2.1.1 Firm innovation

As a proxy of innovation, several variables are used in prior research, with the main ones being the number of patents (e.g., An *et al.*, 2021; Canil *et al.*, 2021), the ratio of research and development expenses (“R&D”) to the total revenue of a firm (e.g., Azzam, 2022), investments in R&D (e.g., Tsui *et al.*, 2022) and the ratio of R&D to the total assets of a firm (Dezsö and Ross, 2012). In this research, the latter (i.e., the ratio of R&D expenses to total assets) is used to avoid representing the start-up companies, that usually do not have significant revenues but are innovative and allocate a big portion of their assets to R&D, as outliers in the analysis. To calculate the *RNDTA* value for each firm-year, the Compustat North America database is used, where the annual research and development expenses and total assets per firm-year are available.

3.2.1.2 Gender Diversity

Regarding gender diversity, the categorical variable *Gender.diversity* is used that represents different diversity percentages in a corporate board. More specifically, by using the percentage of female directors in a board as a guide, the board diversity is calculated as a percentage taking values from 0%, when the female representation is either at 0% or at 100%, up to 100% when the female representation is at 50%. This calculation assumes that a fully diversified board would have the same amount of female and male directors. The categorical variable then uses the calculated percentages, and it takes the following values:

- Value of 1: when gender diversity is below 25% (25% not included)
- Value of 2: when gender diversity is from 25% up to 50% (50% not included)
- Value of 3: when gender diversity is from 50% up to 75% (75% not included)
- Value of 4: when gender diversity is from 75% up to 100% (100% included)

This proxy follows a similar logic as the Blau Index used for age diversity in the research of Mothe and Nguyen-Thi (2021) but going a step further by splitting the gender diversity in separate classes and examining the effect of each class. To identify the gender and age of each director as well as the board size of each firm, the BoardEx database is used.

3.2.1.3 Age diversity

The methodology in the research of Mothe and Nguyen-Thi (2021) is followed to create a proxy for age diversity. Analytically, the Blau’s index of heterogeneity is used since it can capture the number of age categories represented in the board and the equivalence of the numbers per individual category. It is defined as follows:

$$Age.diversity = 1 - \sum_{m=1}^{M} p_m^2$$

where p_m^2 is the proportion of board members in the corresponding age group *m*. According to Masulis *et al.* (2022) the median age of directors has increased in the US from 61 years to 64 from 1998 to 2014 which showcases that mostly experienced individuals take up board positions. Therefore, this study distinguishes five age groups (M = 5): younger than 40, 40-49, 50-59, 60-69 and older or equal to 70. The *Age.diversity* variable takes the minimum value of

0 if all employees are of equal age (perfect homogeneity) and a maximum value of (M – 1)/M if perfect heterogeneity is present. For both cases the indicator for the innovation will be the ratio of R&D expenses to the total revenue of the firm.

3.2.2 Control variables

In this analysis several firm and board characteristics that could have an impact on the dependent variable are controlled for. Analytically, the following control variables, that are often found in relevant literature, are used:

- *Board*.size: the total number of the board of directors which is used as a control variable in the research of Ain *et al.*, 2021. Larger boards are more common to have a higher diversity thus assisting in explaining the examined relationship.
- *ROA* (Return On Assets): ratio of net income / (loss) to the total assets as measured and used in several studies (e.g., Canil *et al.*, 2021; Ain *et al.*, 2021; Dezsö and Ross, 2012). A firm with a higher ROA may have more funds available to distribute on more innovative endeavors.
- *Leverage*: ratio of the total debt to total assets of a firm as calculated in the studies of An *et al.*, 2021 and Canil *et al.*, 2021. Firms with higher leverage can face cash constraints due to significant loan agreements and therefore refrain from investing in riskier R&D activities with uncertain returns (Chindasombatcharoen *et al.*, 2022).
- *CASH*: ratio of cash and cash equivalents to total assets as used and measured in the research of An *et al.*, 2021. Opposite to the leverage, a firm with a significantly high cash position can be more prone to investing portion of these funds to R&D activities.
- *CAPEX*: ratio of capital expenditures to total assets as measured in the research of Canil *et al.*, 2021. Firms with high capital expenditure requirements can shy away from investing further capital into riskier R&D activities.

A summary with a short explanation of each variable and the source of the data used to calculate them is given in Table 8 of appendix A.

4. Results

4.1 Descriptive statistics

The analysis begins with a detailed description of the descriptive statistics suitable for each variable. The descriptive statistics can offer significant insights into the variables examined in all three datasets (*All-Firms*, *Tech-firms, and NTech-Firms)*. More specifically, the research revolves around the three key variables: firm innovation (*RNDTA*), board age diversity (*Age.diversity*) and board gender diversity (*Gender.diversity*). Apart from the key variables, significant insights can be gained from the five control variables.

Firstly, the descriptive statistics for all three datasets are presented in Table 1 below. Concerning *RNDTA*, the mean in the *All-Firms* dataset is around 11.4%, with a median at 5.1%. This suggests that many firms showcase a generally significant investment in innovation activities. However, the standard deviation of 0.179 and the exceptionally high maximum value of 269.1% reflect significant variability in the values of the *RNDTA* in the dataset. This could be a result of including companies that operate in highly innovative sectors where maintaining technological superiority is of the utmost importance and therefore allocating a larger portion of their assets to R&D activities.

Examining the *Age.diversity*, the mean in the *All-Firms* dataset is 0.56, which suggests a moderate level of age diversity in the boards across all firms, with the median being even higher at 0.60. This indicates that most of the firms have a highly heterogenous age distribution in the board members' age and therefore higher board age diversity. The standard deviation is approximately 0.152 and suggests a considerable variation in age diversity across different boards. The minimum and maximum values, as expected, range from 0 to 0.8, further corroborating that there are firms with both very homogeneous and very diverse boards in terms of age in the dataset.

Table 1: Descriptive Statistics

All-Firms

Variables	Mean	Median	StandardDeviation	Minimum	Maximum
RNDTA	0.1141	0.0510	0.1796	0.0001	2.6913
RNDTA_trans	-2.5772	-2.5590	1.0956	-5.9166	1.0428
Age.diversity	0.5636	0.6000	0.1515	0.0000	0.8000
Board.size	8.4202	8.0000	2.0362	5.0000	18.0000
CASH	0.2278	0.1440	0.2437	0.0000	6.1330
CAPEX	0.0282	0.0198	0.0322	0.0000	0.7961
Leverage	0.2681	0.2324	0.2468	0.0000	4.9429
ROA	-0.1054	0.0029	0.3391	-5.8426	2.0733

Tech-Firms

Variables	Mean	Median	StandardDeviation	Minimum	Maximum
RNDTA	0.1037	0.0842	0.0897	0.0002	1.1117
RNDTA_trans	-1.6986	-1.6893	0.3833	-2.8311	0.1078
Age.diversity	0.5693	0.6100	0.1541	0.0000	0.8000
Board.size	8.0805	8.0000	1.7900	5.0000	15.0000
CASH	0.2491	0.1784	0.2415	0.0016	3.5167
CAPEX	0.0214	0.0139	0.0229	0.0001	0.1911
Leverage	0.2513	0.2052	0.2195	0.0001	2.5511
ROA	-0.0577	-0.0204	0.1898	-2.0364	0.5212

NTech-Firms

Variables	Mean	Median	StandardDeviation	Minimum	Maximum
RNDTA	0.1160	0.0422	0.1916	0.0001	2.6913
RNDTA_trans	-2.7969	-2.8358	1.2662	-6.7480	1.0257
Age.diversity	0.5626	0.6000	0.1510	0.0000	0.8000
Board.size	8.4829	8.0000	2.0726	5.0000	18.0000
CASH	0.2238	0.1381	0.2439	0.0000	6.1330
CAPEX	0.0295	0.0210	0.0335	0.0000	0.7961
ROA	-0.1142	0.0076	0.3593	-5.8426	2.0733

Regarding the control variables, the following can be observed:

- *Board.size* is proxy for the total number of directors in a firm's board. The source is examined first with a mean and median of 8.42 and 8 respectively. This suggests a preference for firms to have a moderately sized board of around 8 members. This can reflect a balance between benefiting from diverse expertise from different backgrounds and maintaining efficient decision-making. However, the standard deviation of 2.036 points towards a substantial variability in board sizes among different firms.
- The *CASH* variable has a mean and median of 22.8% and 14.4% respectively. This implies that firms in the dataset tend to hold a significant portion of their assets in cash or cash equivalents. The high liquidity can act as a buffer in case of business uncertainties, but it can also be allocated to innovation activities to boost future profitability. Nevertheless, the standard deviation of 0.244 and the striking maximum value of 613.3% denote the presence of outliers, with some firms hoarding much larger cash assets.
- *CAPEX*, or the capital expenditure ratio, averages around 2.8% with a median of 1.98%. The high standard deviation of 0.322 and the maximum of 79.6% suggest a considerable dispersion in the capital expenditure ratios in the dataset. This could be a result of variations in the capital expenditure requirements of different industries in which the firms operate in.
- The *Leverage* ratio has a mean of approximately 26.8% with a median of 23.2%. The standard deviation of 0.247 and a peak value of 494.3% indicate a considerable spread in leverage among the firms present in the dataset. These figures suggest the existence of firms that operate in high debt levels, possibly due to industry-specific factors or other strategic decisions such as growth or innovation initiatives.
- Lastly *ROA* shows an average of -10.5%, suggesting a generally challenging financial performance across the firms. The significant standard deviation of 0.339 and the range of -584.3% to 207.3% illustrate significantly diverse profitability levels across the firms. This variation could be due to multiple factors, including the age of a firm (e.g., startup), operating efficiencies, industry dynamics, and even risk exposure.

When the above findings are compared with the ones from the other two data sets, interesting patterns emerge. Tech firms, unexpectedly, when compared to the overall average, tend to have a slightly lower R&D expenditure ratio (mean of Tech firms is 0.104) despite having certain number of firms that invest significantly more than others as indicated by the median (0.084) which is higher when compared to the firms overall (0.051) but also to non-tech firms (0.042). Moreover, Tech firms tend to have a marginally higher *Age.diversity* which indicates that even though they usually have a smaller board size (mean board size of 8.08) they seem to prefer board members from different age groups. Finally, Tech firms appear to have higher cash holdings, lower *CAPEX* and despite operating with lower leverage they achieve better profitability from investing their assets (mean of *ROA* is -0.058*)*. This demonstrates that tech firms, which may operate in less mature but more dynamic sectors, showcase different financial characteristics due to their operating environments and challenges.

On the other hand, non-tech firms are characterized by a slightly higher commitment to R&D activities, a nearly identical *Age.diversity*, a larger board size, lower cash holdings, higher CAPEX, greater leverage, and more negative *ROA* than the average of all firms. This could indicate that non-tech firms, are probably situated in more mature and stable sectors, operate with different strategic and financial dynamics, and are influenced by factors such as capital intensiveness and debt management.

Table 2: Frequency of Gender.diversity All-Firms

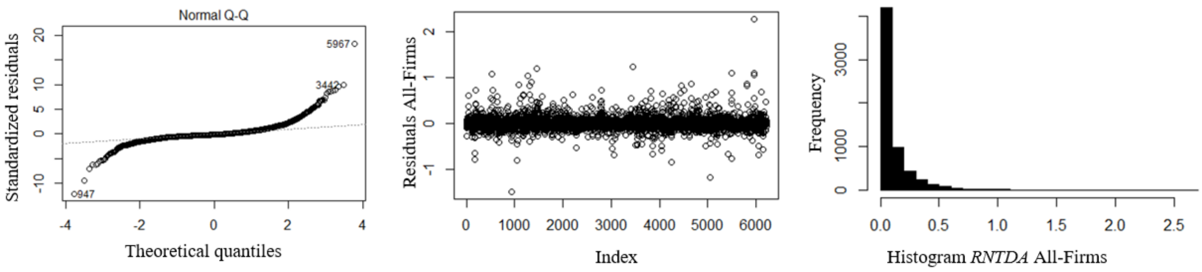
Gender.diversity	Frequency	Percentage
1	1506	24.22
2	2462	39.59
3	1704	27.40
4	547	8.80

The frequency of the categorical variable *Gender.diversity* as shown in Table 2 indicates that the firms' boards have varying degrees of female representation, with most firms falling within the second category, indicative of moderate female representation (25% to 50% diversity). It is highlighted that Tech firms tend to have more gender diverse board than the rest of the firms (refer to Table 6 and 7 of the appendix A), and by comparing percentages, they have the highest proportion of firms in the highest category with highest possible gender diversity (75% to 100%).

4.1.1 Graphical analysis

Before completing the regressions, a graphical visualization is performed including histograms, scatter plots and Q-Q plots. One essential factor that emerges from this preliminary visualization is the skewness of the dependent variable *RNDTA* in all three datasets. Skewness poses a potential violation to the assumptions of the linear regression, which includes the normality of the residuals and homoscedasticity and could lead to biased estimators. To address this issue, the Box-Cox transformation is implemented. This statistical technique transforms non-normally distributed dependent variables to conform closer to a normal distribution (Box and Cox, 1964). The transformation finds an exponent (Lambda λ) by using the maximum likelihood function (i.e., maximizing the log-likelihood function) with the range of Lambda being from -2 to 2 and applies it to the data, to best approximate a normal distribution (Box and Cox, 1964). It is an appropriate choice when dealing with skewed data, as it can help meet the assumptions of parametric tests and linear models. By mitigating the skewness in the variables, the Box-Cox transformation creates a more valid environment for linear regressions.

Figure 1: Data Figures before Box-Cox – *All-Firms*

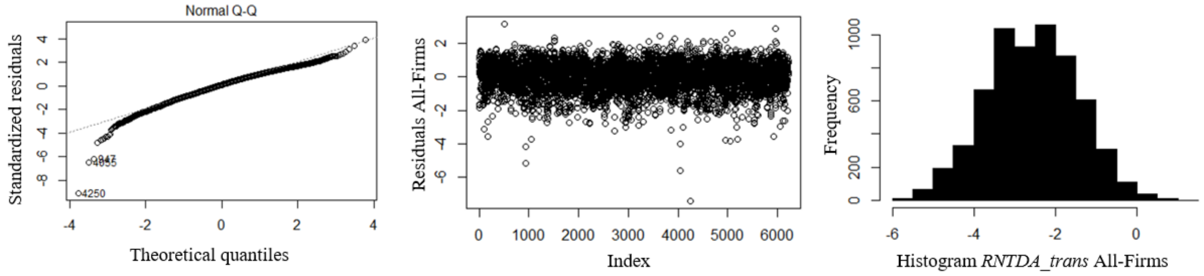


The respective Lambdas for each dataset are calculated and the *RNDTA* variable is transformed (*RNDTA_trans*). The Lambas per dataset are the following:

- *All-Firms*: λ = 0.104
- *Tech-Firms*: λ = 0.331
- *NTech-Firms*: λ = 0.071

In Figure 1 and Figure 2, the different data visualizations, namely the Q-Q plot, the scatterplot, and the histogram, depict the dependent variable before and after the transformation respectively. The improvement in terms of skewness and homoskedasticity is clearly depicted and therefore the *RNDTA_trans* is used in the OLS regressions.

Figure 2: Data Figures After Box-Cox – *All-Firms*



Figures related to the other two datasets can be found in appendix B. It is highlighted that the same results as the above are replicated in the other two datasets. However, it is noted that for the *Tech-Firms*, the right tail of the histogram is longer, depicting more and higher outliers compared to other datasets. This could be either due to the significant R&D investments of high-tech firms or due to several start-ups for which most of their assets are derived from capitalized R&D expenses.

4.2 Empirical results and discussion

In this section, the results of the Ordinary Least Squares (OLS) regression estimations performed to test the hypotheses are analyzed and discussed. In Table 3 the summary of the OLS estimations is depicted.

4.2.1 General comments on the Model

The regression models for all three datasets show significant predictive power as indicated by the F-statistics. The F-statistics for all datasets are statistically significant at 1% significance level, suggesting that at least some of the predictors in the models can explain the dependent variable. Nonetheless, the R-squared and the adjusted R-squared values indicate that the predictive capability of the models varies significantly across the different firm datasets. For tech firms, the adjusted R-squared value of 0.161 implies that approximately 16.1% of the variation in *RNDTA_trans* can be explained by the model. On the other hand, the models for all firms and non-tech firms have adjusted R-squared values of 0.376 and 0.399, respectively, signifying that the models account for approximately 37% and 39% of the variation in the dependent variable. These differences in explanatory power suggest that the determinants of *RNDTA_trans* may vary significantly across different types of firms and different industries.

Following the research of Dezsö and Ross (2012), year fixed effects are included in the analysis since the study makes use of panel data comprised of more than one firm year observation per any firm in each of the dataset. Year fixed effects can assist in controlling time-varying factors that may introduce endogeneity issues in the model and allows the absorption of any unobservable temporal shocks across firms, especially since 2020 and 2021 are pandemic years.

Table 3: OLS estimations per dataset

	Dependent variable: RNDTA_trans		
	(All-Firms)	(Tech-Firms)	(NTech-Firms)
Age.diversity	−0.049	−0.042	−0.069
	(0.075)	(0.075)	(0.093)
Gender.diversity2	0.080***	0.003	0.100***
	(0.029)	(0.032)	(0.036)
Gender.diversity3	0.146***	0.003	0.178***
	(0.034)	(0.037)	(0.041)
Gender.diversity4	0.193***	0.101**	0.172***
	(0.046)	(0.046)	(0.057)
Board.size	−0.042***	−0.012*	−0.045***
	(0.006)	(0.007)	(0.007)
ROA	−1.274***	−0.441***	−1.414***
	(0.037)	(0.064)	(0.043)
Leverage	−0.263***	−0.157***	−0.268***
	(0.046)	(0.053)	(0.056)
CASH	1.280***	0.325***	1.532***
	(0.052)	(0.050)	(0.065)
CAPEX	−3.392***	2.080***	−3.880***
	(0.346)	(0.503)	(0.412)
Constant	−2.489***	−1.646***	−2.757***
	(0.077)	(0.080)	(0.095)
Observations	6,219	969	5,250
R^2	0.377	0.174	0.399
Adjusted R^2	0.376	0.161	0.399
Residual Std. Error	0.866 (df = 6204)	0.351 (df = 954)	0.982 (df = 5235)
F Statistic	268.065*** (df = 14; 6204)	14.307*** (df = 14; 954)	250.073*** (df = 14; 5235)
Fixed Year Effects	Yes	Yes	Yes
Note: statistical significance levels	*p<0.1; **p<0.05; ***p<0.01		

4.2.2 All-Firms dataset – H1 and H2 testing

In the first regression analysis, all the firms are taken into consideration. Regarding age diversity, the coefficient of the respective variable is negative (-0.049), but it is not statistically significant, indicating that board age diversity does not appear to significantly influence the R&D intensity and therefore firm innovation across all firms. These estimations show that the evidence does not support a relationship between board age diversity and the allocation of resources towards R&D in the sample. Therefore, Hypothesis 1 cannot be confirmed.

One the other hand, gender diversity, as measured by the *Gender.diversity* variables, showcases a positive relationship with R&D intensity, with all *Gender.diversity2*, *Gender.diversity3*, and *Gender.diversity4* having positive coefficients (0.080, 0.146, 0.193 respectively) that are statistically significant at the 1% level. This suggests that higher gender diversity on boards is associated with greater R&D intensity in the full sample of North American firms even though the coefficients are low in value (<1). Moreover, the coefficient of *Gender.diversity4* that represents the highest group of diversity, is considerably larger than the other two, indicating that the more gender diverse the board is, the stronger the relationship. These findings suggest that gender diversity on boards may indeed contribute to a board's decision to increase R&D investment. Therefore, the evidence supports Hypothesis 2 when all firms are considered.

Apart from the key variables, it is noted that all control variables present statistically significant coefficients at 1% significance level. All coefficients, except for *CASH*, are negative, indicating that the higher the values of the variables, the more they can adversely impact a firm's commitment to innovation activities. It is highlighted that most of the coefficients are much larger than those of the independent variables meaning that they can be important when predicting the R&D intensity of a firm.

4.2.3 Tech-Firms and NTech-Firms datasets – H3 and H4 testing

In the regression analysis for the second and third dataset, the coefficient of *Age.diversity* in both cases is not statistically significant, suggesting that board age diversity does not significantly influence R&D intensity in either tech or non-tech firms. This is in line with the findings when all the firms are considered in one dataset. Therefore, Hypothesis H3 is not supported by the empirical results.

In terms of gender diversity, there are significant differences between tech and non-tech firms. In the *Tech-Firms* dataset, only one of the *Gender.diversity* variables, namely *Gender.diversity4*, has a positive statistically significant coefficient of 0.101 (significance level 5%). This variable represents the highest bracket of board gender diversity (75% to 100%) meaning that high-tech firms in which female and male representation is approximately equal, tend to commit more of their assets to R&D investments. On the other hand, in the *NTech-Firms* dataset, all the *Gender.diversity* variables are statistically significant at 1% level with higher coefficients than those of the tech firms, implying a positive and stronger relationship between board gender diversity and R&D intensity. Moreover, when compared with the results of the first dataset, the coefficients are mostly larger (except for *Gender.diversity4*) indicating that the inclusion of tech firms in the first dataset may have reduced the importance of the relationship between gender diversity and firm innovation for every gender diversity bracket except the highest one. Thus, Hypothesis H4, which suggested that high-tech firms in North America with a more gender-diversified board of directors would allocate more resources towards research and development than listed firms in other industries, is not supported by the empirical results.

Finally, while the control variables in both the *Tech-Firms* and *NTech-Firms* datasets show statistical significance at 1% significance level (except *Board.size* in tech firms), indicating their importance in influencing R&D intensity, the differences observed between the two datasets primarily relate to the role of gender diversity in shaping R&D investments. This underscores the need to consider more industry-specific factors and dynamics when exploring the relationship between board diversity and firm innovation.

4.3 Robustness checks

Several robustness checks are performed before the OLS regressions are run to check for homoscedasticity, linearity, and normality of residuals. Additionally, using the Box-Cox transformation the variance of the dependent variable is stabilized to improve model fit. As shown in the figures above (refer to Figures 1 and 2) the transformed dataset does not show any significant signs of heteroskedasticity, and the data of the dependent variable approximates a normal distribution. Building on the above preliminary robustness checks, the statistical integrity of the model is checked using tests for multicollinearity, root mean square error (RMSE), and mean absolute error (MAE).

4.3.1 Multicollinearity

To check for multicollinearity the variance inflation factor (VIF) is used since it provides a measure of multicollinearity among the predictor variables in a regression model such as (*Eq.1*). If multicollinearity is present, it can inflate the variance of the regression coefficients, making them unstable and difficult to interpret. The generally accepted threshold of 2.5 per variable is set to test for multicollinearity. Table 4 below shows the VIF measures per variable and per dataset.

Table 4: Multicollinearity after Box-Cox transformation

Data-set	Age.diversity	Gender.diversity	Board.size	ROA	Leverage	CASH	CAPEX
All-Firms	1.06	1.27	1.20	1.27	1.07	1.31	1.03
Tech-Firms	1.05	1.39	1.23	1.16	1.04	1.14	1.05
NTech-Firms	1.07	1.26	1.20	1.31	1.08	1.35	1.04

Based on the values depicted on the above table, which are all below the threshold of 2.5, multicollinearity does not seem to pose a significant problem in the analysis.

4.3.2 Mean Absolute Error (MAE)

The MAE quantifies the average magnitude of prediction errors in the in-sample data without considering direction and, generally, lower MAE values correspond to improved prediction accuracy. (*Eq.2*) shows the equation used to calculate MAE and Table 5 showcases the MAE values per dataset.

$$MAE = \frac{\sum_{i=1}^{n} |Y_i - \hat{Y}_{i}\}}{n} \qquad (Eq.2)$$

In (*Eq.2*), the Y refers to the dependent variable *RNDTA_trans* and $\hat{Y}_i$ to the predicted value of the same variable. When compared to the range of the dependent variable *RNDTA_trans* per dataset these indicate a low to moderate level of error. *Tech-Firms* dataset exhibits the smallest MAE, suggesting that it may offer the most accurate predictions among the transformed data.

Table 5: RMSE and MAE Results

Data-set	RMSE	MAE
All-Firms	0.86	0.68
Tech-Firms	0.35	0.27
NTech-Firms	0.98	0.77

4.3.3 Root Mean Square Error (RMSE)

The RMSE calculates the square root of the average squared differences in the in-sample data between predicted and observed values. It is calculated based on the equation below (*Eq.3*) and it effectively measures the standard deviation of the residuals. Like the MAE, smaller RMSE values signify greater model accuracy. The RMSE values per dataset as depicted in Table 5 when compared to the range of *RNDTA_trans*, suggest that the model's predictive performance can be acceptable.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2}{n}} \qquad (Eq.3)$$

To sum up, while the additional robustness checks showcase the potential presence of some degree of prediction error in the model, it remains a useful tool for investigating the relationship within the datasets.

5. Conclusion

The role of board diversity has been a topic of increasing interest for both academics and practitioners, given its potential to impact firm performance and strategic decisions around investments and growth (Phan and Yu, 2022; Tsui *et al.*, 2022; Ain *et al.*, 2021). This research contributes to the existing relevant literature by examining the effects of gender and age diversity on firm innovation in North America across all industries while isolating the same effect in the technology industry and comparing it against the rest.

To begin with, the study contributes to the broader corporate governance literature by focusing on board diversity, a critical aspect of corporate governance, which has been somewhat overlooked in the past but gains traction in recent years (Phan and Yu, 2022; Tsui *et al.*, 2022; Ain *et al.*, 2021). The research provides robust evidence that board diversity, and more specifically gender diversity, can enhance a firm's commitment to innovation by having a positive effect on R&D investments. Nonetheless, the study also highlights the complex nature of this relationship, demonstrating that the effect of board diversity on innovation can vary across different types of firms and industries. This nuanced understanding can help firms and investors design more effective corporate governance structures and strategies to enhance innovation.

Secondly, by distinguishing between tech and non-tech firms, this study introduces an important factor to the relationship between board diversity and innovation. The findings suggest that while gender diversity positively correlates with a firm's commitment to invest more of its assets in R&D in all firms, this relationship seems to be less significant for tech firms. Moreover, age diversity does not appear to significantly influence a firm's decision on whether to invest its assets for innovative purposes or not in either tech or non-tech firms. Both conclusions provide valuable insights and highlight the importance of considering more industry-specific factors when exploring the link between board diversity and firm innovation. It also calls into question the one-size-fits-all approach to diversity, suggesting that different industries might need to prioritize different aspects of diversity to promote innovation.

Finally, the study innovatively utilizes both gender and age diversity as independent variables in the same analysis, which are also factors that have been explored in prior research (e.g., Galia *et al.*, 2015; Mothe and Nguyen-Thi, 2021) but not under this setting. While the results show that age diversity does not significantly affect firm innovation, the inclusion of this variable in the study extends the conversation on board diversity, encouraging future research to investigate other dimensions of diversity.

Although this study uses a new approach and it produces significant findings, it is not without its limitations. This research is cross-sectional, and although year fixed effects are used it may not capture all potential temporal dynamics in the relationships between board diversity and firm innovation. Future studies could adopt a longitudinal design, controlling for changes in board diversity and firm innovation over time. This approach would allow for the investigation of potential lagged effects. Additionally, the research focuses on North American listed firms only, a geographic setting that might limit the generalizability of the results. Therefore, it would be of interest for future research to replicate this study in other countries or regions, exploring potential cross-cultural variations in the relationships under each study.

Overall, this research is a valuable addition to the existing literature on board diversity and innovation. By highlighting the different impacts of gender and age diversity on innovation and showing how these relationships can differ across tech and non-tech firms, the study provides important insights for academics, business leaders, and policymakers. Furthermore, the study's findings could have meaningful implications for corporate governance practices, industry innovation strategies, and diversity and inclusion policies. Future research should continue to explore this intriguing area, taking into consideration other forms of diversity and expanding the geographic and industry scope.

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7. Appendices

7.1 Appendix A: Tables

Table 6: Frequency of Gender.diversity Tech-Firms

Gender.diversity	Frequency	Percentage
1	201	20.74
2	387	39.94
3	278	28.69
4	103	10.63

Table 7: Frequency of Gender.diversity NTech-Firms

Gender.diversity	Frequency	Percentage
1	1305	24.88
2	2075	39.52
3	1426	27.16
4	444	8.46

Table 8: Definitions of variables

Variable	Definition
RNDTA	Ratio of research and development expenses to total assets of a firm. Source: Compustat North America
RNDTA_trans	Transformed data of RNTDA based on Box-Cox transformation
Age.diversity	Index that shows the heterogeneity in the preset Age groups. Calculated based on director data gathered in BoardEx - North America
Gender.diversity	Categorical variable that represents gender diversity in a firm's board of directors. Calculated based on director data gathered in BoardEx - North America
Board.size	Total number of the directors in a firm's board. Source: BoardEx - North America
ROA	Ratio of net income / (loss) to the total assets of a firm on an annual basis. Source: Compustat North America
Leverage	Ratio of the total debt to total assets of a firm on an annual basis. Source: Compustat North America
CASH	Ratio of cash and cash equivalents to total assets of a firm on an annual basis. Source: Compustat North America
CAPEX	Ratio of capital expenditures to total assets of a firm on an annual basis. Source: Compustat North America
YearFixedEffects	Dummy variable used for the year fixed effects in the regression analysis

7.2 Appendix B: Figures

Figure 3: Data Figures before Box-Cox – *Tech-Firms*

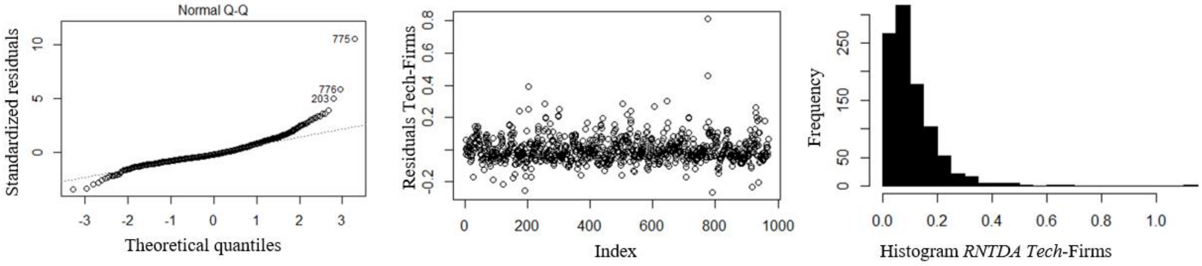

Figure 4: Data Figures After Box-Cox – *Tech-Firms*

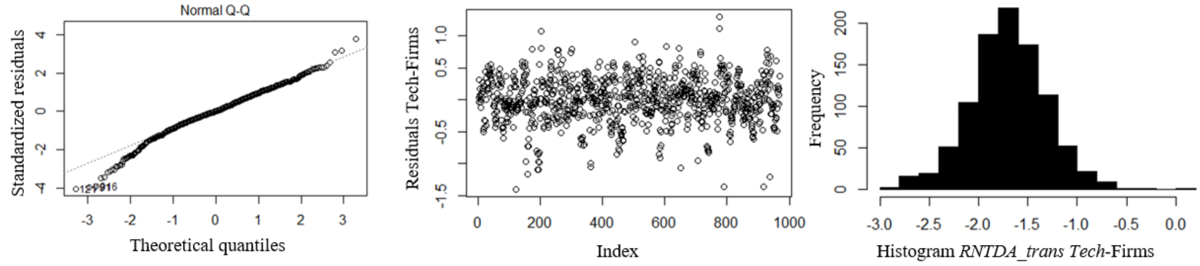

Figure 5: Data Figures before Box-Cox – *NTech-Firms*

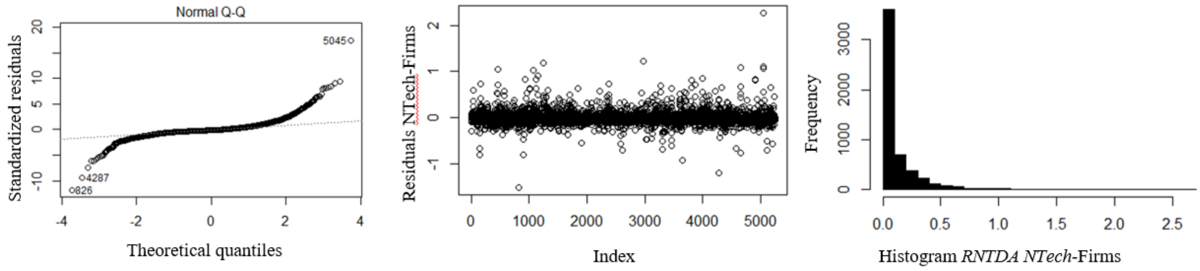

Figure 6: Data Figures after Box-Cox – *NTech-Firms*