Three Essays in Microeconomics

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A Thesis
in
The Department
of
Economics

Presented in Partial Fulfillment of the Requirements
for the Degree of
Doctor of Philosophy (Economics) at
Concordia University
Montréal, Québec, Canada

July 2023

CONCORDIA UNIVERSITY

School of Graduate Studies

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Doctor of Philosophy (Economics)

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Abstract

Three Essays in Microeconomics

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This dissertation consists of three chapters that tackle topics in Microeconomics. The three essays are as follows.

Chapter 1 examines the effects of liquidity requirements on the stability of different interbank network structures. While liquidity requirements strengthen the stability of the financial system, reduce the extent of financial contagion, and prevent the failure of interbank networks, banks with different functions within the interbank network should be bound by varied liquidity requirements. Furthermore, the study demonstrates that excessively strict liquidity requirements can impair the normal operations of financial institutions, potentially impeding economic growth.

Chapter 2 empirically analyzes the effect of the general managerial ability of CEOs on firms' choice of successors. Using recent data collection from *EXECUCOMP* and *Boardex*, I examine the external and internal recruiting decisions of publicly traded firms in North America during the past two decades. Using an instrumental variable approach, I find that a simple probit method is likely to underestimate the effect of successors' general abilities, while the relative importance of general ability is lower for large firms due to asymmetric learning about internal and external candidates, as well as a trade-off between CEO ability and a significant premium to external successors or generalists.

Chapter 3, co-authored with Dr. Ming Li, theoretically studies the quality disclosure strategies of an industry in the absence of regulation and proposes the optimal disclosure strategy for an industry in a vertical differentiation duopoly model. In a price-competitive environment, we demonstrate that industries can collude on how to disclose private information about product qualities, and it is optimal for the industry to reveal only the order of the product qualities in order to maximize joint profits. It also suggests that disclosing any quality cutoffs will not enhance the joint profit of the industry.

Acknowledgments

First, I want to thank my inspiring supervisor, Dr. Ming Li, who led me through my PhD with expertise and passion and shared the enthusiasm of years of discovery. His constant interest in academics inspired me and kept me interested in my research. His kindness as a person made my time at Concordia truly enjoyable.

I would like to thank Dr. Prosper Dovonon for being willing to share his knowledge and expertise and for providing me with plenty of help with empirical studies. I also want to thank Dr. Huan Xie and Dr. Dipjyoti Majumdar for their exceptional courses in economics, which have benefited me immensely.

Also, I want to thank Dr. Szilvia Pápai, Dr. Effrosyni Diamantoudi, and Dr. Damba Lkhagvasuren for their hard work as former Graduate Program Directors and for offering me helpful advice and direction.

I also want to thank my colleagues: Siming Xie, Wenting Xu, Shahir Safi, Farrokh Darvishi, Rouzbeh Ghouchani, Asefeh Salarinezhad, Doris Ngandjoukouyem, Noémie Cabau, and Widad Achargui. I am grateful to them all for showing me how to work hard and be kind. I also want to thank the enthusiastic staff who helped me in the department and answered all of my questions: Ms. Elise Melancon (the former Graduate Program Assistant), whose dedication and hard work are truly inspiring; Ms. Melissa Faisal and Ms. Kelly Routly, who are always helpful, passionate, and genuinely kind. Above all, I want to thank my best friend Hanzhang Wen, who is always there for me with his wisdom and endless energy.

And finally, I would like to express my deepest gratitude toward my family. Without their help and encouragement, I couldn't make it to this point.

Contributions of Authors

Chapters 1 and 2 are solo-authored.

Chapter 3: This work is co-authored by Dr. Ming Li. We evaluated the relevant literature, Dr. Ming Li formulated the research questions, and we developed the theoretical model and analyses together. I did the proofs and wrote the manuscript. Together, we revised it based on our discussions and comments.

Contents

List of Figures

List of Tables

Chapter 1

Liquidity Requirements in A Financial Network

1.1 Introduction

Basel III, a global and voluntary regulation framework, was enacted in December 2009 to support the health of the banking system. One of the most well-known parts of the regulations in Basel III is the liquidity requirement. Liquidity risk arises from a bank's use of short-term funding, such as commercial papers, to fund long-term financing needs. This will not cause problems in a healthy financial environment. However, during financial difficulties, banks are not likely to roll over their commercial paper, so they will default on their creditors which can even cause the banking system's failure. The liquidity requirements of Basel III were designed to guarantee adequate short-term funds when macroeconomic shocks are sufficiently large. These requirements have been implemented gradually since 2013 when the global economy started to recover. Previous cost-benefit studies of Basel III liquidity requirements consider banks that were either in financial difficulties but not governed by the liquidity requirements or governed by the liquidity requirements but in healthy financial environments.

To study the potential influences of the Basel III liquidity policy during financial difficulties, I simulate the financial difficulties and analyze the effects of Basel III liquidity requirements on banks' ability to repay their debts. More importantly, as the interbank loan is one of the largest parts of banks' short-term funding, I further study the effects of those liquidity requirements on the likelihood of the failure of banking systems as a whole.

Initially, I show that this regulatory policy would, in contrast to the "robust-yet-fragile" theory of the complete network as described by Haldane (2013), largely offset the adverse effects of a large negative shock on well-connected networks, especially during financial crises. The improvement of stability, with tighter liquidity requirements in financial networks, is specifically meant for distressed banking systems because it prevents financial contagion from spreading. Therefore, it is less likely that the banking system will default as a whole.

Specifically, I show that financial contagion due to short-term interbank lending and borrowing could be managed by setting appropriate liquidity requirements. The effects of the liquidity requirements depend on two factors. The first is the structure of the networks. The stability of poorly interconnected networks, compared with intensely interconnected networks, is less influenced by Basel III liquidity requirements.

The second factor is whether the liquidity requirements are tight enough to counteract the adverse effects of exogenous shocks to the financial market. Regardless of the network structures, this research shows that tighter liquidity requirements improve, at least weakly, the robustness of the financial system. Specifically, poorly interconnected banking systems will get weakly less fragile, and intensely interconnected banking systems will become much more stable, especially during financial crises.

1.1.1 Regulatory Policies of the Banking System

To monitor the factors that affect the health of banking systems and to regulate financial markets, especially when they are exposed to large macroeconomic shocks, the Basel Committee implemented several regulatory agreements. The Basel Committee intended to increase the capital requirements for both credit risk and market risk to respond to the deficiencies in financial regulations revealed in the 2007-08 financial crisis. The global and voluntary regulatory framework, Basel III, was published in December 2009. It has six major topics of regulatory areas: Capital Definition and Requirements, Capital Conservation Buffers, Countercyclical Buffers, Leverage ratios, Liquidity Risk, and Counterparty Credit Risk (Hull, 2012; Basel Committee, 2013, 2014). These regulations were gradually implemented between 2013 and 2019.

The liquidity requirements are the most important aspect of guaranteeing the health of banking systems. According to Müller (2006), short-term lending might be a source of contagion. As interbank short-term loans are the most common way for banks to cover their short-term funding shortages, the illiquidity of one bank can cause a crash in the banking system. Because of the asymmetry and non-transparency of information on a bank's products and services, it is harder for banks to increase their liquidity when a negative shock strikes. Liquidity regulations were designed to guarantee adequate funds when macroeconomic shocks are sufficiently large. Two quantitative measures in Basel III were designed to counter liquidity pressure:

$$1.\ \text{Liquidity Coverage Ratio (LCR)}: \frac{\text{High-quality Liquid Assets}}{\text{Net Cash Outflows in a 30-Day Period}}$$

$$2.\ \text{Net Stable Funding Ratio (NSFR)}: \frac{\text{Amount of Stable Funding}}{\text{Required Amount of Stable Funding}}$$

Both measures are required to be greater than 100%.[1] If a financial institution does not meet this regulation, the amount of high-quality liquid assets and the amount of stable funding must increase or cash outflows and the required amount of stable funding must decrease to satisfy the requirement. Interbank loans are the most common way for banks to cover a short-term fund shortage and are also the most influenced by lower liquidity. Banerjee and Mio (2018) suggest that the Basel III liquidity requirements will reduce interbank loans but will not affect the amount of capital lent to the real economies, and my approach to meet these requirements is to limit a bank's debts.

My paper focuses on the effects of liquidity requirements on the stability and resiliency of financial networks. The main goal of this paper is to identify whether Basel III's regulations will make it less likely for the banking system to fail as a whole.

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[1] "Net Cash Outflows over a 30-Day Period" refers to a bank's predicted cash outflows in stressed market conditions. It covers expected cash outflows from liabilities (such as deposits and borrowings) and cash inflows from assets (such as loan repayments and asset sales). Under stressed market conditions, banks must maintain enough "High-quality Liquid Assets" (HQLA), or assets that are easily convertible into cash without substantial loss of value, to offset their estimated net cash outflows over a 30-day period. The NSFR requires banks to make sure that their long-term assets are backed by stable sources of funding for a year.With an NSFR of at least 100%, a bank has enough money to pay its long-term debts. The NSFR's numerator is a bank's available stable funding (ASF), such as retail deposits, wholesale funding, and equity, and the denominator is a bank's required stable funding (RSF), or the amount of funding a bank is obliged to maintain to finance its assets over a one-year period on the basis of the risk characteristics of those assets and the time required to liquidate them (Basel Committee, 2013, 2014).

1.1.2 2007-08 Financial Crisis Review

Over the last few decades, the degree of economic globalization has been deepening. The recent financial crisis in 2007-08, which arose from the U.S. Subprime crisis not only affected global financial institutions but also the global economy, and global economic growth slowed significantly. Specifically, the U.S. economy witnessed a negative growth of the GDP by 0.89% in the fourth quarter of 2008,[2] which was the largest decline in the previous 7 years. Also, the Personal Consumption Expenditure decreased by 3.8%.[3] At the same time, the economy in Europe got worse and the manufacturing industry shrank substantially. In addition, many countries suffered from fiscal deficits and inflation.

Financial markets also deteriorated sharply, especially stock markets. Hundreds of U.S. banks of middle or small size closed down, and Lehman Brothers, once the fourth largest U.S. investment bank, collapsed in 2008. Shortly after, Merrill Lynch was acquired by Bank of America, and the Dow Jones index, CAC40 index, DAX Performance index, etc., dropped sharply.[4] The stock market in the Asian Pacific region also got hit.

1.1.3 Why The Banking System Matters and the Factors Behind Banking Crises

What factors lead to a banking system failure has become a hot topic. Many researchers have attempted to identify the causes of financial crises. Of these, Kindleberger et al. (1996) and Bernanke (2001) find that bank crises will always worsen economic and financial environments, even though they might not be the primary cause. An analysis of the failure of Canadian and U.S. banks during the Great Depression by Haubrich (1990) aligns with this view. Haubrich points out that the reason Canada suffered less during the depression was that fewer banks failed is that Canada had a concentrated banking system under closer supervision and regulations. Therefore, a much smaller percentage of Canadian failed, compared with their US counterparts.[5]

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[2] GDP data is available at https://research.stlouisfed.org/.

[3] PCE data is also available at https://research.stlouisfed.org/

[4] Index data is available at https://www.macrotrends.net/

[5] "Around 20% of all U.S. banks failed, and as a result, over one third of all banks ceased to exist due to failure, mergers, or liquidations. Comparatively, the number of Canadian branches declined from 4,049 to 3,640." (Haubrich, 1990)

Caprio and Klingebiel (1996) summarize both macroeconomic and microeconomic factors that are the most influential. Although macroeconomic shocks, such as large volatility and shallow financial markets, matter, they are not the biggest threat to the banking system. Rather, extreme or excessive credit growth, asymmetric information about banks' products or services on the part of purchasers and banks, and a specific bank's management play more significant roles in banking crises. Also, a single bank's failure and default can result in a contagion that affects the entire banking system.

1.1.4 Related literature

On a theoretical basis, some previous researchers investigate the existence of financial contagion in the banking network. Allen and Gale (2000) argue that for sufficiently large shocks, complete connections might become contagion channels. Freixas et al. (2000) add that risk sharing of the interbank networks leads to bad market discipline. In addition, Müller (2006) asserts that short-term lending might be a source of contagion.

In order to model interbank contagion, Eisenberg and Noe (2001) show the existence of a payment equilibrium in the interbank loan model, no matter what structure an interbank network has. The payment equilibrium includes repayments and liquidation decisions. Blume et al. (2011, 2013) use an artificial interbank contagion framework. Glasserman and Young (2015) further analyze the possibility of financial contagion in the presence of network-independent bounds.

On the basis of these papers, some other researchers study the effects of financial networks' structures on financial contagion. Some studies imply that well-interconnected banking systems are more likely to fail. Vivier-Lirimont (2006) suggests that the likelihood of a banking network's failure increases as the number of the banks' counterparties grows. Moreover, Haldane (2013) argues that highly interconnected networks might create a channel for potential fragility beyond a certain range, even though it serves as a risk absorber within that range. Additionally, Acemoglu et al. (2012, 2015) compare the influences of different-sized shocks on clustered networks and discuss the default cascades. They also show that different network structures are influenced by financial contagion differently.

Other studies attempt to simulate financial contagion in the real world. Before the publication of the Basel III requirements, many central banks conducted simulations to predict contagion (Čihák, 2007). Upper (2007) uses a counterfactual simulation, including on- and off-balance data, to estimate contagion in interbank systems. Anand et al. (2015) adopt two approaches to estimate the boundary of contagion in the interbank system.

Previous studies of the effects of Basel III Liquidity Requirements use empirical methods in time series to estimate them. The most closely related policy analysis to my study is that of Banerjee and Mio (2018), who point out that Basel III liquidity requirements will reduce interbank loans but will not affect the amount of capital lent to real economies. Banerjee and Mio (2018) analyze data on UK banks between 2008 and 2012, adopt a local projection methodology, and use regression-adjusted difference-in-differences to estimate the pre- and post-effects of the liquidity requirements. Also, Dietrich et al. (2014) focus on the net stable funding ratio (NSFR), which is one of the Basel III liquidity requirements. They study the bank-specific characteristics of Western counties from 1996 to 2010 and claim that a tighter requirement promotes sustainable funding structures of financial institutions. They also find that many banks, larger and faster-growing institutions particularly, have not obeyed NSFR minimum requirements in the past. However, those banks did not obtain higher profits when they violated NSFR minimum requirements. Hong et al. (2014), based on income statements and balance-sheet data of U.S. commercial banks from 2001 to 2011, use a discrete-time model to link bank failure to insolvency and liquidity risk. Furthermore, systemic liquidity risk contributed significantly to bank failures in 2009–2010.

Although these studies provide evidence of the network of the interbank loan system and the linkage between individual bank failure and liquidity, they fail to analyze the linkage between the failure of the banking system and liquidity preparation. Second, the sample analyzed in those studies mainly considers Western counties and different structures of the banking systems in other regions of the world are not considered. What's more, even though the sample in the above studies includes data on the 2007-2008 financial crisis, the liquidity requirements were not met by most banks at that time. As a result, they fail to show the potential effects of liquidity requirements on banking performance during financial crises.

Theoretically, Dasgupta (2004) studies the relationship between liquidity shocks and financial contagion and shows that a completely interconnected banking system allows for liquidity risk sharing and is more resistant to contagion than incomplete networks. Empirically, Drehmann and Tarashev (2013) examine the linkage of interbank loans among banks in the real world and confirm that there is an actual linkage. In fact, central banks act as the intermediary in interbank lending and borrowing in Western countries and are thus of higher significance.

In this chapter, I mainly contribute to conducting a theoretical investigation of the effects of Basel III liquidity requirements on financial contagion in interbank lending and borrowing. As suggested by prior researchers, such as Allen and Gale (2000) and Acemoglu et al. (2015), understanding the network structure of failed banking systems is significant in order to analyze the potential effects of liquidity requirements on banking systems as a whole. Therefore, I adopt a model that can simulate good and bad financial situations for all network structures following Acemoglu et al. (2015, 2012). Yet, different from that of Acemoglu et al. (2015, 2012), I consider banks to be bounded by liquidation requirements by assuming that the total amount any bank can borrow is limited. A limited interbank loan is used in order to simulate a scenario in which interbank lending is restricted while applying Basel III liquidity requirements but has no impact on the amount of capital lent to real economies, as suggested by Banerjee and Mio (2018).

To sum up, this chapter, in line with Caprio and Klingebiel (1996), shows the importance of regulatory frameworks in the interbank systems, mainly focusing on the effect of Basel III liquidity requirements on interbank networks. More specifically, I analyze how the liquidity requirements of Basel III affect the stability of the interbank lending and borrowing system, including the introduction of limitations on interbank loans to project the outcomes of liquidation requirements. Additionally, as suggested by Haubrich (1990) and Acemoglu et al. (2012, 2015), the structure of the interbank network is important in determining the likelihood of financial contagion. In this chapter, while adapting the model setup of Acemoglu et al. (2015), I further discuss in depth the influence of liquidity requirements on financial networks when macroeconomic shocks are different-levelled. While first considering a single shock, small or large, in the system, I further discuss the case when multiple shocks hit the interbank loan system. It has been observed that stricter requirements allow networks to be more resilient to large shocks. To understand the different structures of financial networks in different regions, I examine the influence of Basel III liquidity policies on different network structures under both small and large shocks.

The rest of the chapter is organized as follows. Section 1.2 presents the theoretical model setup. Sections 1.3.2-1.3.4 assume that banks' project liquidations result in zero value: Sections 1.3.2-1.3.3 describes the financial contagion when a small and large single shock hits the banking network, respectively; Section 1.3.4 presents the result when multiple shocks hit the banking network. Section 1.3.5 relaxes the assumption and allows banks to realize the non-zero value in liquidation. Section 1.3.6 relaxes the assumption that banks are homogeneous in interbank loans and allow heterogeneity. Section 1.4 concludes.

1.2 Setup

1.2.1 Model

Following the model of Acemoglu et al. (2012, 2015, 2016), I consider a network model in which banks have two funding sources: outside funding and interbank loans. The products and services banks provide are described as bank projects, which are subject to macroeconomic shocks. Therefore, their return from them is not certain.

Assume that a financial network system has $n = 1, 2, ..., N$ risk-neutral banks, and the economy in the network lasts for three periods, $t = 0, 1,$ and 2. Banks in the system start initial actions at $t = 0$. The period $t = 1$ and $t = 2$ simulate the short-term and long-term actions of banks after the initial period. In the initial period, $t = 0$, Bank i has a capital of k_i and it can decide the actions regarding how to use its capital by either holding it as cash c_i for liquidity concerns, lending to other banks to earn interest, or investing in a project to obtain project returns in both the short term and the long term. In other words, all banks in the network will get short-run and long-run project returns at both $t = 1$ and $t = 2$.

Consider standard debt contracts signed at $t = 0$. As suggested by Müller (2006), short-term lending could result in financial contagion in the banking system. For liquidity concerns, assume that all debts must be cleared in the short term-namely, at $t = 1$. Thus, I can check whether the banks can repay their creditors in the short term, which is determined by their liquidity. If banks cannot meet full liability at $t = 1$, they must liquidate their projects partially or fully to repay their creditors.

Since the goal is to analyze the liquidity requirements' effects on the stability and resiliency of networks, banks are assumed to be able to liquidate projects immediately. The projected return, as stated above, has both a short-term return and a long-term return. The short-term return is affected by exogenous macroeconomic shocks to the banks.

At $t = 1$, let z_i be a random return of bank i, and $z_i \in \{a - \epsilon, a\}$ can take only two values a or $a - \epsilon$ for any bank where a is a fixed value,[6] and ϵ defines the exogenous macroeconomic shock. The long-term return at $t = 2$ is a fixed, held-to-maturity, long-term, and non-pledgeable return A. In the case in which the banks need to liquidate, partially or fully, let $\zeta < 1$ be the fraction of the project's full value that can be recovered.

The resources for banks' liabilities are simplified as outside loans and loans within the financial network. For debt outside the interbank system, let $v > 0$ be the obligation outside of the banking system. Assume that the outside loan is to simulate the outside fund resources of banks, such as deposits from depositors, in the real world. As for the interbank loan, let $y_{ij} = (1 + Rij)k_{ij}$ be the face value of the debt of bank j to bank i, where R_{ij} is the corresponding interest rate and k_{ij} is the amount of capital that bank j borrows from bank i at $t = 0$. Thus, the total liability of bank j is $v + y_j$, where y_j is the aggregate liability of bank j within the interbank loan system, such that $y_j = \sum_{j \neq i} y_{ij}$. Banks in the system are the junior creditors, while outside sources are the senior creditors.[7] In the banking system, senior creditors will have the first right to repayment. And junior creditors get repaid later with equal priority. In the case in which the borrowers have insufficient funds to repay in full, junior creditors get paid at a ratio of the face value of the debts they controlled over the total amount of borrowers' interbank liabilities. In the extreme case, when borrowers cannot even repay senior creditors in full at $t = 1$, junior creditors will get zero repayments. Let $x_{js} \in [0, y_{js}]$ be the repayment from bank s to bank j at $t = 1$.

The interbank repayment depends on the total cash inflow of borrowers. Therefore, I consider whether borrowers can repay their creditors with their cash inflows.

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[6] Note that z_i is $i.i.d.$ on banks. Setting up a model in which bank returns are independent of bank borrowing and lending is for simplicity's sake. It is important to note, however, that this assumption could fail to capture the entire complexity of real-world interbank interactions, as interdependencies and interbank transactions might alter banks' predicted profits in practice. For a more realistic analysis of interbank behavior, while assuming independence can provide initial insights, it is necessary to acknowledge the limitations and consider more comprehensive models that incorporate the interdependencies between interbank borrowing, lending, and projected returns.

[7] Interbank network is therefore defined by the creditor-debtor relationships among the banks.

Let $h_j = c_j + z_j + \sum_{j \neq s} x_{js}$ be the total cash inflow of j when it does not liquidate. Liquidation decisions depend on whether total cash inflows without liquidation can cover the total liability of the borrowers.

When $h_j > v + y_j$, bank j can meet all liabilities; when $h_j < v + y_j$, bank j needs to liquidate to cover $v + y_j - h_j$ shortage.

Further, if a partial liquidation can cover the above shortage, then the liquidation amount of the project will be $\frac{1}{\zeta}(v + y_j - h_j)$. Otherwise, a full liquidation at amount A has to be made. Let

$$l_j = [\min\{\frac{1}{\zeta}(v + y_j - h_j)), A\}]^+ \in [0, A] \tag{1}$$

denote the liquidation decision of bank j, where $[.]^+$ stands for the situation in which a bank does not liquidate its project if it can meet its liabilities with the cash it holds, short-run returns, and repayments by other banks.

Default is defined as a situation in which a bank cannot repay its creditors - senior or junior- with full liquidation. When $h_j + \zeta A < v$, j defaults on senior creditors and junior creditors receive nothing; i.e. $x_{js} = 0, \forall s$. When $h_j + \zeta A \in (v, v + y_j)$, senior creditors get paid in full and junior ones get paid a proportion of the face value of debts they loaned to j over j's total liability. Thus, payment from bank j to bank i is

$$x_{ij} = \frac{y_{ij}}{y_j}[\min\{y_j, h_j + \zeta l_j - v\}]^+. \tag{2}$$

As shown by Dietrich et al. (2014), liquidity requirements play the role of limiting the interbank loan without affecting the aggregate amount lent to the real world. When the requirements are implemented, I put a limitation on interbank loan b, where $b \leq y_j$, to simulate the effect in the interbank network. Thus, I modify the payment and liquidation decision as follows: for a bank j bound by this liquidity requirement, its total liability is $v + b$. Denote:

$$l_j^{'} = [\min\{\frac{1}{\zeta}(v + b - h_j), A\}]^+ \in [0, A], \tag{3}$$

$$x_{ij}^{'} = \frac{y_{ij}}{b}[\min\{b, h_j + \zeta l_j^{'} - v\}]^+. \tag{4}$$

1.2.2 Network Structure

The following are some definitions of the financial network:

Definition 1.1. A financial network is symmetric if

$$y_{ij} = y_{ji}$$

Definition 1.2. For regularity, all banks have the same liability:

$$\sum_{i \neq j} y_{ij} = \sum_{l \neq k} y_{lk} = \overline{y}.$$

Definition 1.2.1. If the banks are bound by the limitation amount b, then:

$$\sum_{i \neq j} y_{ij} = \sum_{l \neq k} y_{lk} = b \leq \overline{y}.$$

I consider k-Regular Networks in the analysis following Acemoglu et al. (2015) and Acemoglu et al. (2016).[8] For example, $k = 2$ means that every bank borrows from and lends to two other banks.

Figure 1.1 shows the least and most interconnected k-regular networks: the ring and complete networks.

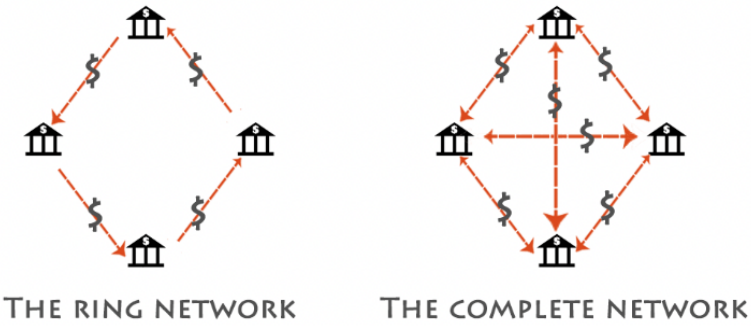

Figure 1.1: Examples of k-regular Networks

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[8] "A k-Regular Network is defined as a network in which the edges are directed and have the same weight, and every node has an equal degree of k. Degree refers to the number of banks a bank borrows from and lends to in the network" (Acemoglu et al., 2015)

Definition 1.3. A network $\{\tilde{y_{ij}}\}$ is a $\gamma - convex$ of network $\{y_{ij}\}$ and $\{\hat{y_{ij}}\}$, if $\exists \gamma \in [0,1]$ such that

$$\tilde{y_{ij}} = (1-\gamma)y_{ij} + \gamma \hat{y_{ij}}, \quad \forall i, j.$$

Definition 1.4. A regular network is $\delta - connected$, if there exists a collection of banks $S \subset N$ such that $\max\{y_{ij}, y_{ji}\} \leq \delta y, \quad \forall i, j \in S$.

This defines a network in which the cash flow between any two banks is limited.

Definition 1.5. For two given subset banks M and S, $\{\tilde{y_{ij}}\}$ is a $(M, S, \mathcal{P}) - majorization$ of the regular financial network $\{y_{ij}\}$ if

$$\tilde{y_{ij}} = \begin{cases} \sum_{k \neq j} p_{ik} y_{kj} & \text{if} \quad i \notin S, j \in S \\ y_{ij} \quad \text{if} \quad i, j \in M \end{cases}$$

Here $\mathcal{P}$ is a doubly stochastic matrix of the appropriate size.[9] The $(M, S, \mathcal{P}) - majorization$ network defines a transformation from a certain network form to another network form in which banks have more junior debtors. The $(M, S, \mathcal{P}) - majorization$ network can potentially control the cash outflow of banks because each bank's interbank debt is more evenly distributed among a greater number of junior creditors.

1.2.3 The Fragility and Stability of Networks

Conditional on the realization of p negative shocks, the social surplus of a network is the sum of the total short-term and long-term returns of all banks in the system subject to the shocks and lost value in liquidations. Social surplus u where liquidation results in no value:

$$u = n(a + A) - p\epsilon - (1 - \zeta) \sum_{i=1}^{n} l_i.$$

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[9] A matrix such that all elements are nonnegative and each row or column sums up to one.

For simplicity, the case in which liquidation results in no value -i.e., $\zeta = 0$- will be considered first. It will be relaxed later. In this case, in which $\zeta = 0$, the social surplus is solely dependent on the number of banks that default in the network:

$$u = n(a + A) - p\epsilon - \#defaults.$$

The stability and resiliency of a network capture the expected and the minimal social surplus in the network conditional on p negative exogenous shocks, respectively. They can measure how much is expected and the minimum aggregate amount of profit a network can get.

Definition 1.6. Consider two regular frameworks $\{y_{ij}\}$ and $\{\tilde{y_{ij}}\}$:

(i) $\{y_{ij}\}$ is *more stable* if $E_p u \geq E_p \tilde{u}$ conditional on p shocks are realized in the system .

(ii) $\{y_{ij}\}$is *more resilient* if $\min u \geq \min \tilde{u}$, in which $minimum$ capture the worst case in presence of p shocks realized in the system .

The stability and resiliency of a network, in the case in which liquidation results in no value, can be described as a function of the expected and the maximal number of defaults in the network.[10] Thus, comparing the stability and resiliency of the networks could be easily conducted by counting the expected and the maximal number of defaults in the interbank system.

1.3 Analysis

1.3.1 Outline

In previous studies, Banerjee and Mio (2018) and Dietrich et al. (2014) examine the influences of Basel III liquidity requirements using data on Western banks. On the basis of the framework of Acemoglu et al. (2015), in which the stability and resiliency of differently structured networks under different shocks are discussed, I will further discuss the theoretical impact of Basel III Liquidity Requirements on the stability of differently structured banking systems in different macroeconomic environments. As Dietrich et al. (2014) show that many banks have not obeyed NSFR minimum

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[10] Stability and resilience are improved when the effects of shocks on banks other than the ones that were hit are kept to a minimum.

requirements in the past, my study is meant to demonstrate the potential costs and benefits of the liquidity regulatory policy.

Mainly, I analyze cases in which the liquidity regulations bind for banks, which leads to a change in interbank lending and borrowing decisions. In the beginning, I assume that banks in the interbank network are the same size. Thus, I impose the same amount b as the limitation on any bank in the interbank-loan network. In order to study the influence of the limitation on the network's stability and resiliency, I consider that macroeconomic shocks, which are exogenous to the banking system, hit the network.

The first scenario is that there is a single shock to the network. Specifically, I study the small single-shock case and the large single-shock case. This is to check the stability and resiliency of networks in both good financial conditions and in a financial crisis. The second scenario is that multiple shocks hit the network. Again, situations in which both small shocks and large shocks hit the banking systems, will be investigated. Next, I include the liquidation decisions of banks in the model to check whether banks are able to repay their interbank debts and outside debts by selling their assets. Later in this section, I will consider the heterogeneity of bank sizes and the limitations. The assumption that banks are of the same size will be relaxed by imposing scales on bank debts. Corresponding to bank sizes, limitations on both interbank loans and outside loans will be scaled with different sizes. The cash held by each bank is normalized to zero.

1.3.2 Small Single Shock

First, I focus on the effects of Basel III liquidity requirements on the interbank network when a small single shock strikes. As discussed by Allen and Gale (2000), Freixas et al. (2000), and Acemoglu et al. (2015), when a shock that is smaller than the excess liquidity strikes the network, potential losses are shared by other banks in a well-interconnected network. In the complete network, specifically, the loss can be transmitted and shared by all banks in the network. For the least-interconnected network - the ring network- the risk will be transferred to the sole creditor of the bank hit directly by the shock. The risk further transfers to all creditors in this system and causes default.

Based on these results, I further examine when the liquidity regulations bind for banks. In addition, liquidity requirements play the same role as setting limits on interbank loans (Banerjee and Mio, 2018). If there exist small macroeconomic shocks when applying limitation b to an interbank loan, I observe that the amount of b will determine the system's robustness. In other words, implying tighter or looser liquidity regulations will lead to a change in network stability. I also observe that the critical value of the limitation amount is $f(\epsilon) = v - a + \epsilon$, which is a linear function of the exogenous shock.

Proposition 1.1. Let a critical value be $\epsilon^* = n(a - v)$ and suppose $\epsilon < \epsilon^*$, then there exists a linear function $f(\epsilon)$ of ϵ *s.t.*

Case 1. If $b \geq f(\epsilon)$, regardless of whether b binds for banks or not:

(1) The ring network is the least resilient and least stable.

(2) The complete network is the most resilient and stable.

(3) The $\gamma - convex$ of the ring and complete networks becomes weakly more stable and resilient as γ increases.

Case 2. If banks are bound by limitation $b < f(\epsilon)$ on an interbank loan:

(1) The complete network is the most resilient and stable network.

(2) The stability and resiliency of the ring network and $\gamma - convex$ network are weakly improved:

   (a) The expected and the maximal numbers of default in the ring network will be equal to or less than the case in which banks have unlimited liabilities.

   (b) The expected and the maximal numbers of defaults in the $\gamma - convex$ network will be equal to or less than the case in which banks have unlimited liabilities.

The results in Case 1 imply the influence of liquidity requirements on the interbank network when all banks in the network meet the regulation with their normal interbank lending and borrowing. This is consistent with the result of Acemoglu et al. (2015), by which banks can have unlimited liabilities. In this case, the liquidity requirements will not affect the stability or resiliency of interbank networks.

However, the results in Case 2 imply that the stability and resiliency of the network have been weakly improved for different interbank network structures if a tighter interbank loan limitation b is imposed. Interbank networks tend to be more robust than the case in which banks can have unlimited liability. As banks lend and borrow less from each other, the limitation on interbank debts ensures that banks are equipped with more liquid funds to repay their creditors.

This typically applies to the ring network. The higher liquidity preparation enables the higher possibility of banks repaying both senior and junior creditors. Because each bank in the ring network has only one junior creditor, it further prevents the risk of defaulting from transferring to the sole interbank creditor of the distressed bank. Thus, it is less likely that the whole banking system will fail as a whole.

Given the previous findings by Dietrich et al. (2014) that many banks did not meet the liquidity requirement in the past, I can conclude that tighter liquidity requirements can lead to a weakly more stable interbank network while setting loose liquidity requirements will not benefit the stability of the network. Tighter liquidity requirements contribute to decreasing the number of defaulting banks in the network.

1.3.3 Large Single Shock

To see the potential influence of the Basel III liquidity requirements, it is also important to analyze the situation in which a large shock strikes the network; For example, during a financial crisis.

Again, I apply limitation b on interbank loans: Let $f(\epsilon) = v - a + \epsilon$ be a linear function of the shock ϵ. The effects of the liquidity regulation depend on whether the regulation is tight enough to counteract the effect of the large negative shock on the financial market:

Proposition 1.2. Let a critical value be $\epsilon^* = n(a - v)$ and suppose $\epsilon > \epsilon^*$, then there exists a linear function $f(\epsilon)$ of ϵ *s.t.*

Case 1. If $b \geq f(\epsilon)$:

(1) The ring network is the least stable and the least resilient, where it has the same expected and maximal number of defaults as the case in which banks have unlimited liabilities.

(2) For a small enough δ, any $\delta - connected$ network is strictly more stable and resilient than the

ring network.

(3) The complete network is weakly more stable and resilient than any $\delta - connected$ network, and it is the most stable and resilient.

Case 2. If $b < f(\epsilon)$:

(1) The $\delta - connected$ network is not necessarily more stable or resilient than the ring network: The expected and the maximal numbers of defaults in the $\delta - connected$ will be equal or less, compared with the case in which banks have unlimited liabilities.

(2) The complete network is still the most stable and resilient form: It has the smallest expected and maximal numbers of defaults.

(3) The $(D, j, \mathcal{P}) - majorization$ network decreases the number of defaults.

Again, in line with the results in Section 4.2, loose liquidity requirements will not help to stabilize the interbank network. As can be seen in Case 1, the stabilities of the networks stay the same as in the results of Haldane (2013) and Acemoglu et al. (2015), where banks have unlimited liability. These researchers suggest that the adverse effects of a large negative shock are directly transmitted to the intensely interconnected networks. In less-interconnected networks, such as $\delta - connected$ networks, fewer junior creditors in the financial network bear the loss transmission. This is because control of the cash flow in the $\delta - connected$ network allows the potential losses in distressed banks to be absorbed by their senior creditors.

As for the ring network in Case 1, the potential losses from a shock that is beyond a network's ability to absorb will infect more banks in the network. This is again because of the fact that each bank in this network has only one junior creditor.

The effects of tighter liquidity requirements are shown in Case 2. These effects include a reduction in liquidity risk sharing, a decrease in the number of defaults, and an increase in network stability and resilience. In fact, the liquidity regulation serves as a limitation on the liability of each bank and helps to stabilize the network largely by offsetting the adverse effects of a large negative shock on a well-interconnected network. Therefore, in a more intensely interconnected form, the $(D, \{j\}, \mathcal{P}) - majorization$ network, banks share the limited liquidity risk. The possibility that they hold adequate short-term funding gets higher. Hence, they are more likely to repay creditors,

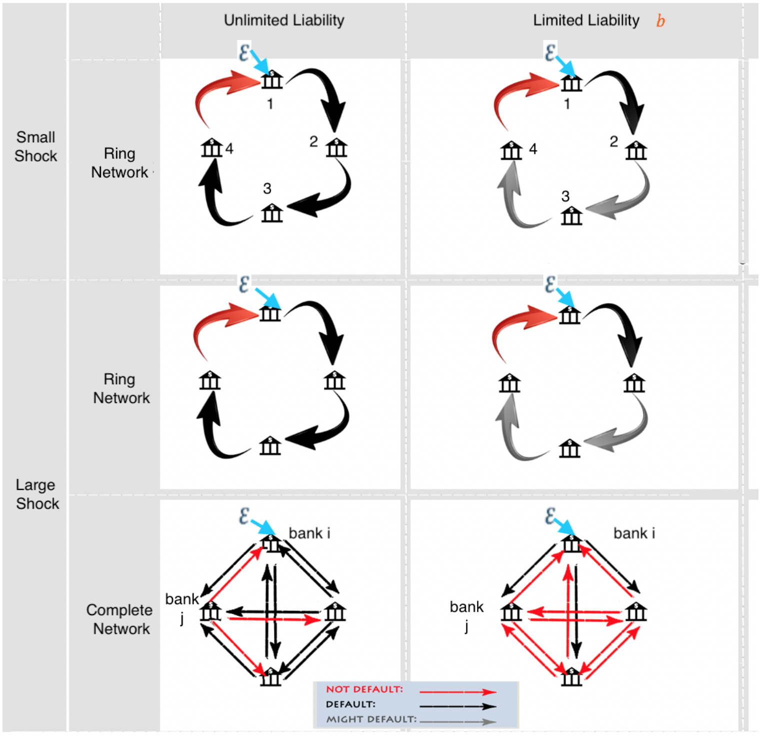

Figure 1.2: Examples of Defaults in Small and Large Shocks Cases

and this network is more stable and resilient than the original network form.

In addition, since the liquidity requirements target a wider range of banks in the interbank network, they have stronger effects than merely controlling cash flow among certain banks. Thus, the more interconnected an interbank network is, the more its stability will benefit from the liquidity requirement. As for the most interconnected network, the complete network, stability benefits the most during severe financial difficulty. Each bank in the complete network equally shares the limited liquidity insufficiency, so it has the smallest number of defaults.

Figure 1.2 shows examples of 1.1 and 1.2 by displaying how banks default with and without liquidation requirements b in the ring and complete networks when there are four banks in the system and both small and large macroeconomic shocks. Bank 1 is assumed to hit by the shock.

1.3.4 Multiple Shocks

An important observation about the critical threshold of the exogenous shock is that it decreases in p (Acemoglu et al., 2015). This means that the magnitude and size of negative shocks play a similar role. Using this similarity, I modify the critical threshold to $\epsilon_p^* = n(a-v)/p$ in the single-shock scenario. Thus, I can simply simulate the multiple-shocks scenario using the single-shock model. I apply regulation $b$on interbank loans:

Proposition 1.3. Set $\epsilon_p^* = n(a-v)/p$. There exists $f_(\epsilon, p)$ *s.t.*

Case 1. If $\epsilon < \epsilon_p^*$ and $b < f(\epsilon, p)$:

(1) The complete network is still the most resilient and stable network, where it has smaller expected and maximal numbers of defaults compared with the unlimited liability case.

(2) The ring network is not necessarily the least resilient nor the least stable. The expected and maximal numbers of defaults are equal to or smaller than the numbers in the unlimited liability case.

Case 2. If $\epsilon > \epsilon_p^*$ and $b < f(\epsilon, p)$:

(1) The complete network is still the most resilient and stable network, where it has smaller expected and maximal numbers of defaults compared with the unlimited liability case.

(2) The ring network is not necessarily the least resilient nor the least stable. The expected and maximal numbers of defaults are equal to or smaller than the numbers in the unlimited liability case.

Similar to the single-shock case, the tighter liquidity requirements of each bank counteract the adverse effects of large negative shocks on the well-interconnected system. Again, this is consistent with the result of Acemoglu et al. (2015), in which banks have unlimited liability. In Case 1 in which small shocks hit the interbank networks, the networks' stability has been weakly increased. The stricter the liquidity requirements, the more short-term liquid funding banks are able to acquire. Thus, they have a higher ability to repay their creditors. This especially applies to the more densely interconnected structures, such as the complete network, in which banks share liquidity risks and are equally exposed. The stability and resilience of the less densely interconnected network are weakly improved. With the tight limitation on interbank loans, it is more likely that banks reserve adequate liquid funding and prevent the distress from spreading widely.

In Case 2 when large shocks hit, the above results still hold with the tight limitations. Again, senior creditors serve as risk absorbers in the ring network. In the complete network, the connections become a channel for each bank to bear a relatively small amount of the short-term funding shortage. Overall, in multiple shocks cases, the effects of Basel III liquidity requirements are consistent with the effects in the single-shock cases-That is, tighter liquidity requirements help to reduce the defaults in interbank networks and boost the stability of the networks.

1.3.5 Nontrivial Liquidation with Multiple Shocks

The results in sub-sections 1.3.2-1.3.4 are based on the assumption that bank liquidations have zero value-namely, in the case in which $\zeta = 0$. This section examines the situation in which $\zeta > 0$. Liquidation decisions will change the critical thresholds of shocks. Assume that banks can partially liquidate their projects at $t = 1$. When applying limitation b on interbank loans:

Proposition 1.4. Set critical values $\epsilon_*(\zeta) = n(a - v) + \zeta A$ and $\epsilon^*(\zeta) = n(a - v) + n\zeta A$. Then there exists $f(\epsilon, \zeta)$ *s.t.* for $b < f(\epsilon, \zeta)$:

Case 1. If $\epsilon < \epsilon_*(\zeta)$:

(1) The complete network is still the most resilient and stable network, in which it has smaller expected and maximal numbers of defaults compared with the unlimited liability case.

(2) The ring network is not necessarily the least resilient nor the least stable. The expected and maximal numbers of defaults are equal to or smaller than the numbers in the unlimited liability case.

Case 2. If $\epsilon > \epsilon^*(\zeta)$:

(1) The complete network is still the most resilient and stable network, where it has smaller expected and maximal numbers of defaults compared with the unlimited liability case.

(2) The $\delta - connected$ network is not necessarily more stable or resilient than the ring network. The expected and maximal numbers of defaults are equal to or smaller than the numbers in

the unlimited liability case.

Case 3. If $\epsilon \in [\epsilon_*(\zeta), \epsilon^*(\zeta)]$:

1. The complete network is still the most resilient and stable network, where it has smaller expected and maximal numbers of defaults compared with the unlimited liability case.
2. The ring network is not necessarily the most fragile. The expected and maximal numbers of defaults are equal to or smaller than the numbers in the unlimited liability case.
3. The $\delta - connected$ network is not necessarily more stable or resilient than the ring network. However, its expected and maximal numbers of defaults are equal to or smaller than the numbers in the unlimited liability case.

The proposition above is consistent with the results of the previous sections. The liquidation decisions of the banks will not change the effects of the liquidity requirements of Basel III. In the presence of small shocks, with the limitation on interbank loans, the ring network can absorb the losses in project liquidations. Thus, fewer defaults will occur in this network. On the other hand, the complete network remains the most stable and resilient, as every bank is more likely to hold adequate short-term funds for repayment.

When large shocks hit the network, the liquidity requirements again increase the possibility that banks in the ring network will repay their junior creditors. Thus, its stability and resilience will be weakly improved. As discussed in subsection C, liquidity regulation is more powerful than simply controlling the cash flows among certain banks. Thus, the cash-flow-controlled network-namely, the $\delta - connected$ network- will not necessarily be more stable than the ring network. Again, the most interconnected network, i.e., the complete network, will be the least fragile during severe financial distress. The liquidity policy limits the adverse effects of large negative shocks, and all banks in the system will share the risk equally.

1.3.6 Heterogeneity

The above sections examine the case in which the banks in the financial network are of homogeneous size and have a homogeneous amount of debt. In reality, financial institutions are of different sizes, and therefore they obtain different amounts of debt from creditors according to their demands. In order to simulate it, the liabilities, y_i and v, and the limited amount of interbank loans b will be scaled by $\theta_i > 0$ for each bank i. Assume that each bank i in the subset M, i is bound by the limitation on interbank loans. Let $\theta_i b$ denote the upper bound of liability of bank i. For any other bank $i \in M^c$, it is not bound by the limitation on interbank loans. Denote its liability as $\theta_i y_i$.

Proposition 1.5. Suppose that bank j is struck with a negative shock:

(1) If the negative shock $\epsilon \leq (a - v) \sum_{k=1}^{n} \frac{\theta_k}{\theta_j}$, then bank j will not default.

(2) If the negative shock $\epsilon > (a - v) \sum_{k=1}^{n} \frac{\theta_k}{\theta_j}$, then bank j defaults on the senior creditors without limitation b, but does not necessarily default on the senior creditors when limitation b is applied.

In the case of heterogeneity, the restriction on interbank loans will allow banks to maintain more liquid assets, improve their ability to repay senior creditors, and possibly increase the stability of the financial network. This is consistent with previous scenarios, in which all the banks are of a homogeneous size in sub-sections 1.3.2-1.3.5.

Contrary to the study by Banerjee and Mio (2018), I observe in the proposition that the liquidity requirements will assist the network in improving its ability to repay outside loans. The difference between my study and theirs is that I further prove that liquidity regulations help to prevent financial contagion from spreading in the interbank network, even in the case of a financial crisis.

Based on the finding of Dietrich et al. (2014) that a large number of banks did not obey the Liquidity Requirements of Basel III in the past, this chapter demonstrates the potential benefits and costs for banks adopting the Basel III liquidity requirements. Even though the *World Economic Situation and Prospects (2018)* states that 2017 witnessed 3% growth in global GDP, possible changes in regional policies and possible natural disasters still pose potential risks to global economics. Thus, it implies that obeying the liquidity requirements of Basel III will help to stabilize financial markets under these potential threats.

1.4 Conclusion

Basel III introduced Liquidity requirements -the LCR and NSFR- to guarantee adequate banks' short-term funds when macroeconomic shocks are sufficiently large. In this paper, I analyze the effects of liquidity requirements on the stability of interbank systems with different structures. This is valuable as many banks did not meet the liquidity requirements in the past and financial network structures differ around the world. In both healthy financial conditions and during financial crises, liquidity requirements are useful for maintaining the health of the financial system and protecting the banking system from failure. I show that the liquidity requirements, at least weakly, improve the stability of the financial system and decrease the extent of financial contagion.

My results are consistent with the statement by Caprio and Klingebiel (1996) that the regulatory framework is more important for banking system health. My results are also consistent with the findings of Banerjee and Mio (2018) that liquidity requirements help prevent contagion in an interconnected banking system. Yet, I further show that liquidity requirements help in the repayment of outside debts. Even though Müller (2006) argues that short-term lending in the banking system may result in contagion, I show that this could be managed by setting appropriate liquidity requirements.

The effects of the policy depend on whether the liquidity requirements are tight enough to counteract the adverse effects of negative shocks to financial markets. In general, in contrast to the "robust-yet-fragile" theory of the complete network of Haldane (2013), I found that the liquidity policy limits the adverse effects of a large negative shock on densely interconnected networks. Especially during financial crises, tighter liquidity requirements prevent interbank systems from failing.

The effects of the liquidity requirements also depend on the structure of the interbank network. A densely interconnected network, in a poorly behaving market, will no longer be extremely fragile if banks meet stricter liquidity requirements. Rather, the liquidity requirements serve as cushions for banks to stockpile adequate short-term funds to repay debts during financial difficulties. As for poorly interconnected networks, they will become weakly more stable if they apply the appropriate liquidity requirements.

The main challenge for the Basel Committee is to set appropriate liquidity requirements for banks with different functions in the interbank network. Drehmann and Tarashev (2013) show empirically that in the real world, central banks in Western countries play a more important role than other banks in interbank networks. Thus, the heterogeneity of banks should be carefully analyzed when setting liquidity regulations.

Another concern is that liquidity adequacy must be ensured to allow regular financial services and products to function. Extremely tight liquidity requirements impede normal financial services for financial institutions due to a shortage of available short-term funds. As Dietrich et al. (2014) argue, the financial institutions' major function of performing maturity transformation will be limited by extremely tight liquidity requirements. As reported in *World Economic Situation and Prospects 2018*,[11] the global economy has been growing in recent years since the financial crisis of 2007-2008. Impeding the normal functions of financial institutions can potentially reduce the speed of economic growth.

As can be seen in the results, the effects of the liquidity requirements depend on the size of the macroeconomic-level shocks. Further research could combine the estimation of these shocks, such as natural disasters and new international policies, in the model. One possible way is to identify the optimal loan limitations for interbank networks on the basis of the expected shock. Amiti and Weinstein (2018) introduce a methodology to estimate investment shocks by classifying investment shocks into four categories. The aggregate shocks could then be estimated with a linear combination of those categories.

In addition, since I consider the theoretical effect of the liquidity requirements of Basel III on k-regular networks, further study could analyze the effects of these requirements on actual networks in different areas of the world.

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[11] https://www.un.org/development/desa/dpad/publication/world-economic-situation-andprospects- 2018/

1.5 Appendix A

From sections 1.3.2 from 1.3.5, I assume that the interbank liability of each bank is homogenous. Assume that liquidity binds for all banks, then

$$\sum_{i \neq j} y_{ij} = \sum_{i \neq j} y_j = b = \overline{y},$$

where y_{ij} is the debt of j to i.

1.5.1 Notations and Lemmas

The setup of the model is following Acemoglu et al. (2015). The situation where banks have unlimited liability to creditors is discussed in their study. I continue with the notations, Lemma B5, and Lemma B6 in Acemoglu et al. (2015). Below are the proofs of propositions when banks have limited liabilities (bound by limitation b). Let:

c_i be the bank i's cash on hand;

$v > 0$ be every bank's obligation outside the banking system;

$z_i \in \{a - \epsilon, a\}$ be the random return of bank i, where a is a fixed value and ϵ captures the negative macroeconomics shocks;

ζ be the fraction of a project's full value that can be recovered.

Assumptions for each bank i are as follows:

1. The cash on hand is normalized to 0. i.e.,

$$c_i = 0.$$

2. Bank i is able to repay debt from senior creditors if there is no shock in the macroeconomic environment. i.e.,

$$a > v.$$

3. Bank i is not able to repay debt from senior creditors if there is a shock ϵ. i.e.,

$$v < a - \epsilon.$$

4. Bank liquidation results in zero value. i.e.,

$$\zeta = 0.$$

Lemma 1.1. (Acemoglu et al. (2015) *Lemma B5*). If $\zeta = 0$, the number of banks that default in a system satisfies:

$$p \leq \#default < \frac{p\epsilon}{a - v}$$

where p is the realized number of shocks in the banking system.

Proof. Suppose that each bank's total interbank liabilities match its total interbank claims and that $v > a - \epsilon$, every bank that experiences negative shock defaults. The lower bound is therefore straightforward. Recall that z_i denotes a random return of bank i, where $z_i \in \{a - \epsilon, a\}$, To get the upper bound, note that for every bank i defaults but can satisfy all of its senior liabilities, the following holds:

$$z_i + \sum_{j \neq i} x_{ij} = v + \sum_{j \neq i} x_{ji}$$

Denoting the set of such banks by m and summing all banks $i \in m$, it follows that

$$\sum_{i \in m} z_i + \sum_{i \in m} \sum_{j \neq i} x_{ij} = vm + \sum_{i \in m} \sum_{j \neq i} x_{ji} \tag{5}$$

In contrast, for any bank i that defaults on its senior liabilities (assuming such a bank exists), we have the following:

$$z_i + \sum_{j \neq i} x_{ij} < v$$

The sum of all such banks, q, indicates that

$$\sum_{i \in q} z_i + \sum_{i \in q} \sum_{j \neq i} x_{ij} < vq \tag{6}$$

Therefore, the total number of default

$$\#defaults = m + q,$$

and among these defaults banks, p banks are hit with shocks and get random return $z_i = a - \epsilon$, while other $m + q - p$ banks get random return $z_i = a$. Denoting d as the set of banks that do not default and combining equations (5) and (6) yields

$$\sum_{i \in m} \sum_{j \neq i} x_{ij} + \sum_{i \in q} \sum_{j \neq i} x_{ij} - \sum_{i \in m} \sum_{j \neq i} x_{ji} < v(m+q) - p(a-\epsilon) - (m+q-p)a.$$

Note that the first term on the left-hand side is the repayments collected by bank i that defaults on their junior creditors, where the repayments can only be collected from a non-default bank set d. The second term is the repayments collected by bank i that defaults on their senior creditors, where the repayments can be collected from non-default banks $i \in m \cup d$. And the third term is the repayments from banks that default on their junior creditors to banks $i \in n \cup d$. Therefore, it can be simplified as:

$$\sum_{i \notin d} \sum_{j \in d} x_{ij} - \sum_{i \notin d} \sum_{j \in d} x_{ji} < p\epsilon - (a - v)\#defaults.$$

The left-hand side is the repayments of banks that do not default to the defaulting banks, whereas the second term is the repayment collected by banks that do not default; hence, the left-hand side is non-negative and the right-hand side of the above equivalence is strictly positive. Hence, the left-hand side is strictly positive and the number of defaults is strictly less than $\frac{p\epsilon}{a-v}$. □

Lemma 1.2. (Acemoglu et al. (2015) *Lemma B6*) Let ϵ_p^* be the critical value of the shock, then:

(i) If $\epsilon < \epsilon_p^*$, then at least one bank in the banking system does not default.

(ii) If $\epsilon > \epsilon_p^*$, then at least one bank defaults on its senior creditor outside the banking system.

Proof. Part 1. Assume that $\epsilon < \epsilon_p^*$ and that every bank defaults. Hence,

$$z_i + \sum_{j \neq i} x_{ij} \leq v + \sum_{j \neq i} x_{ji}$$

for every bank, and

$$\sum_{i \in n} z_i + \sum_{i \in n} \sum_{j \neq i} x_{ij} \leq \sum_{i \in n} v + \sum_{i \in n} \sum_{j \neq i} x_{ji}$$

$$\Longrightarrow na - p\epsilon \leq nv.$$

This leads to a contradiction to $\epsilon < \epsilon_p^*$.

Part 2. Assume that $\epsilon > \epsilon_p^*$ and no bank defaults on its senior creditor, then for any bank i

$$z_i + \sum_{j \neq i} x_{ij} \geq v + \sum_{j \neq i} x_{ji}$$

and

$$\sum_{i \in n} z_i + \sum_{i \in n} \sum_{j \neq i} x_{ij} \geq \sum_{i \in n} v + \sum_{i \in n} \sum_{j \neq i} x_{ji}$$

$$\Longrightarrow na - p\epsilon \geq nv.$$

Again, it contradicts the assumption that $\epsilon \geq \epsilon_p^*$.

$\square$

1.5.2 Proof of Proposition 1.1

Proof. Recall that the repayment from j to i is

$$x_{ij} = \frac{y_{ij}}{b} \min\{b, h_j - v\},$$

if banks are bounded by liquidity requirements, and the cash inflow of bank j is

$$h_j = z_j + \sum_{j \neq s} x_{js}.$$

Following I consider implying a liquidity requirement b which binds for all banks:[12]

$$b < (n-1)(a-v).$$

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[12] If b does not bind for banks, then the results are the same as Acemoglu et al. (2015)'s discussions and Case 1.

Case 1:

In the ring network, the repayment is solely from bank i to bank $i+1$, i.e.

$$\sum_{s \neq i+1} x_{i+1,s} = x_{i+1,i}.$$

And bank $i+1$ is the sole junitor creditor of bank i, i.e.,

$$y_{i+1,i} = y_i = b, \quad \forall i.$$

Thus, the repayment from bank i to bank $i+1$ satisfies following equations:

$$\begin{cases} x_{i+1,i} = \min\{b, h_i - v\} \\ \qquad h_i = z_i + x_{i,i-1} \end{cases}$$

$$\Longrightarrow x_{i+1,i} = \min\{b, x_{i,i-1} + z_i - v\}.$$

Without loss of generality, assume that bank 1 suffers with a single negative shock ϵ. According to Lemma 1.2, bank n will not default, i.e.,

$$x_{1n} = b$$

For bank 1, as it suffers from a negative shock ϵ, its short-run return satisfies

$$z_1 = a - \epsilon.$$

For bank 2 to n, their short-run returns satisfy

$$x_{1n} = b.$$

Case 1.1 Ring Network Applying Limitation b

Conditional on realizing one negative shock ϵ on bank 1. When imposing a relatively loose requirement $b \geq f(\epsilon) = v - a + \epsilon$ such that,

$$\begin{cases} b + a - \epsilon \geq v \\ (n-1)(a-v) \geq b \end{cases}$$

then all banks can meet senior liabilities in full. Thus, the repayment from bank τ to its junior creditor $\tau + 1$ is

$$x_{\tau+1,\tau} = b + \tau(a - v) - \epsilon.$$

Assume that the last default bank is bank τ, then

$$a + x_{i+1,i} \geq b + v, \forall i \geq \tau.$$

$$\Longrightarrow \tau \geq \frac{\epsilon}{a-v} - 1,$$

where τ is the upper bound in Lemma 1.1. Compared to other networks, the ring network has the smallest maximal and the smallest expected number of defaults.

Case 1.2 Complete Network Applying Limitation b

Conditional on realizing a small shock $\epsilon < \epsilon^*$, according to Lemma 1.2, there exists at least one bank that will not default. And other $n-1$ banks will not default because the repayments in the complete network are symmetric. Thus, no matter what value the limitation *b*, there will be only one bank that defaults in the complete network. Thus, the maximal and expected numbers of defaults reach the lower bound.

Case 2.

Case 2.1 Complete Network Applying Limitation b

Conditional on realizing a small shock $\epsilon < \epsilon^*$, according to Lemma 1.2, there exists at least one bank that will not default. And other $n-1$ banks will not default because the repayments in the complete network are symmetric. Thus, no matter what value the limitation b, there will be only one bank that defaults in the complete network. Thus, the maximal and expected numbers of defaults reach the lower bound.

Case 2.2.1 Ring Network Applying Limitation b

If applying a relatively strict liquidity limitation b, s.t. b such that b satisfies the following conditions

$$\begin{cases} b < f(\epsilon) = v - a + \epsilon \\ (n-1)(a-v) \geq b, \end{cases}$$

so bank 1 can meet senior liabilities in full. The repayments among banks satisfy:

$$\begin{cases} x_{2,1} = 0 \\ x_{3,2} = \min\{b, a - v - 0\} \\ x_{4,3} = \min\{b, a - v - x_{3,2}\} \\ \dots \\ x_{\tau+1,\tau} = \min\{b, a - v - x_{\tau,\tau-1}\} \\ \dots \\ x_{1,n} = \min\{b, a - v - x_{n,n-1}\}. \end{cases}$$

Assume the last default bank is bank τ,

a. If liquidation requirement b is extremely strict, s.t. $b \leq a - v$, then the repayments satisfy:

$$\Longrightarrow \begin{cases} x_{2,1} = 0 \\ x_{3,2} == b \\ x_{4,3} = \min\{b, a - v - b\} = a - v + b \\ \dots \\ a + x_{i+1,i} \geq b + v, \forall i \geq \tau \end{cases}$$

$$\Longrightarrow \tau \geq 1.$$

There is at least one bank that defaults in the ring network.

b. If liquidation requirement b satisfies $b > a - v$, then the repayments satisfy:

$$\implies \begin{cases} x_{2,1} = 0 \\ x_{3,2} = a - v + b \\ \ldots \\ a + x_{i+1,i} \geq b + v, \forall i \geq \tau \end{cases}$$

$$\implies \tau \geq 0.$$

Knowing that bank 1 will surely default on its senior creditor, there is, again, at least one bank that defaults in the ring network. By imposing liquidity requirement b, the maximal and expected numbers of defaults of the ring network will, therefore, weakly decreases.

Case 2.2.2 $\gamma - convex$ Network Applying Limitation b

The repayments of a $\gamma - conver$ network of a complete network and a ring network satisfy

$$\tilde{x_{js}} = \gamma x_{js} + (1-\gamma)\hat{x_{js}},$$

where x_{js} and $\hat{x_{js}}$ are repayments from s to j in ring network and complete network, respectively. Repayments x_{js} and $\hat{x_{js}}$ are non-decreasing functions of b as shown above. Therefore, in the $\gamma - convex$ network, repayment $\tilde{x_{js}}$ is also a non-decreasing function of b, and the last defaulting bank $\tilde{\tau}$ is non-decreasing in b. The maximal number and expected value of defaults are non-decreasing in b. □

1.5.3 Proof of Proposition 1.2

Proof. Note that a large shock is defined as

$$\epsilon > \epsilon^* = n(a - v).$$

Consider for situation that $b < (n-1)(a-v)$ such that limitation b binds for all banks,

***i.** Ring Network Applying Limitation b*

Without loss of generality, assuming that bank 1 is hit with shock ϵ. According to Lemma 1.2, bank 1 defaults on its senior creditor, and the repayment from bank 1 to bank 2 is $x_{21} = 0$.

a. If $b \geq f(\epsilon) = v - a + \epsilon$:

Combined with the definition of large shock $\epsilon > \epsilon^* = n(a-v)$, the limitation b thereby satisfies

$$\Longrightarrow b \geq v - a + \epsilon > (n-2)(a-v).$$

And the repayment from bank τ to bank $\tau+1$ is

$$x_{\tau+1,\tau} = b + \tau(a-v) - \epsilon, \forall \tau > 1.$$

Assume the bank τ is the last bank that defaults, then

$$\begin{aligned} a + x_{\tau+1,\tau} &\geq b + v \\ \Longrightarrow \tau \geq \frac{\epsilon}{a-v} - 1 &> n-2 \\ \Longrightarrow \tau &\geq n-1. \end{aligned}$$

In this case, only bank n will not default, and the default number reaches the upper bound in Lemma 1.1.

b. If $b < v - a + \epsilon$:

$$\Longrightarrow x_{21} = 0$$

b.i. If $b < a - v$, the repayments are

$$\begin{aligned} x_{32} &= b \\ x_{\tau+1,\tau} = (\tau-2)(a-v) &+ b, \forall \tau \geq 3. \end{aligned}$$

According to Lemma 1.2, at least one bank does not default. Again assume that bank τ is the last bank that defaults. The cash flow of bank τ satisfies

$$\begin{aligned} & a + x_{\tau+1,\tau} + v \\ & \implies \tau \geq 1. \end{aligned}$$

b.ii. If $b \geq a - v$, the repayments are

$$x_{\tau+1,\tau} = (\tau - 1)(a - v) + b, \forall \tau \geq 2.$$

According to Lemma 1.2, at least one bank does not default. Again assume that bank τ is the last bank that defaults. The cash flow of bank τ satisfies

$$\begin{aligned} & a + x_{\tau+1,\tau} + v \\ & \implies \tau \geq 0. \end{aligned}$$

Bank 1, by Lemma 1.2, will default for certain. Therefore, the value of τ is updated to $\tau \geq 1$. Considering situation **b.i** and **b.ii**, when applying strict limitation b, The maximal and expected value of the number of defaults of the ring network will not necessarily reach the upper bound of the defaults.

ii $\delta - connected$ *Network Applying Limitation* b

Remind the definition of a $\delta - connected$ Network, if there exists a collection of banks $S \subset N$ such that $\max\{y_{ij}, y_{ji}\} \leq \delta y, \forall i, j \in S$.

When $b < (n-1)(a-v)$, assume that any bank in the collection of banks S is bounded by b, i.e.,

$$\max\{y_{ij}, y_{ji}\} \leq \delta b, \forall i, j \in S$$

a. If $b \geq v - a + \epsilon$, the ring network reaches the upper bound of the maximal and expected number of defaults. Therefore, any $\delta - connected$ network has less or the same maximal and expected number of defaults as the ring network.

b. If $b < v - a + \epsilon$, bank $\tau(\tau \geq 1)$ is the last defaulting bank in the ring network. The maximal and expected number of defaulting banks in the $\delta - connected$ network can not be compared to the ring network.

***iii** Complete Network Applying Limitation* b

Assume that bank 1 suffers from a large shock ϵ, at least one bank defaults in the complete network as the result of Lemma 1.2. For the rest $n-1$ banks, their cash flows satisfy

$$\begin{aligned} b &< (n-1)(a-\epsilon) \\ \Longrightarrow b &< (n-2)\frac{b}{n-1} + (a-v). \end{aligned}$$

Therefore, their cash flows can meet all their senior and junior liabilities and these $n-1$ banks will not default. The expected and maximal default number in the complete network are both 1, which is at the lower bound of the defaults.

***iv** $(D, j, \mathcal{P})$-majorization Network Applying Limitation* b

As $\epsilon > \epsilon^* = n(a-v)$, we have $\epsilon-(a-v) > (n-1)(a-v)$. For $b < (n-1)(a-v) < f(\epsilon) = v-a+\epsilon$, the following equation represents the interbank borrowing and lending:

$$(\mathcal{I} - \tilde{\mathcal{Q}_{dd}})^{-1}[(a-v)\vec{1} - b\tilde{\mathcal{Q}_{dj}}] = (1-\gamma)(\mathcal{I} - \mathcal{Q}_{dd})^{-1}[(a-v)\vec{1} - b\mathcal{Q}_{dd}] + \gamma(a-v-\tfrac{b}{n-1})(1-\mathcal{Q}_{dd})^{-1}\vec{1},$$

where $\mathcal{Q}$ is the matrix in which i, j element is equal to the fraction of bank i's liability to j

$$\mathcal{Q} = (q_{ij})_{n\times n} = (\frac{y_{ij}}{\min\{y_j, b\}})_{n\times n}, \tag{7}$$

d is the set of banks that default but can still pay their liabilities to senior creditors, and $\mathcal{Q}_{dd}$ is the corresponding matrix of set D. As $(\mathcal{I} - \mathcal{Q}_{dd})^{-1}$ is an inverse matrix, it is non-negative, and $(a-v)\vec{1} - b\tilde{\mathcal{Q}_{dj}}$ and $(a-v)\vec{1} - b\mathcal{Q}_{dd}$ are non-negative because $b < (n-1)(a-v)$. Therefore equation (7) ≥ 0.

This result shows that all the banks in set D can meet both their senior and junior liabilities. Thus, not all the banks in set D default. Compared to the situation where there is no limitation b(Acemoglu et al.(2015a)), the maximal and expected numbers of default in $(D, j, \mathcal{P})$-majorization Network decrease.

□

1.5.4 Proof of Proposition 1.3

Proof. Assume that p shocks hit the network, the corresponding normalized single critical value is

$$\epsilon_p^* = \frac{n(a-v)}{p},$$

And let $f(\epsilon, p) = \min\{(v-a+\epsilon)(p-1), (n-1)(a-v)/p\}$.

Case 1. When $\epsilon < \epsilon_p^*$:

Complete Network: As an extension of Lemma 1.2 in which at least one bank does not default in a single shock situation. The case now is that when p shocks hit, as the complete network is completely symmetric, there will be $n-p$ banks that does not default.

Ring Network: Assume that bank $i+1$ to bank $i+p$ in the ring network are hit with shocks. Therefore, the ring-network default chain has a length and $\tau \geq p$. The last bank that defaults is $i+\tau$. According to Lemma 1.2, there will be at least one bank that does not default and this bank is bank i because the distance between bank i and the last defaulting bank $i+\tau$ is the farthest among all the banks.

a. If $b < f(\epsilon, p) \leq (p-1)(v-a+\epsilon)$, the repayments from bank i to bank $i+1$ satisfy

$$\begin{cases} x_{21} = b \\ x_{32} = a - \epsilon - v + b \\ x_{i+1,i} = b + (p-1)(a-v) - (p-1)\epsilon, \forall i \geq 3. \end{cases}$$

Bank $i+\tau$ denotes the last bank that defaults, and it satisfies

$$\begin{cases} x_{i+\tau+1,i+\tau} = b + (\tau-1)(a-v) - p\epsilon. \\ a - v + x_{i+\tau+1,i+\tau} \geq b. \end{cases}$$

Combing the above inequalities with small shock definition and the number of shocks restriction:

$$\begin{cases} \tau \geq \dfrac{(p-1)\epsilon}{a-v} = \dfrac{p\epsilon}{a-v} - \dfrac{\epsilon}{a-v} \\ \epsilon < \epsilon_p^* = \dfrac{n(a-v)}{p} \\ p < n \end{cases}$$

$$\Longrightarrow \tau \geq \frac{p\epsilon}{a-v} - 1.$$

The number of defaults will not necessarily reach the upper bound, and the maximal and expected numbers of defaulting could decrease.

b. If $b \geq (p-1)(v-a+\epsilon)$, all banks meet their senior liablity v. So the repayment from bank i to bank $i+1$ satisfies

$$x_{i+1,i} = b + (p-1)(a-v) - (p-1)\epsilon, \forall i.$$

The last defaulting bank $i+\tau$ satisfies

$$\begin{cases} x_{i+\tau+1,i+\tau} = b + \tau(a-v) - p\epsilon. \\ a - v + x_{i+\tau+1,i+\tau} \geq 0, \end{cases}$$

where the second inequality specifies $i+\tau$'s cash flow.

$$\Longrightarrow \tau \geq \frac{p\epsilon}{a-v} - 1.$$

In this case, the number of defaults in the network τ reaches the upper bound as stated in Lemma 1.1. So the ring network has the largest maximal and expected values of defaults.

Case 2. When $\epsilon > \epsilon_p^*$, as $\epsilon > \epsilon_p^* = n(a-v)/p$:

Complete Network: According to Lemma 1.2, at least p banks default on senior creditors. Consider when $b < f(\epsilon, p) \leq (n-1)(a-v)/p$: for other $n-p$ banks, the cash flow of each bank satisfies

$$b \leq (n-p-1)\frac{b}{n-1} + a - v,$$

which indicates that these $n-p$ banks are able to repay their junior creditors their cash on hold and that they will not default. Hence, the maximal and expected number of defaults are at the lower bound in Lemma 1.

Otherwise, when $b \geq (n-1)(a-v)/p$, for any remaining $n-p$ banks, the above equation in part a does not hold. The number of defaults will reach the upper bound defined in Lemma 1.1.

Ring Network: Consider that the shocks hit the ring network from bank 1 to bank p and defaults happen from bank 1 to p. The upper bound of the number of default $\overline{\tau}$ is

$$\overline{\tau} = \frac{p\epsilon}{n}(\geq n).$$

Assume τ is the last bank that defaults.
When a relatively strict limitation $b < f(\epsilon, p) \leq (n-1)(a-v)/p$ applies, then the cash flow of bank τ follows

$$\begin{aligned}(\tau+1)(a-v) &< b \\ \Longrightarrow \tau &< \frac{n-1}{p}.\end{aligned}$$

The length of the default chain will surely decrease. So as the maximal and expected numbers of defaults. When a relatively loose limitation $b \geq (n-1)(a-v)/p$, then the cash flow of bank τ follows

$$\begin{aligned}(\tau+1)(a-v) &\geq b \\ \Longrightarrow \tau &\geq \frac{n-1}{p}\end{aligned}$$

The length of the default chain τ will not necessarily reach the upper bound. So a loose requirement b will possibly decrease the maximal and expected numbers of defaults in the ring network.

□

1.5.5 Proof of Proposition 1.4

Proof. Propositions 1.1-1.3 apply to the situation that bank liquidations have the same value of zero, namely, $\zeta = 0$. Here, the assumption is relaxed to $\zeta > 0$, in which banks' liquidations have values greater than zero.

Let $\epsilon_*(\zeta)$ and $\epsilon^*(\zeta)$ denote the critical values of the single small and large shocks, respectively.

Case 1. A small shock $\epsilon < \epsilon_*(\zeta)$ hits the banking system.

Complete Network: According to Lemma 1.2, there is at least one bank that does not default. As the banking system is symmetric in the complete network, the other $n-1$ banks will not default. As a result, the maximal and expected numbers of defaults reach the lower bound of defaults in Lemma 1.1.

Ring Network: If a limitation $b \geq (n-1)(a-v) + \zeta A$, then any banks is not bound by requirement b. Thus, the result of the maximal and expected numbers of defaults will be the same as the unlimited liability situation. Below I discuss when banks are bound by requirement b, namely,

$$b < (n-1)(a-v) + \zeta A.$$

a. If $b < f(\epsilon, \zeta) = v - a + \epsilon - \zeta A$, and

a.i. if the shock $\epsilon \geq 2(a-v) + \zeta A$, then the repayments satisfy

$$\begin{cases} x_{21} = 0 \\ x_{32} = b + \zeta A \\ x_{43} = a - v + b + \zeta A \\ \dots \\ x_{i+1,i} = (i-2)(a-v) + b + \zeta A, \forall i \geq 3 \end{cases}$$

Assume that τ is the last bank that defaults, its cash flow thereby satisfies

$$a + x_{\tau+1,\tau} \geq b + v.$$

$$\Longrightarrow \tau \geq \frac{\zeta A}{a-v} + 1.$$

a.ii. if the shock $\epsilon < 2(a-v) + \zeta A$, then the repayments satisfy

$$\begin{cases} x_{21} = 0 \\ x_{32} = (a-v) + \zeta A \\ \cdots \\ x_{i+1,i} = (i-1)(a-v) + b + \zeta A, \forall i \geq 3 \end{cases}$$

Assume that τ is the last bank that defaults, its cash flow thereby satisfies

$$a + x_{\tau+1,\tau} \geq b + v.$$

$$\Longrightarrow \tau \geq \frac{\zeta A}{a-v}.$$

Cases (a.i) and (a.ii) imply that a strict requirement b will possibly help to decrease the length of defaults in the ring network when the negative shock is quite small. In a large-shock case, it might not decrease the maximal or the expected number of defaults.

b. If $b \geq f(\epsilon, \zeta) = v - a + \epsilon - \zeta A$,

adding the restriction that $b < (n-1)(a-v) + \zeta A$, all banks can meet both their junior and senior liabilities. No bank defaults. As a result, the maximal and expected numbers of defaults reach the lower bound of defaults.

Case 2. When a large shock $\epsilon > \epsilon^*(\zeta)$ hits the network:

Complete Network: As $b < f(\epsilon, \zeta)$, $b \leq \frac{n-2}{n-1}b + (a-v) + \zeta A$. All banks can meet both their senior and junior liabilities. No bank defaults and the maximal and expected numbers of defaults are at the lower bound defined in Lemma 1.1.

$\delta - connected$ *Network:* Similar to the analysis of Proposition 1.2:

a. When $b \geq f(\epsilon, \zeta) = v - a + \epsilon - \zeta A$, the $\delta - connected$ network has smaller maximal and expected numbers of defaults than the ring network. And the ring network reaches the lower bound of defaults.

b. When $b < v - a + \epsilon - \zeta A$, the $\delta - connected$ network does not necessarily have smaller maximal nor expected numbers of defaults than the ring network because the maximal and expected numbers of defaults in the ring network have been decreased by implying the limitation b on cash flow.

Case 3. When $\epsilon_*(\zeta) \le \epsilon \le \epsilon^*(\zeta)$ and $b < f(\epsilon, \zeta)$:

Complete Network: Same as the discussion in *Case 2* that all banks can meet both senior and junior liabilities and no bank defaults.

Ring Network: Assume that bank τ is the last bank that defaults. For all other banks to repay creditors, their aggregate liquidation is

$$\begin{aligned}\sum_1^n l_i = \tau\zeta A + [\epsilon - \tau(a - \epsilon) + \zeta A]^{-1} \\ \Longrightarrow \tau \le 1.\end{aligned}$$

Hence, the ring network will not necessarily reach the upper bound of defaults.

$\delta - connected$ Network: the $\delta - connected$ network will not surely have smaller maximal nor expected numbers of defaults than the ring network. As seen in *Case 3.2*, limitation b helps to decrease the defaults in the ring network. ☐

1.5.6 Proof of Proposition 1.5

Proof. Suppose that bank j is hit with a negative shock ϵ. If j is not bound by liquidity requirement b, then the results will be the same as the unlimited liability case (Acemoglu et al. (2015) *Proposition 12*) that bank j will default on its senior creditor. Consider that j is bound by b below:

Part 1. And if the shock is small that $\epsilon \le (a - v)\sum_{k=1}^n \frac{\theta_k}{\theta_j}$, the cash flow of bank j satisfies

$$c_j + z_j + \sum_k x_{jk} \ge \theta_j v + \sum_{k \ne j} x_{kj},$$

where LHS stands for the cash inflow of bank j and RHS stands for j's cash outflow. In addition,

$$\begin{cases} z_j = \theta_j(a-\epsilon) \quad (j\text{'s short-run return}) \\ c_j = 0 \quad (j\text{'s cash on hold}) \\ \sum_{k\neq j} x_{jk} = b \quad (j\text{'s short-run return}). \end{cases}$$

Bank j in this situation has enough liquid assets to repay all of its liabilities and it will not default.

Part 2. If the shock is large that $\epsilon > (a-v)\sum_{k=1}^{n}\frac{\theta_k}{\theta_j}$, the cash flow of bank j satisfies

$$c_j + z_j + \sum_k x_{jk} < \theta_j v + \sum_{k\neq j} x_{kj},$$

bank j does not have enough to repay its junior creditor.

Additionally, if

$$\epsilon > (a-v)\sum_{i=1}^{n}\frac{\theta_k}{\theta_j} + \frac{b\sum_{i\in M}\theta_i + \overline{y}\sum_{i\notin M}\theta_i}{\theta_j},$$

where M is the set of the banks which are bound by limitation b. Assume that bank j is hit with negative shock ϵ and

$$\begin{cases} z_j = \theta_j(a-\epsilon) \quad (j\text{'s short-run return}) \\ \sum_{k\neq j} x_{jk} = \sum_{i\in M}\theta_i b + \sum_{i\notin M}\theta_i \overline{y} \quad (\text{repayments } j \text{ collects}) \\ \epsilon > (a-v)\sum_{i=1}^{n}\frac{\theta_k}{\theta_j} + \frac{b\sum_{i\in M}\theta_i + \overline{y}\sum_{i\notin M}\theta_i}{\theta_j} \quad (\text{large shock}). \end{cases}$$

$$\Longrightarrow \sum_{k\neq j} x_{jk} + z_j < \theta_i v.$$

This means that j's cash inflow is not sufficient for it to repay its senior liabilities. As a result, bank j will default on its senior creditors. □

Chapter 2

An Empirical Analysis of The CEO Labor Market

2.1 Introduction

CEO compensation increased by 1,322% from 1978 to 2020 (Mishel and Kandra, 2021),[1] and CEO compensation and appointment trends have also changed over the previous few decades. During the 1970s and 1990s, the external CEO appointment rate for SP 500 companies climbed from 14.9% to 26.5% (Murphy and Zabojnik, 2004, 2007; Frydman, 2019). Over the past two decades, the CEO's basic salary and bonuses and the rate of hiring candidates from outside the company have moved in opposite directions. Between 2000 and 2020, the average CEO compensation of North American public trading companies in the COMPUSTAT EXECUCOMP database decreased by 20%, from \$1.3 million to less than \$1.1 million. The drop in CEO base salary and the bonus is consistent with the reform of CEO compensation structures. Edmans et al. (2017) illustrate that CEOs' base salaries have been a substantially smaller portion of their total compensation over time, falling from 42% of total compensation in 1992 to 13% in 2014. In the period from 2001 to 2020, During the 2000s and 2010s, the proportion of outsider appointees fell to around 21%. In the meantime, Cziraki and Jenter (2022) discovered that the majority of newly hired CEOs were previous employees or had close relationships with the hiring company. Large companies are less likely to recruit external CEO successors.

Previous studies have shown a great interest in firm and CEO characteristics that would impact CEO compensation. Baker et al. (1988) and others demonstrate that the size of the company has a

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[1] The rise in CEO compensation is adjusted for inflation in the work by Mishel and Kandra (2021).

major influence in determining the CEOs' compensation. CEOs are assigned extra tasks to execute strategies such as downsizing for companies with severe performance declines (Hofer, 1980). In addition to corporate characteristics, existing studies suggest that CEO characteristics such as talent (Falato et al., 2011; Adams et al., 2018) and influence within the firm (Bebchuk et al., 2002) may also affect firm performance and CEO compensation. Initial compensation can better explain the labor market by distinguishing a CEO's rent-extraction behavior since new CEOs have minimal entrenchment power (Bebchuk et al., 2002; Devers et al., 2007). Some research (e.g., Chen (2015) and Chang et al. (2016)) reveal a relationship between the initial compensation of a company's new CEO and its risk and performance improvement.

Yet, the CEO-firm matchings in the CEO labor market have been studied considerably less.[2] As a result, it is ambiguous how effective CEO hiring is or which model can adequately explain it. In the presence of asymmetric learning about internal and external candidates, some research suggests that companies are more likely to select successors who have prior knowledge of the company (Becker, 1962; Jovanovic, 1979). Some researchers like Gabaix and Landier (2008), Edmans et al. (2009), and Gabaix et al. (2014) find that the CEO labor market is in line with perfectly competitive models in which CEO abilities are not only visible but also fully applicable once the CEO transfers to a different company. These models could further explain the rapid increase in CEO compensation since the 1970s if the firm size is expanding and CEO talent matches this expansion. If the market supply is sufficiently large, companies will be able to select the ideal candidate for their managerial skill needs (Murphy and Zabojnik, 2004, 2007; Frydman, 2019). Once CEOs and businesses are optimally matched, CEO pay would ascend significantly. Empirically, the accumulation of general transferrable abilities also explains the increase in CEO compensation (Custódio et al., 2013), and generalists with a broader skill set are more likely to be hired in companies unrelated to acquisition (Chen et al., 2021).

This paper specifically provides empirical studies for the following three questions: first, how would the general ability of successors influence the firm's hiring decision? Second, what characteristics influence the impact of general ability on hiring? and third, what could be the causes of

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[2] Theoretical studies include Murphy and Zabojnik (2007); Pan (2017); Frydman (2019).Murphy and Zabojnik (2007) and Frydman (2019) explain that external and internal appointing corresponds to maximizing company profits; Pan (2017) matches CEOs and firms based on multidimensional criteria.

firms' preferences? To understand how CEO and firm characteristics influence companies' hiring decisions, I adopt Frydman and Jenter (2010) and Murphy and Zabojnik (2007) CEO labor market structures, focusing primarily on hiring decisions for successors. I use a pooled data set that has information about the work experience of 3,300 new CEOs of public trading firms in North America from 2001 to 2020. According to Gabaix and Landier (2008), companies' need for CEO managerial skills is a critical element in CEO-company matching. Following Custódio et al. (2013), I construct an index with multiple aspects of CEOs' prior work experience as a measure of their general ability. The index is a weighted combination of the first two components of the principal components analysis of five proxies for a CEO's prior experience, including the previous number of companies, the previous number of industries, the previous number of positions, whether he or she has previously served as CEO, and whether he or she has worked for a multi-segment company. More importantly, employers are able to observe these five factors directly from candidates' resumes, allowing for a direct explanation of the relationship between general skills and firms' hiring decisions. Using the nonlinear Probit model and instrumental variables, I evaluate how hiring decisions related to general skills and the influence of other CEO attributes on the significance of general skills in recruiting decisions.

The empirical investigations demonstrate three basic findings. First, despite the fact that both the Probit and instrumental estimates imply that the increase in general ability positively and significantly increases the CEO's probability of being hired externally, I find that the Probit method underestimates the impact of general skills in hiring decisions by 50–60%. In addition, the influence of general ability varies among successors with different characteristics: holders of certifications that indicate their background in specific fields, such as Charted Financial Analyst (CFA) and Chartered Professional Accountant (CPA), and females without certificates, relative to males without certificates, have a greater likelihood of being externally recruited from the CEO market if they have higher general skills. Second, even though general skills raise the probability of getting hired externally, this increase diminishes as firm size increases: larger firms are more likely to promote internal candidates. Intuitively, companies will only hire externally if the expected profit is greater than that of hiring internal candidates. Under labor market theories such as Murphy and Zabojnik

(2007), CEOs with a broader set of general managerial skills are matched with larger firms and compensated highly. The findings suggest that internal promotion may, in fact, lead to greater revenues for companies, especially those with larger sizes. In particular, among external successors, external insiders who previously held a management position in the recruiting firms are compensated significantly lower than external outsiders, even if they are hired by larger firms and have acquired greater general skills. Such findings suggest that the relative significance of general skills may decline for complex and large firms (Cziraki and Jenter, 2022), while a high premium associated with external hiring (Yonker, 2017) may be one of the firms' considerations. Finally, while both general ability and company size increase the total compensation of newly appointed CEOs, CEO characteristics, including general skills, have no significant influence on base salary and bonus from 2001 to 2020, in contrast to previous studies of CEO compensation prior to or in the early 2000s (e.g., Custódio et al. (2013)). In fact, CEO cash compensation after 2002 appears to have stabilized at a certain level (Frydman and Jenter, 2010), whereas performance pay is convenient and relatively low-cost, requiring little short-term cash flow (Murphy, 2002), which further explains the cost-related motivation behind firms' hiring decisions.

This paper contributes to the literature in the following aspects. First, it is complementary to the literature on strategic leadership by revealing the complementarities of the firm-CEO match and studying how CEO characteristics influence firms' hiring decisions. In the study, I address an underlying endogenous problem: a CEO is externally employed due to a broader set of working experience and general skills, or the CEO has a greater general ability because he or she is externally hired. In most cases, CEO job hopping is not observable: those in the CEO labor market pool are actively seeking employment and, as a result of their high mobility, may gain diverse work experience (Yonker, 2017). In the previous literature, it has been difficult to determine whether the general ability is a determining factor in the hiring process as exogenous differences in the CEO's general ability are not observed. Previously employed proxies, such as the MBA dummy, Ivy League dummy, and the General Ability Index, are prone to endogenous problems.[3] In this paper, I use the CEO's prior experience as an independent board member in firms other than the

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[3] For example, Murphy and Zabojnik (2007) adopt MBA dummy as a proxy for general ability, while Custódio and Metzger (2014) and Chen et al. (2021) employ General Ability Index as a proxy.

hiring firm to create instrumental variables and identify the impact of general skills on firms' hiring decisions to contribute in ways other than firms' strategic behaviors (e.g., Custódio and Metzger (2014) and Chen et al. (2021)). The findings also show that the impact of general abilities on hiring decisions differs by other CEO characteristics, such as background and gender.

This study also adds to the literature on human capital by demonstrating that over the past two decades, general skills have been less relevant than firm-specific talents, particularly for larger firms. In contrast to previous studies of Murphy and Zabojnik (2007), Frydman (2019), and Custódio et al. (2013), which investigate CEO-firm matching prior to 2007, I show that from 2001 to 2020, larger firms are less likely to hire externally, general ability is less important to larger firms, and general ability is not a determinant in new CEO cash compensation. The findings are in line with recent empirical studies such as Cziraki and Jenter (2022). Given the asymmetric learning about internal and external candidates (Waldman, 1984; Friedrich, 2016), a considerable compensation premium demanded by external successors may offset the expected potential value gained by externally employing generalists. In addition to the finding that some CEO candidates are more willing to work for less-compensated local firms (Yonker, 2017), I find that outsider successors who have little knowledge about the hiring firms receive a considerable premium for uncertainty in relocation and adaptation to new firms. Comparatively, the results suggest that external insiders who previously held management positions in the recruiting firms are paid much less than external outsiders but have a broader skill set and are also being hired by larger companies. In conclusion, the results imply that firms' hiring decisions may be influenced by the tradeoff between benefit and cost in the CEO hiring process. Given the complexity of large-scale companies, firm-specific expertise may be more valuable than broad management skills.

The rest of the chapter is organized as follows. Section 2.2 presents the data descriptions. Section 2.3 reports the analyses of CEO-firm matchings pre- and post-alleviating endogeneity problem and further discusses whether the impact of general ability on firms' hiring choices differs in other CEO characteristics. Section 2.4 concludes.

2.2 Data Description

2.2.1 Sample

The initial sample consists of a panel of 38,737 north American CEO-firm-years in the 2001-2020 period drawn from the EXECUCOMP database, in which 3,820 CEOs were newly appointed in the above firms from 2001 to 2020. Then I manually matched these newly appointed CEO profiles with the BoardEx database to obtain their previous employment histories, of which 232 CEO profiles in the initial sample are missing in the BoardEx database. Previous employment experience including the number of previous companies they worked in, the number of previous industries according to the two-digit Standard International Code (SIC), the number of previous roles, whether they previously held CEO positions, and whether they worked in a conglomerate company is collected. CEOs' previous number of industries is restricted to publicly traded firms. The profiles that miss any above characteristics are dropped. The final sample consists of 3,330 new CEO appointing cases. As suggested by Cziraki and Jenter (2022) that a large percentage of CEO successors are previous employees, the internal and external CEOs are defined as follows: whoever worked in a firm for over one and a half years consistently prior to being promoted as a CEO or had more than three years of accumulative past working experience in the company is considered internally promoted, and a CEO is considered to be externally hired otherwise. Dummy variable External takes the value of 1 if a CEO was externally hired and takes the value of 0 if a CEO was internally promoted. As such, I am able to more accurately capture firms' preferences during the hiring process. In addition, I compute General Ability Index (GAI) following Custódio et al. (2013) as a proxy to measure CEOs' general abilities as a set of previous work experience. Table 2.1

Table 2.1: 2001-2020 New CEO Appointing Trends

	2001-2010	2011-2020
Newly Appointed CEO	1,584	1,746
As % of All CEO	9.620%	9.547%
Internal Promotion %	78.914%	78.170%
External Promotion %	21.086%	21.830%
Age at CEO Appointing		
All New CEOs	52.643	54.095
Internal Promotion	52.890	54.252
External Promotion	51.890	53.306

Sample consists of 3,330 new North American publicly traded firms CEO from 2001 to 2020.

shows the summary statistics of the CEO appointing trend from 2001 to 2020, and Table 2.2 shows the summary statistics of all variables in the final sample.

The definitions of variables in Table 2.2 can be seen in Table 2.14 in the *Appendix*. As a substantial proportion of new CEOs began their employment in the middle of the fiscal year, their first-year compensation is just partial. Thus, I use the total and cash compensation for the second year as dependent variables. For those whose second-year salaries are missing, I estimated them by adjusting their first-year salaries to the average industry-year percentage change in compensation. The estimations are shown in Panel A of Table 2.2.

2.2.2 General Ability Index

To measure new CEOs' general managerial abilities, I adopt the General Ability Index proposed by Custódio et al. (2013): "The index of general managerial ability is the combination of the first component after applying principal components analysis to five CEO past-experience variables (variable (1)-(5)) including Number of Positions, Number of Firms, Number of Industries, CEO Experience, and Conglomerate Experience, in which all of above five variables can be used as proxies for a CEO's general ability." For the previous-CEO-position variable, I assign the value of 1 if he/she held a CEO position prior to a new appointment in the sample, and assign the value of 0 otherwise. For the Conglomerate-experience variable, I assign the value of 1 if a CEO worked in a multi-segment company in the past, and assign the value of 0 otherwise. Nine industries are classified according to the first two-digit of the SIC code. Industries include Construction, Finance, Insurance, and Real Estate, Manufacturing, Mining, Public Administration, Retail, Services, Wholesales, and Transportations, Communications, Electric, Gas, and Sanitary Services.

The Principal Component Analysis (PCA) of the sample in this study with these five variables has a KMO (or Kaiser-Meyer-Olkin) value of 0.622 and the Bartlett test of sphericity is significant with $p-$value at 0.000, which indicates that PCA analysis is suitable for these five variables. The Eigenvalues of the first two components are greater than 1, and the cumulative loadings of components 1 and 2 are 66.921%. Therefore, I compute General Ability Index using the first two

Table 2.2: Summary Statistics for Newly Appointed CEOs 2001-2020

Variable	Mean	Median	Standard Deviation	Minimum	Maximum	Observations
Panel A						
Cash Pay ($ thousand)	1028.000	799.600	915.700	0.000	6375.000	3330
Total Pay ($ thousand)	5529.000	3628.000	5968.000	150.000	31361.000	3330
Equity Pay ($ thousand)	2281.559	497.945	6761.059	0.000	276612.000	3330
Total Pay Yearly Change Average %	144.600	28.490	1121.000	-100.000	47190.000	2529
Total Pay Yearly Change Average %	186.200	36.620	1743.000	-99.940	53951.000	2471
Estimated Cash Pay ($ thousand)	1057.822	799.592	1135.438	0.000	27585.460	3330
Estimated Total Pay ($ thousand)	8083.883	4043.134	11697.150	181.782	70996.940	3330
Panel B						
General Ability Index	0.000	-0.126	1.000	-1.830	2.592	3330
Previous Number of Firms	6.065	5.000	3.907	1.000	21.000	3330
Previous Number of Roles	9.783	9.000	3.665	3.000	19.000	3330
Previous Number of Industries	2.430	2.000	1.419	1.000	7.000	3330
Previous CEO Dummy	0.507	1.000	0.500	0.000	1.000	3330
Conglomerate Experience Dummy	0.688	1.000	0.464	0.000	1.000	3330
Age	53.404	53.000	6.675	39.000	76.000	3330
Male Dummy	0.948	1.000	0.222	0.000	1.000	3330
External Appointing Dummy	0.221	0.000	0.415	0.000	1.000	3330
External Outsider Dummy	0.202	0.000	0.401	0.000	1.000	3330
Independent Board Year	1.539	0.000	0.255	0.000	12.668	3330
Independent Board Number	0.554	0.000	1.108	0.000	5.000	3330
Certificate Dummy	0.074	0.000	0.262	0.000	1.000	3330
Board Dummy	0.768	1.000	0.422	0.000	1.000	3330
Total Career Year	26.600	26.330	7.708	13.331	56.608	3330
Ratio $\frac{\text{Longest Serve In A Firm}}{\text{Total Career Work Year}}$	0.644	0.610	0.238	0.213	1.000	3330
Panel C						
Sales ($ millions)	6685.251	1687.000	14804.180	1.000	88915.000	3300
Sales$_{t-1}$ ($ millions)	6681.270	1680.000	14546.720	1.000	85064.000	3249
Tobin's Q	1.816	1.446	1.156	0.723	8.243	3199
Tobin's Q$_{t-1}$	1.774	1.394	1.223	0.000	8.239	3259
Leverage	0.261	0.233	0.219	0.000	0.989	3244
Leverage$_{t-1}$	0.281	0.244	0.265	0.000	1.432	3259
ROA	0.0660	0.0680	0.106	-0.474	0.365	3254
ROA$_{t-1}$	0.0670	0.0680	0.109	-0.477	0.371	3259
ROE	0.0110	0.0310	0.133	-0.687	0.293	3258
ROE$_{t-1}$	0.0100	0.0310	0.133	-0.666	0.293	3259
CAPEX	0.0400	0.0280	0.0430	0.000	0.272	3231
CAPEX$_{t-1}$	0.0430	0.0300	0.0470	0.000	0.280	3259
CASH	0.152	0.0920	0.166	0.000	0.799	3260
CASH$_{t-1}$	0.147	0.0820	0.167	0.000	0.803	3259
Stock Returns	1.132	1.072	0.534	0.183	3.658	3176
Stock Returns$_{t-1}$	1.103	1.042	0.688	0.000	4.030	3233
Annualized Volatility	0.455	0.352	0.405	0.104	2.661	3139
Annualized Volatility$_{t-1}$	0.430	0.345	0.346	0.104	2.470	3206

The variables are defined following Custodió et al.(2013)(Table A1), see definitions in Table 2.14.

components, whose factor loadings are as follows:

$$F_1 = 0.453x_1^* + 0.414x_2^* + 0.425x_3^* + 0.007x_4^* - 0.143x_5^*$$

$$F_2 = 0.005x_1^* + 0.006x_2^* - 0.153x_3^* + 0.540x_4^* + 0.615x_5^*$$

where x_i^* are standardized variables of those five previous-experience proxies with zero means and standard deviations of 1. While the first component, F_1, is an overall indicator of past experience in different roles, companies, and past experience as a CEO with relatively large coefficients (> 0.4), the second component, F_2, is a factor that mainly explains industry-related experience including the past experience in different industries and whether a CEO worked in a multi-segment company previously. The overall General Ability Index (GAI) is constructed with weighted components F_1 and F_2 as:

$$GAI = 0.2839x_1^* + 0.2600x_2^* + 0.2068x_3^* + 0.2082x_4^* + 0.1431x_5^*. \tag{8}$$

I further standardized General Ability Index with a mean of zero and a standard deviation of one.

2.3 Is General Skills A Determinant in CEO Hiring?

In this section, I first report the results of the baseline regression: the impact of candidates' general abilities on the external appointing dummy controlling for firm sizes. Second, the instrumental variable method is employed to alleviate the endogeneity concern in the model.

2.3.1 Baseline Regression Model

Previous theoretical studies suggest that CEO appointment is jointly determined by the general managerial skills of CEO candidates and the size of organizations recruiting CEOs and hiring choices varies in firm sizes (Murphy and Zabojnik, 2007; Baker et al., 1988; Frydman, 2019; Pan, 2017). The primary purpose is to determine if general ability is a main factor in external CEO hiring and how it has different effects regarding firm sizes. In accordance with Custódio et al. (2013), I employ the general ability index constructed using Principal Component Analysis with five proxies of the CEO's previous experience as a proxy for general management ability. As for firm size proxies, firms' total assets, total revenues, book value equity, or market value equity are frequently employed in existing studies (Al-Khazali et al., 2005). Here I adopt the logarithm of *Sales Over Net(Sales)* in the firms' balance sheets as the company size measure. To evaluate the effects of general skills in different firm sizes, I use a non-linear model. In addition, I use these two proxies as the main explanatory variables to construct the Probit model and evaluate the impacts of hiring company sizes and candidates' general abilities on the external appointment, where the external appointment is a binary dummy variable that takes the value of 1 if a new CEO is externally hired and 0 if he or she is internally promoted. Candidates who work more than one and a half years consistently right before they were promoted as CEO in the hiring firms or have more than 3 years cumulative experience in these firms are considered to be internally promoted. The following is the model:

$$Prob(Y_{ijt-1} = 1|W_{ijt-1}) = \phi(\beta_0 + \beta_1 X_{it-1} + \beta_2 Z_{jt-1} + \beta_3 \theta_{jt-1} + \beta_4 G_{it-1} + \beta_5 \gamma_{t-1} + \beta_6 \zeta_j) \quad (9)$$

where W_{ijt-1} represents the set of regressors

$$W_{ijt-1} = (1, X_{it-1}, Z_{jt-1}, \theta_{jt-1}, G_{it-1}, \gamma_{t-1}, \zeta_j)^T$$

The dependent variable Y_{ijt-1} represents the external or internal appointment of CEO i by firm j at time $t-1$. Note that the first year a CEO i begins working for a company j occurs at time t and that the hiring decision is made prior to the new CEO taking office. The prediction model, therefore, incorporates CEO and firm characteristics at time $t-1$, prior to the first year of the successor CEOs' employment with the recruiting firms.

The two variables X_{it-1} and Z_{jt-1} are the main explantory variables: X_{it-1} represents CEO $i's$ General Ability Index at time $t-1$, whereas Z_{jt-1} represents the firm's $j's$ size at time $t-1$. Control variables include new CEO $i's$ and hiring firm $j's$ characteristics: G_{it-1} represents successor CEO i's characteristics, such as gender, age, whether he or she held a board position, total career years, the ratio of the company in which he or she stayed longest over total career years, and whether he or she possessed special certifications such as CFA and CPA at the time $t-1$. The variable θ_{jt-1} represents the hiring firm j's other characteristics at time $t-1$, including Tobin's

Q, ROA, ROE, Leverage, stock returns, CAPEX, and annualized volatility. In addition, year and industry effects are taken into consideration: γ_{t-1} denotes the year dummy, whereas ζ_j denotes the industry dummy. Businesses are classified into nine industries based on the Standard Industrial Classification (SIC): construction, finance, insurance, and real estate; manufacturing; mining; public administration; retail; services; wholesales; and transportation, communications, electric, gas, and sanitary services.

Table 2.3: Baseline Regressions Reduced Form

Dependent Variable: External Dummy	Probit				LPM
	(1)	(2)	(3)	(4)	(5)
General Ability Index	0.212***		0.230***	0.216***	0.059***
	(0.026)		(0.027)	(0.031)	(0.009)
LnSales t-1		-0.052***	-0.080***	-0.067***	-0.018***
		(0.017)	(0.017)	(0.018)	(0.005)
CEO Control Variables	No	No	No	Yes	Yes
Firm Control Variables	No	Yes	Yes	Yes	Yes
Industry & Year Dummies	Yes	Yes	Yes	Yes	Yes
Observations	3206	3206	3206	3206	3206
R^2	.	.	.	.	0.097
χ^2	205.633	190.165	265.942	283.523	.

Standard errors in parentheses. Standard errors are clustered to CEO-firm appointing. The dependent variable is External Dummy at hiring year t. Firm control variables include firms' Tobin's Q, ROE, ROA, Stock Returns, Leverage, CAPEX, and Annualized Volatility in the year $t-1$. CEO control variables include age, gender, certificate dummy, board dummy, total years of career, and the ratio of the longest time served in one company over entire career time. Industries are classified into nine industries according to the first two-digit Standard Industrial Classification(SIC).* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 2.3 displays the outcomes of a Probit regression by using pooled CEO appointment data from 2001 to 2020. Year and industry dummies are included to capture heterogeneity. The direct estimation is supported by the first two columns which indicate that a one-unit increase in general ability or firm size has a statistically significant effect on the probability of external appointment after controlling for the effects of industry and year. While an increase in general ability is positively associated with the probability of external appointment, an increase in firm size is negatively associated with this probability. Control variables firm characteristics (Tobin's Q, ROA, ROE, leverage, stock returns, CAPEX, and annualized volatility) and CEO characteristics (gender, age, whether he or she held a board position, total career years, the ratio of the company in which he or she stayed the longest over total career years, and whether he or she possessed special certifications such as CFA and CPA) are added in the next two columns, respectively. The linear probability model (LPM) estimate is consistent with the Probit regression findings in columns (1) to (4) regarding the correlations between general ability and external appointing and between company size and external appointing, as shown in column (5). The results indicate that the result of the regressions is consistent with intuition.

2.3.2 Approches To Endogeneity

These regression results may only demonstrate a statistical relationship between general management skills and external appointments, and not their effect. There is still an endogeneity problem since not all important factors are observable. For example, it is not always clear what type of skills and knowledge an employer seeks in a successor CEO. Businesses facing challenging transitions, such as mergers and acquisitions (Chen, 2015; Custódio and Metzger, 2014), may expect the new CEO to be an expert in the transition who has superior negotiation skills. However, there are two potential structural flaws with the General Ability Index: it examines employment history from all previous employers. Initially, a percentage of the external CEO's total competencies may be firm-specific. If the recruited CEO has prior experience with the recruiting firm, such as having worked on the same project as the current employer, a greater proportion of the CEO's total managerial skills can be applied directly to this firm. In addition, candidate mobility affects the General Ability Index, a proxy for overall managerial abilities. For example, the number of previous companies is an indicator of the inter-company mobility of CEOs; job-hoppers may have a much higher General Ability Index as a consequence of their frequent job-hopping. Nowadays, job-hoppers are more likely to seek positions in the CEO market, whereas less mobile candidates may choose to remain in their current position (Yonker, 2017; Fahlenbrach et al., 2010) and are therefore unobservable. Even the control variables in the baseline regressions provide a proxy for the mobility of a CEO: the ratio of the longest number of years spent at a company to the total number of years spent in the career. This may not reflect their current career concerns. Thus, the estimation of the impact of the general ability index on the probability of an external appointment may be biased.

To address these underlying concerns, I use the instrumental variable method to alleviate the endogeneity issue and examine the causal relationship between general ability and the firm's hiring decision. The instrumental variables are chosen on the grounds that they cannot be applied directly to recruitment firms, and it is irrelevant if the CEO has a tendency to be present in the job market. Thus, I suggest the independent board experience in firms other than the recruiting firms as an instrumental variable.

Firstly, being a member of an independent board of directors is seen as a sign of skill, given that firms carefully choose such individuals (Cohen et al., 2012; Duchin et al., 2008).[4] An independent board member strategically manages and administers the organization. This includes important financial, risk, and strategic decisions. Independent board members are expected to know not only the company's financial statements, key performance metrics, and risk management, but also its industry and markets. Also, independent board members must be good communicators and able to work with the CEO and other executives. Required are strategic thought, constructive criticism, and questioning the status quo.

Panel B of Table 2.4 shows the results of the first stage of IV estimations, which controls for both instrumental variables and other control variables. The findings show that the instrumental variables are not weak instruments, confirming that the number and years of independent board experience generate a positive attribution to the CEO's general ability. As displayed in Panel C, the Amemiya-Lee-Newey overidentifying test in the Probit model and the Hansen J statistic in the linear probability model both indicate that the year and quantity of independent board experience in other firms are valid instruments.[5]

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[4] The U.S. Securities and Exchange Commission's press release on November 4, 2003, in which the Commission approved new rules proposed and adopted by the New York Stock Exchange (NYSE) and the Nasdaq Stock Market, stipulates that the board must affirmatively determine whether a director is "independent" (either directly or as a partner, shareholder, or officer of an organization that has a relationship with the company). This selection process guarantees that the board has the skills and qualities necessary to make impartial and well-informed decisions in the best interests of the company and its shareholders. In addition, service on an independent board is not often regarded as a primary occupation, and the annual salary is not anticipated to exceed $120,000.

[5] In the linear model, Sargan (1958) use the residuals generated from instrumental variable regression to examine the exogeneity of instruments in linear models; in discrete models such as logit and probit, Amemiya-Lee-Newey (ALN) (Lee, 1992; Amemiya, 1978; Newey, 1987), which is based on the estimation of an auxiliary GMM model built from estimates in reduced form can be used for this purpose.

Table 2.4: Instrumental Variable (IV) Regression Results Reduced Form

Panel A: Second stage results				
Dependent Variable: External Dummy				
	Probit (1)	IV (2)	LPM (3)	IV (4)
General Ability Index	0.216***	0.343***	0.059***	0.100***
	(0.031)	(0.065)	(0.009)	(0.021)
LnSales t-1	-0.067***	-0.078***	-0.018***	-0.022***
	(0.018)	(0.019)	(0.005)	(0.005)
CEO Control Variables	Yes	Yes	Yes	Yes
Firm Control Variables	Yes	Yes	Yes	Yes
Industry & Year Dummies	Yes	Yes	Yes	Yes
Observations	3206	3206	3206	3206
R^2	.	.	0.097	0.040
χ^2	283.523	286.420	.	.
Panel B: First stage results				
Independent Board Years		0.104***		0.104***
		(0.008)		(0.008)
Independent Board Number		0.157***		0.157***
		(0.020)		(0.020)
R^2		0.496		0.496
Panel C: IV diagnostics				
F of instruments				406.144
Hansen's J Statistics χ^2				1.453
P-value of Hansen's J				0.2280
P-value of endogeneity test		0.026		0.022
Amemiya-Lee-Newey overidentifying test $\chi^2(1)$		1.022		
P-value of Amemiya-Lee-Newey		0.313		
Weak IV Anderson-Rubin test $\chi^2(2)$		28.650***		

Standard errors in parentheses. Standard errors are clustered to CEO-firm appointing. The dependent variable is External Dummy at hiring year t. The instrumented variables are General Ability Index at hiring year t. CEO and firm control variables are the same as Table 2.3. Industries are classified into nine industries according to the first two-digit Standard Industrial Classification (SIC). * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Independent board expertise gathered in other companies cannot directly influence a hiring company's choice via the required firm-specific knowledge channel since it cannot be immediately applied to the unique environment and requirements of the employing firm. Although experience as an independent board member at another company may show a candidate's skills and competence, it does not ensure that the candidate will be able to work successfully in the setting of the hiring firm, since each company has its own unique difficulties, aims, and objectives.

Nevertheless, due to the distinction between the roles of independent board members and CEOs, the independent board's experience cannot directly influence the recruiting firm's selection of the successor CEO. The roles of the chief executive officer and independent board member demand distinct skill sets and areas of expertise. A chief executive officer is in charge of running the day-to-day activities of a company and making tactical decisions that foster its growth and profitability. In comparison, independent board directors are responsible for providing oversight and guidance to the firm's management team, including the CEO, to guarantee that it is performing in the best interests of shareholders and other stakeholders. Experience as an independent board member may show an understanding of corporate governance and decision-making processes, yet it could not adequately reflect that the candidate has the particular talents essential to be an excellent CEO. A CEO is expected to show great leadership, managerial, and communications skills, in combination with a thorough grasp of the company's industry, markets, and consumers. Thus, during the recruiting process, the hiring company would value the candidate's skills and qualities directly connected to the CEO role. Experience as a member of an independent board of directors in other companies should only be used to demonstrate a candidate's general management abilities.

Cziraki and Jenter (2022) provide insight into the small pool of candidates from which companies typically select their CEOs, despite the fact that no specific research has been done to examine the direct relationship between interpersonal connections made through serving as independent board members and the likelihood of being hired by recruiting firms. According to their research, more than 80% of new CEOs are insiders, i.e., board members, workers, or previous employees of the hiring company. The survey also shows that over 90% of incoming CEOs are already known to boards, either due to their former insider position or due to prior interactions with the directors themselves. This implies that hiring committees favour candidates they are familiar with, highlighting the significance of connections and ties already in place. Future research could be done to investigate whether serving as an independent board member of other firms helps build connections for the recruiting firms after the potential candidate takes office and therefore increases the possibility of the potential candidate being hired.

Table 2.4 Panel A displays the results of the IV estimations. Column (2) shows the IV regression result using the two-step IV-Probit process, whereas the linear probability model is estimated using the generalized method of moments (GMM) estimator in column (4). The results of IV regressions are consistent with the results of baseline regressions in that general managerial ability is positively and statistically significantly correlated with the probability of external appointment, whereas the firm size is negatively and statistically significantly correlated with this probability. In order to the effects of firm size and general ability, marginal effects in the Probit model are reported in Table 2.5 columns (1) and (2).

Table 2.5: Instrumental Variable (IV) Marginal Effects Reduced Form

Dependent variable: External Dummy	Probit	IV	LPM	IV
	Marginal Effects			
	(1)	(2)	(3)	(4)
General Ability Index	0.059***	0.094***	0.059***	0.100***
	(0.008)	(0.018)	(0.009)	(0.021)
LnSales t-1	-0.018***	-0.021***	-0.018***	-0.022***
	(0.004)	(0.005)	(0.005)	(0.005)
CEO Control Variables	Yes	Yes	Yes	Yes
Firm Control Variables	Yes	Yes	Yes	Yes
Industry & Year Dummies	Yes	Yes	Yes	Yes
Observations	3206	3206	3206	3206

Standard errors in parentheses. Standard errors are clustered to CEO-firm appointing. The dependent variable is External Dummy at hiring year t. The instrumented variables are General Ability Index at hiring year t. CEO and firm control variables are the same as Table 2.3. Industries are classified into nine industries according to the first two-digit Standard Industrial Classification (SIC). * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 2.5 columns (1) and (2) show that the Probit baseline model underestimated the impact of general ability on external hiring. The instrumental variables estimate an effect about 50%-60% larger than the probit estimates. This suggests that some factors prohibit the general ability's effect, causing the Probit model to underestimate this effect. Column (2) shows that if the general ability index increases by 1 unit, the probability of external hiring increases by 9.4%. The difference between linear probability estimates and IV estimates is consistent with the difference between Probit and IV-Probit estimates. Using IV-Probit estimates, the marginal impacts of a firm's size rise by approximately 10% compared to Probit estimates: if a firm's size increases by one unit, the probability of externally hiring a CEO successor reduces by 2 percent. The regression results suggest that larger companies are less likely to hire an external CEO. Table 2.6 and Figure 2.1 show the average marginal impacts of general probability for different company sizes based on IV estimations, which decrease by approximately 50 percent from a small firm with the logarithm of sales equal to 0 to a large firm with the logarithm of sales equal to 10.

Table 2.6: External Appointing Marginal Effects by Firm Sizes

	(1)	(2)	(3)	(4)	(5)	(6)
General Ability Index	0.122 ***	0.117***	0.110***	0.101***	0.091***	0.081***
	(0.024)	(0.024)	(0.022)	(0.020)	(0.017)	(0.015)

Standard errors in parentheses. Standard errors are clustered to CEO-firm appointing. Columns (1) to (6) are corresponding to LnSales at $t-1$ taking values of 0, 2, 4, 6, 8, and 10. $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The dependent variable is External Dummy at hiring year t. Firm control variables and CEO control variables are the same as Table 2.3.

One possible explanation is that the proportional relevance of firm-specific abilities over general abilities may also increase as the size of the firm increases (Baker et al., 1988; Cziraki and Jenter, 2022). In reality, due to the complexity of large organizations, the demand for firm-specific skills may grow faster than that for general skills. Differences in CEO salary, on the other hand, could influence firms' preference for internal promotions over hiring outsiders. External recruiting can be costly, especially for large, complicated, multi-segment organizations. Despite the fact that outsiders are more likely to be hired due to their superior and transferable general management skills (Murphy and Zabojnik, 2007; Falato et al., 2015), it takes a while to become adapted to the environments in all segments and divisions. In addition to generalists receiving a significant ability premium in the CEO market (Murphy and Zabojnik, 2007; Custódio et al., 2013), externally hired successors would demand a risk premium (Carter et al., 2019) due to the unpredictability of their fit in the new company (Peters and Wagner, 2014). While firms have asymmetric learning about external and internal candidates that there is higher uncertainty regarding external hiring, Li and Ueda (2005) show that CEO who is a “safer” choice are paid substantially less. For large, complex, and multi-segment firms, the benefit from hiring external candidates with a boarder set of general skills could be offset by the high compensation premium and internal candidates might potentially generate higher profit.

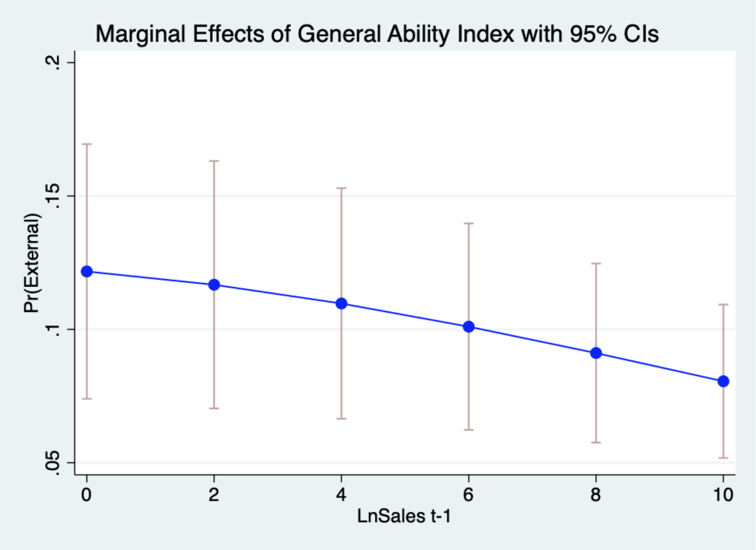

Figure 2.1: Marginal Effects of General Ability at Different Firm Sizes

2.3.3 General Ability And Other CEO Characteristics

Additionally, there are some concerns about whether other CEO characteristics, such as gender and background, are the determinants in firms’ hiring choices and whether the effect of general ability varies according to these other CEO characteristics. Previous studies on CEO gender mainly consider the relationship between gender and firm performance and that between gender and compensation. Compared to male-led firms, female-led firms have less debt, more stable earnings, and are more likely to stay in business, but their performances are not significantly different (Khan and Vieito, 2013; Faccio et al., 2016). Adams and Ferreira (2009) show that Female directors have an important influence on board contributions and firm performance, and CEO equity compensation is significantly greater when a gender-diverse board is present. Meanwhile, studies in CEO background show that CEOs with a background in finance typically maintain companies’ financial

Table 2.7: General Ability Index And Other CEO Characteristics IV Regressions Reduced Form

Dependent Variable: External Dummy	Probit			IV		
	(1)	(2)	(3)	(4)	(5)	(6)
General Ability Index	0.216***	0.451***	0.215***	0.343***	0.801***	0.301***
	(0.031)	(0.116)	(0.032)	(0.065)	(0.248)	(0.068)
LnSales t-1	-0.067***	-0.067***	-0.068***	-0.078***	-0.078***	-0.080***
	(0.018)	(0.018)	(0.018)	(0.019)	(0.019)	(0.019)
Male Dummy	-0.002	0.084	-0.002	0.021	0.144	0.008
	(0.114)	(0.128)	(0.124)	(0.121)	(0.136)	(0.115)
Certificate Dummy	0.098	0.102	0.098	0.085	0.101	0.109
	(0.099)	(0.100)	(0.100)	(0.100)	(0.099)	(0.100)
Male Dummy × General Ability Index		-0.248**			-0.492*	
		(0.118)			(0.255)	
Certificate Dummy × General Ability Index			0.021			0.428**
			(0.110)			(0.184)
CEO Control Variables	Yes	Yes	Yes	Yes	Yes	Yes
Firm Control Variables	Yes	Yes	Yes	Yes	Yes	Yes
Industry & Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3206	3206	3206	3206	3206	3206
χ^2	283.523	287.861	283.751	286.420	291.457	292.922

Standard errors in parentheses. Standard errors are clustered to CEO-firm appointing. The dependent variable is External Dummy at hiring year t. Other CEO and firm control variables are the same as Table 2.3. Industries are classified into nine industries according to the first two-digit SIC. Male ×General Index Dummy has P-value of 0.52 in the IV regression. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

policies more actively and responsibly in terms of capital gain or loss, and they are more likely to be employed by mature and diversified companies (Custódio and Metzger, 2014; Kaplan et al., 2012). Certifications such as CFA or CPA demonstrate that individuals have achieved specialized technical expertise in fields like finance and accounting. These skills might not be sufficient for CEO positions, but are proven and can be transferred across firms easily. Certified successors with strong general managing ability can be excellent external candidates for CEO positions because they have technical expertise and team leadership skills. In fact, managers with finance or accounting background are more detail-oriented and more accurate in their estimates of firms' future incomes (Bamber et al., 2010). In the following part, I examine this possibility in light of gender and whether or not a CEO possesses specialist certifications such as Chartered Financial Analyst (CFA) and Certified Professional Accountant (CPA). Table 2.7 shows the estimates of Probit and IV regressions for the variation of the effect of general ability in CEO characteristics. The evaluation of whether the influence of general ability varies if a CEO is certified in specific domains is displayed in columns (3) and (6). The IV estimate in column (6) demonstrates a positive and statistically significant difference between the effects of general ability on external appointment for CEOs with and without particular certifications. The estimation of whether the impact of general ability differs in CEO gender is displayed in columns (2) and (5). Using Probit estimations, the effects of general ability on external appointing in males are statistically and negatively lower than in females; however, using IV estimations, the difference between the effects of general ability on external appointing in males and females is not statistically distinguishable. It might be the case that, under certain circumstances, the effects of general ability on the probability of external employment may differ between males and females. Particularly, those who lack certifications in specific fields may have to rely more on their general abilities to demonstrate their prospective worth in the CEO role. In consideration of this, I further examine the sub-samples.

Table 2.8 shows the IV estimates of the impact of general ability for two sub-samples. The first sub-sample consists of successors without certifications in specified disciplines, whereas the second sub-sample includes solely male CEO successors. The first four columns illustrate the moderating effects of gender on the impact of general ability among non-certified successors. In particular, the impact of general management skills among non-certified males is substantially lower than that of

Table 2.8: Male And Non-Certificate Sub-samples IV Regressions Reduced Form

Dependent Variable: External Dummy	Non-Certificate Sub-sample				Male Sub-sample			
	(Probit) (1)	(IV) (2)	(LPM) (3)	(IV) (4)	(Probit) (5)	(IV) (6)	(LPM) (7)	(IV) (8)
General Ability Index	0.499***	0.806***	0.129***	0.194***	0.200***	0.263***	0.055***	0.079***
	(0.121)	(0.236)	(0.031)	(0.049)	(0.032)	(0.066)	(0.009)	(0.020)
LnSales t-1	-0.072***	-0.078***	-0.019***	-0.022***	-0.065***	-0.083***	-0.018***	-0.023***
	(0.019)	(0.020)	(0.005)	(0.005)	(0.018)	(0.020)	(0.005)	(0.006)
Male Dummy	0.088	0.158	0.006	0.020				
	(0.134)	(0.145)	(0.031)	(0.032)				
Certificate Dummy					0.118	-0.138	0.033	0.045
					(0.102)	(0.126)	(0.031)	(0.033)
Male × General Ability Index	-0.298**	-0.560**	-0.074**	-0.120**				
	(0.123)	(0.243)	(0.032)	(0.051)				
Certificate × General Ability Index					0.059	0.819***	0.021	0.173***
					(0.112)	(0.268)	(0.036)	(0.061)
CEO Control Variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm Control Variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry & Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2967	2967	2967	2967	3036	3036	3036	3036
R^2	.	.	0.106	0.047	.	.	0.095	0.032
χ^2	280.427	282.439	.	.	258.805	269.268	.	.

Standard errors in parentheses. Standard errors are clustered to CEO-firm appointing. The dependent variable is External Dummy at hiring year t. Other CEO and firm control variables are the same as Table 2.3. Industries are classified into nine industries according to the first two-digit SIC code. Non-Certificate sub-sample include CEO whose certificate dummy equals to 0. Male sub-sample included only male CEO. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

non-certified females. The results in the next four columns show that the effects of general management skills vary significantly between male successors with and without professional certification. The outcomes of the regressions are consistent with prior concerns, as demonstrated by the findings. Table 2.8 only displays statistically significant moderating effects; to examine the impact of general ability across groups, average marginal effects of general ability are estimated and displayed in Table 2.9.[6]

The first two columns in Table 2.9 show that: when the general ability increases by one unit in the female group, the probability of being recruited by an outside firm increases by around 18%. This is nearly three times as high as the rate observed in males. Using IV estimation within a linear probability model yields a similar result. One possible explanation could be that some CEOs simply have more public profiles than others (Malmendier and Tate, 2009). Considering the fact that only about five percent of new CEO positions are filled by women between 2001 and 2020, it is highly likely that generalist female CEOs will have a considerably higher profile and receive more attention than their male competitors. Risk aversion and ethical sensitivity could also be taken into account when firms evaluate external candidates for the position of CEO. Khan and Vieito (2013) and Ho et al. (2015) show that the performance of female-led companies is comparable to that of male-led businesses, however, female-led companies have lower corporate risk. Hence, companies that seek to lower risk exposure and uphold ethical principles may favor female CEO candidates. Nonetheless, firms that value both CEO backgrounds, such as certification in a field like finance or accounting and attributes like ethical sensitivity and risk aversion, may have to make a trade-off when selecting CEO successors. For some firms, technical expertise may be more valuable than ethical sensitivity and risk aversion when appointing CEO successors.

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[6] Table 2.16 in Appendix (Section 2.5) shows a summary of the internal and external hiring decisions, categorized by gender and whether or not the successor CEO holds a certificate, with different general ability levels.

Table 2.9: Average Marginal Effects of General Ability Index by CEO Characteristics

Dependent Variable: External Dummy	By Gender (Non-Certificate Sub-sample)			By Certificate (Male Sub-sample)		
	IV(Probit)		IV(LPM)	IV(Probit)		IV(LPM)
	Female	Male		Without Certificate	With Certificate	
General Ability Index	0.176 ***	0.067***	0.194***	0.072***	0.224***	0.079***
	(0.034)	(0.018)	(0.049)	(0.018)	(0.030)	(0.019)
Male Dummy × General Ability Index			-0.120**			
			(0.051)			
Certificate Dummy × General Ability Index						0.173***
						(0.061)

Standard errors in parentheses. Standard errors are clustered to CEO-firm appointing. The dependent variable is External Dummy at hiring year t. Other CEO and firm control variables are the same as Table 2.3. Industries are classified into nine industries according to the first two-digit Standard Industrial Classification (SIC). * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table 2.10: Average Marginal Effects of General Ability Index by CEO Characteristics At Representative Values

	By Gender (Non-Certificate Sub-sample)		By Certificate (Male Sub-sample)	
	Female	Male	With Certificate	Without Certificate
General Ability Index				
(At General Ability Index=-1.8)	0.024	0.046***	0.014	0.048***
	(0.019)	(0.007)	(0.011)	(0.006)
(At General Ability Index=-0.8)	0.096***	0.058***	0.102***	0.062***
	(0.017)	(0.013)	(0.021)	(0.013)
(At General Ability Index=0.2)	0.222***	0.070***	0.313***	0.075***
	(0.063)	(0.019)	(0.074)	(0.019)
(At General Ability Index=1.2)	0.294***	0.080***	0.372***	0.086***
	(0.086)	(0.024)	(0.061)	(0.024)
(At General Ability Index=2.2)	0.226***	0.087***	0.167***	0.093***
	(0.018)	(0.026)	(0.064)	(0.026)

Standard errors in parentheses. Standard errors are clustered to CEO-firm appointing. The dependent variable is External Dummy at hiring year t. Other CEO and firm control variables are the same as Table 2.3. Industries are classified into nine industries according to the first two-digit Standard Industrial Classification (SIC). Sub-sample selections are the same as Table 2.9. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

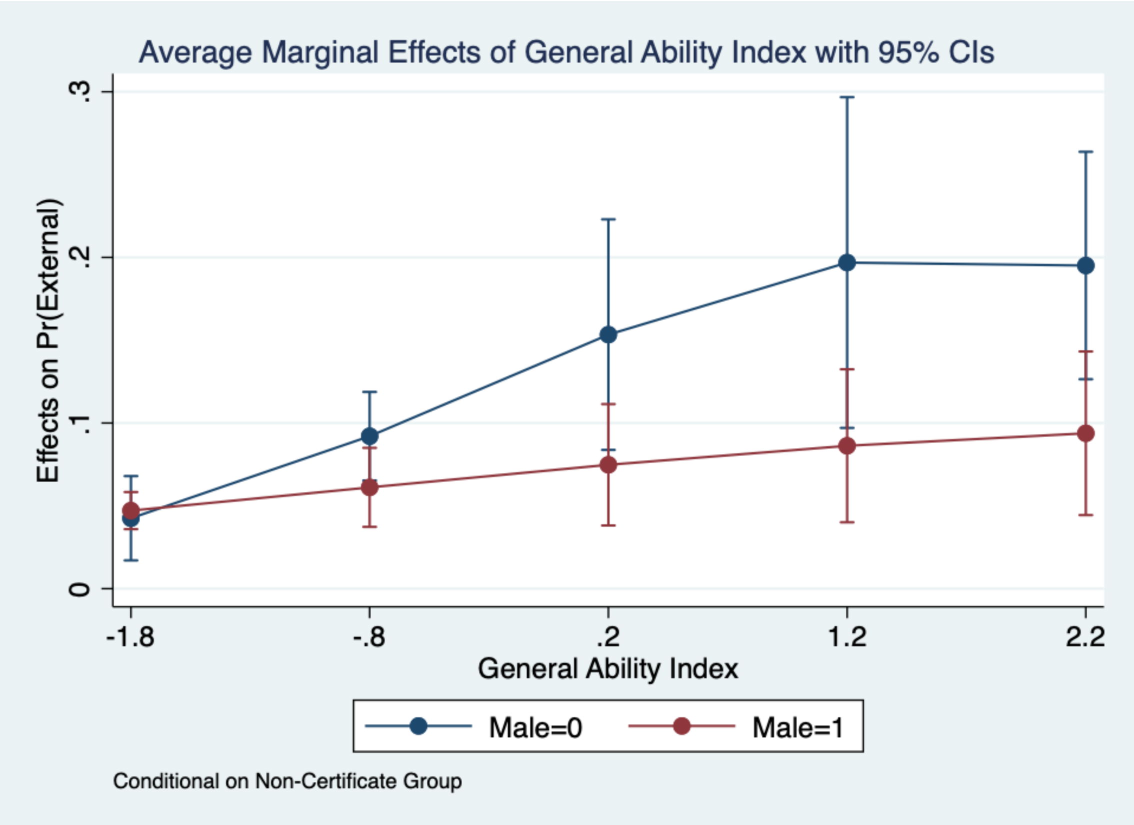

Figure 2.2: Marginal Effects of General Ability Index By Gender

Figure 2.2 shows the average marginal effects of general ability at different general ability levels in males and females without certificates. The estimates of the average marginal effects are shown in Table 2.10.[7] When the general ability is very low (less than or equal to the 1st percentile), the effect of a one-unit increase in general ability on the probability of being hired externally is slightly smaller (almost equal) for females than for males. Yet, when general ability exceeds the 1st percentile, these impacts are reversed for males and females. The gap in marginal impacts is the greatest when the successors are in the top 20 percentile of their general ability.

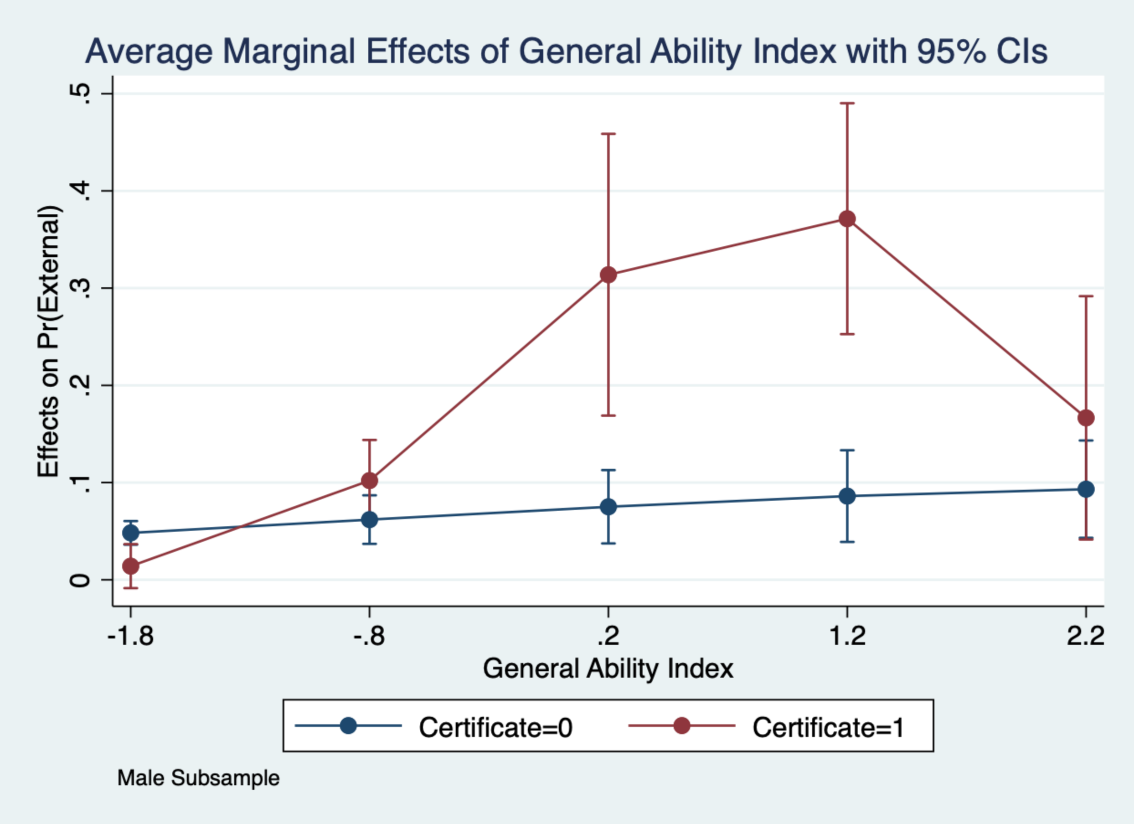

Figure 2.3: Marginal Effects of General Ability Index By Certificate

The last four columns in Table 2.9 show that: when general ability increases by one unit, the probability of external hiring for male successors with certifications increases by 22 percent, which is around three times the probability for those without certifications. Figure 2.3 depicts the average marginal effects of general ability at various levels of general ability for male certificate holders and male non-certified successors(Estimates of the average marginal effects are shown in Table 2.10.

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[7] Compensation in the Figure 2.4 are the initial Total, Cash, and other compensation, General Ability Index (GAI) in the figure is calculated in 8 and prior to being standardized with a mean of zero and a standard deviation of one.

Figure 2.3 shows that: when the general ability is low (below the 10th percentile), the effect of a one-unit increase in general ability on the probability of being hired externally is smaller for certificate-holding males than for other males. When general ability passes the 10th percentile, however, these effects are reversed. The difference in marginal effects is greatest when the successors are in the top 20th percentile of general ability and decreases subsequently, but an increase of one unit in general ability still results in a greater probability of external promotion for male certificate holders. As previously discussed, a certificate is credible, demonstrates skill in a specific field, and is highly transferable. In addition, the disclosure styles of managers promoted from accounting and finance are more detailed-oriented and tend not to be not overconfident in firm performance (Bamber et al., 2010).[8] When companies require combined skills, particularly mature and complex firms (Custódio and Metzger, 2014), certified experts with outstanding general management skills are ideal options.

2.3.4 Insider Or Outsider? Analysis From A Perspective of CEO Compensation

Figure 2.4 shows the trends of CEO compensation and general ability,[9] which suggests similar increasing trends between the general ability index and the new CEO's initial total compensation. I expect that CEOs who have a higher general ability get paid higher in terms of total compensation and performance-based compensation, whereas not significantly correlated to base salary and bonus. I construct the linear regression model is as follows:

$$Payment_{ijt} = \beta_0 + \beta_1 X_{it} + \beta_2 Z_{jt} + \beta_3 \theta_{jt} + \beta_4 \theta_{jt-1} + \beta_5 G_{it} + \gamma_t + \zeta_j + \eta_{ijt} \tag{10}$$

where $Payment_{ijt}$ denotes the dependent variable— initial compensation of CEO i as firm j's CEO at time t. The explanatory variable, X_{it} denotes candidate i's general skills at time t, which is the same as candidate i's general skills at time $t-1$,[10] and Z_{jt} denotes the firm j's size at time t.

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[8] Bamber et al. (2010) analyze CEOs' effect on firms voluntarily disclosure of management earnings forecasts: "Managers' unique disclosure styles are associated with observable demographic characteristics of their personal backgrounds: managers promoted from finance, accounting, and legal career tracks, managers born before World War II, and those with military experience develop disclosure styles displaying certain conservative characteristics; and managers from finance and accounting and those with military experience favor more precise disclosure styles."

[9] Compensation in Figure 2.4 are the initial total, cash, and other compensation. General Ability Index(GAI) in the figure is calculated with PCA shown in the equation8 and prior to being standardized with a mean of zero and a standard deviation of one.

[10] The General Ability Index is computed based on the experience of the CEO i previous to his or her first year as CEO (year t). For CEOs with General Ability Index X_{it-1}, I suppose that their general abilities did not change between the

Firm $j's$ performance characteristics at time t and $t-1$ are used in the model as control variables as CEO i payment agreement: θ_{jt} denotes the firm j's Tobin's Q, ROA, stock returns, and annualized volatility at time t, while θ_{jt-1} denotes firm j ROA and stock returns at time $t-1$ additionally. CEO characteristics including age, gender, and certificate dummy are denoted with G_{it}. The variable γ_t represents the time effects, ζ_j represents the industry effects, and η_{ijt} is the error term.

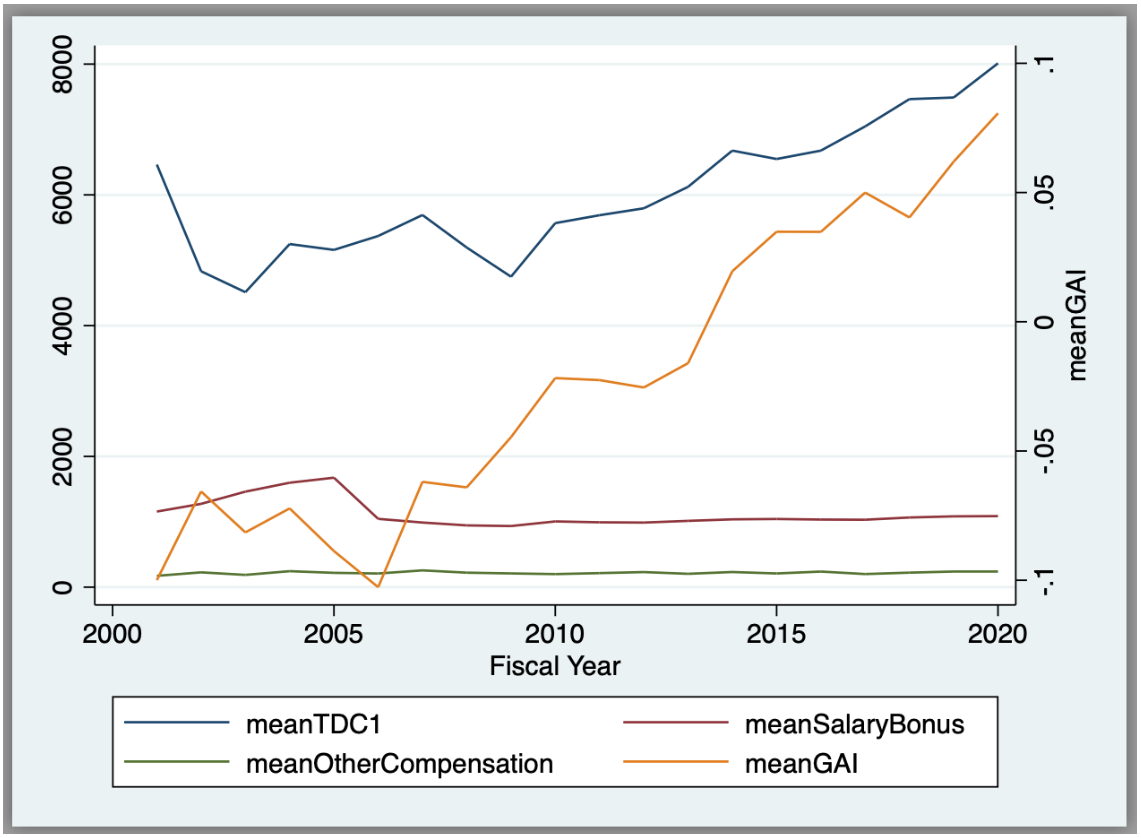

Figure 2.4: CEO Compensation and General Ability Index Trends

New CEO Initial Compensation

Table 2.11 reports the estimated total compensation, base compensation, and ratio of equity to total compensation during the first year of a CEO's employment. The dependent variable is the logarithm of Compustat total compensation (TDC1) under the 1992 reporting format, which consists of salary, bonus, other annual payments, the total value of restricted stock granted, the total value of stock options granted calculated using a model of Black-Scholes (Black, 1976; Scholes,

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end of year $t-1$ and the start of year t.

Table 2.11: The Impact of General Ability on CEO First-Year Compensation

	Total Pay				Salary Bonus			Ratio Equity
	OLS (1)	OLS (2)	OLS (3)	OLS (4)	OLS (5)	OLS (6)	OLS (7)	(Tobit) (8)
General Ability Index			0.135***	0.109***			0.016	0.041***
			(0.022)	(0.020)			(0.023)	(0.009)
Age		-0.013***	-0.017***	-0.012***		-0.003	-0.003	-0.003**
		(0.003)	(0.003)	(0.003)		(0.004)	(0.004)	(0.001)
Male Dummy		-0.033	-0.009	0.036		0.109	0.111	-0.104***
		(0.072)	(0.072)	(0.066)		(0.129)	(0.127)	(0.031)
Certificate Dummy		0.051	0.054	0.037		-0.070	-0.069	0.031
		(0.070)	(0.069)	(0.064)		(0.091)	(0.091)	(0.028)
LnSales	0.407***	0.411***	0.398***	0.357***	0.219***	0.219***	0.217***	0.054***
	(0.013)	(0.013)	(0.014)	(0.014)	(0.016)	(0.016)	(0.016)	(0.009)
Ratio Equity				1.347***				
				(0.340)				
Constant	4.857***	5.530***	5.816***	5.475***	4.831***	4.889***	4.923***	-0.558***
	(0.128)	(0.211)	(0.216)	(0.220)	(0.126)	(0.212)	(0.221)	(0.135)
Firm Control Variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry & Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3139	3139	3139	3139	3139	3139	3139	3139
R^2	0.310	0.314	0.324	0.413	0.145	0.146	0.147	.

Standard errors in parentheses. Standard errors are clustered to CEO-firm appointing. The dependent variable is the logarithm of CEO total pay in Columns (1-(4), is the logarithm of CEO cash pay in Columns (5)-(7), and is the ratio of equity over total pay in column (8) at hiring year t. Firm(performance) control variables include hiring year's Tobin's Q, Stock Returns, ROA, Annualized Volatility of year t, and the previous year's Stock Returns and ROA. Industries are classified into nine industries according to the first two-digit Standard Industrial Classification (SIC). Ratio Equity refers to the ratio of equity over total compensation.* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

1976), long-term incentive payouts, and all Other totals. As a substantial proportion of new CEOs began their employment in the middle of the fiscal year, their first-year compensation are just partial. Thus, I use the total and cash compensation for the second year as dependent variables. For those whose second-year salaries are missing, I estimated them by adjusting their first-year salaries by the average industry-year percentage change in salaries.

Ordinary Least Square (OLS) regression results are shown in Table 2.11 columns (1)-(7). After controlling for firm performance and fixed effects, column (1) shows direct estimates indicating one unit of increase in firm size (approximately 1.7 times the increase in sales) corresponds to a roughly 40% increase in total compensation for the new CEOs. In the following two columns, CEO characteristics such as age, gender, certificate, and general ability index are gradually added. Column (4) adds the ratio of equity over total compensation (Ratio Equity) in order to examine the robustness of the impact of the general ability index when controlling for compensation risk because risk-averse CEOs may seek a premium for accepting equity pay if firms offer more incentives to generalist CEOs (Custódio et al., 2013). After controlling for compensation risk, the coefficient of general ability remains positive and significant despite its lower magnitude. General ability increases overall pay by 10% each standard deviation. Estimated new CEO cash compensation are displayed in columns (5) through (7). One unit of increase in a company's size correlates to a 20 percent rise in new CEO cash compensation. The correlation between general ability and initial base compensation for CEOs is not statistically significant, even though it is positive. In comparison, a 10% increase in general ability is equivalent to a 1% rise in total compensation. The estimates of firms' and CEOs' ratios of equity to total compensation are presented in column (8). The Tobit model is used since the equity ratio is left-censored with a value of zero. An increase in business size corresponds to a 5% increase in the ratio of equity over total pay, and an increase in general ability corresponds to a 4% increase in it. Interestingly, men CEO successors receive roughly 10% less equity ratio than their female counterparts. Moreover, younger CEOs typically receive greater total compensation as well as equity ratios. Particularly, each extra year of age results in a one percent decrease in total compensation and a three percent decrease in the ratio of equity over total pay, respectively. In accordance with Custódio et al. (2013), the results indicate that generalists with higher general ability earn significantly higher total compensation. However, contrary to the theoretical argument presented by Murphy and Zabojnik (2007) and the empirical findings by Custódio et al. (2013) who investigated the period prior to 2007, new CEO's initial cash compensation is affected by managers' general abilities positively but statistically insignificantly over the period of time spanning from 2001 to 2020.

External Outsider Compensation

As previously discussed in Section 2.3, one possible explanation of why larger firms tend to hire internally is that external hiring is costly, especially for large, complicated, multi-segment organizations. External successors request a risk premium because of the uncertainty of their fitting in and relocation (Carter et al., 2019; Yonker, 2017; Peters and Wagner, 2014). Due to unfamiliarity with the new company's projects, the adaption incurs training expenses and may result in a higher cost and a lower overall profit. During the data collection process, I discovered that among the external CEO successors, there are a few who did not work for the hiring firms in the past one and a half years, but who previously held managerial positions in the hiring firms for more than one year but fewer than three years; I characterize these individuals as "External Insiders". And I categorize the remaining candidates hired externally as "Outsiders".

Table 2.12 presents the mean CEO and firm characteristics for the samples of external insiders, internally promoted CEOs, and outsiders as well as the associated differences. The average general ability of external insiders is higher than that of both the internally promoted CEO and outsiders. And firms that hire external insiders have larger average sizes than those that promote from within and hire outsiders. External insiders have a degree of firm-specific knowledge and require less time to become effective as CEOs. Based on this, I would test the cost-related hypothesis.

Table 2.13 shows the estimated new CEO total pay and cash pay after adding the external outsider and internal promotion dummies to OLS shown in Table 2.11, with the estimated external insiders' total and cash pay serving as the comparison baseline. The coefficient of firm size is still consistent with previous studies of new CEO compensation including Chen (2015) and others. Columns (2) and (4) show that the internally promoted new CEO and outsider insiders earned similar total and cash compensation, in which the differences are not statistically distinguishable. Yet external outsiders receive a significant premium of approximately 30 percent in total compensation

Table 2.12: Internal, External Outsider, and External Insider: Mean and Differences

	Mean			Difference		
	External Insider	Internal Promotion	External Outsider	External Insider v.s Internal	External Insider v.s. External Outsider	External Outsider v.s. Internal
General Ability Index	1.222	-0.070	0.150	1.292***	1.072***	0.220***
	(0.946)	(0.970)	(1.025)	(0.117)	(0.122)	(0.044)
LnSales	7.692	7.546	7.209	0.146	0.483**	-0.337***
	(1.617)	(1.677)	(1.602)	(0.201)	(0.208)	(0.071)
Age	59.227	53.447	52.666	5.780***	6.561***	-0.781***
	(6.649)	(6.795)	(5.885)	(0.827)	(0.849)	(0.264)
Male Dummy	0.909	0.948	0.951	-0.039	-0.042	0.002
	(0.290)	(0.221)	(0.216)	(0.036)	(0.036)	(0.009)
Certificate Dummy	0.061	0.071	0.086	-0.011	-0.026	+0.015
	(0.240)	(0.257)	(0.281)	(0.030)	(0.031)	(0.012)
Tobin's Q	1.813	1.819	1.806	-0.006	0.007	-0.013
	(1.260)	(1.152)	(1.167)	(0.157)	(0.163)	(0.052)
ROA	0.066	0.069	0.053	-0.003	0.013	-0.017***
	(0.080)	(0.105)	(0.111)	(0.010)	(0.011)	(0.005)
Stock Returns	1.052	1.126	1.162	-0.074	-0.110*	0.036
	(0.495)	(0.511)	(0.622)	(0.061)	(0.065)	(0.027)
ROA$_{t-1}$	0.067	0.071	0.050	-0.004	0.017	-0.021***
	(0.107)	(0.107)	(0.115)	(0.013)	(0.014)	(0.005)
Stock Returens$_{t-1}$	1.013	1.129	1.012	-0.116	0.000	-0.117***
	(0.624)	(0.677)	(0.731)	(0.078)	(0.082)	(0.032)
Annualized Volatility	0.510	0.450	0.554	0.060	-0.044	0.105***
	(0.668)	(0.622)	(0.668)	(0.083)	(0.086)	(0.029)
Observations	66	2,593	671	2,659	737	3,264

compared to external insiders, despite the fact that external insiders have a higher average general ability and are employed by larger firms which both correspond to significantly higher compensations. Compared to outsiders, who face a greater risk of adapting to a new environment, external insiders return to previous companies with a significantly lower risk. Thus, external insiders would demand a substantially lower risk premium.

Table 2.13: Internal, External Outsider, and External Insider CEOs Initial Compensation

	Total Pay		Cash Pay	
	(1)	(2)	(3)	(4)
General Ability Index	0.109***	0.098***	0.016	0.019
	(0.020)	(0.021)	(0.023)	(0.020)
External Outsider Dummy		0.325***		0.505*
		(0.125)		(0.297)
Internal Promotion Dummy		0.044		0.375
		(0.121)		(0.293)
LnSales	0.357***	0.362***	0.217***	0.219***
	(0.014)	(0.014)	(0.016)	(0.016)
Constant	5.475***	5.279***	4.923***	4.462***
	(0.220)	(0.257)	(0.221)	(0.445)
Firm Control Variables	Yes	Yes	Yes	Yes
CEO Control Variables	Yes	Yes	Yes	Yes
Industry & Year Fixed Effects	Yes	Yes	Yes	Yes
Observations	3139	3139	3139	3139
R^2	0.413	0.420	0.147	0.151

Standard errors in parentheses. Standard errors are clustered to CEO-firm appointing. The dependent variable is the logarithm of CEO total pay in Columns (1) and (2) and the logarithm of CEO cash pay in Columns (3)-(4) of the hiring year t. CEO and Firm control variables are the same as Table 2.11. Industries are classified into nine industries according to the first two -digit Standard Classification (SIC). *The base outcomes are the total and cash compensation* of external insiders. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

2.4 Conclusion

CEO and firm matching is unquestionably an important topic in the CEO labor market, and there has been a growing body of empirical research on the subject in recent years. This chapter provides empirical evidence to demonstrate the impact of general ability, a component of human capital, on the hiring decisions of CEOs. From an empirical perspective, the results quantify the effect of general skills in a direct manner. The empirical method of constructing instrumental variables has been established to be practicable, which alleviates the endogenous issues widespread in empirical studies of CEO and firm matchings and expands the study's limits. The moderating analysis reveals that the effect of general skills differs depending on other CEO characteristics, such as gender and background. This study also has important implications for the reevaluation of the relative significance of general and firm-specific abilities during the past few decades. It is well-known that a CEO's human capital may have a significant effect on a company's success, making it a crucial factor in the hiring process. If the CEO possesses the required general and firm-specific talents, they can boost the company's productivity, leading to an increase in revenue and market share. From 1970 until the beginning of the new millennium, external recruiting increases dramatically, with the relative importance of general talents over firm-specific skills viewed as a major component of this trend. Given the decline in external hiring over the past two decades, this study shows the need to reevaluate not only the relative relevance of general and firm-specific talents but also the cost-benefit tradeoff between external and internal hiring. In particular, the results show the factors that firms might consider when recruiting CEO successors: while external candidates are likely to have a greater range of general managerial experience, they may also demand higher premiums for the uncertainty of fit and for their superior general skills.

2.5 Appendix B

2.5.1 Variables Definitions

Table 2.14 displays the definitions of variables. Panels A, B, and C, respectively, define CEO compensation, CEO characteristics, and firm characteristics.

2.5.2 Robustness Check: Industry Classification and Appointment After 2009

According to the North American Industry Classification System (NAICS) classification,[11] I re-classify hiring firms into 20 industries and replace the industry dummies classified according to Standard Industrial Classification in Tables 2.3 and 2.4 with these industry dummies classified according to NAICS in the regression and the results are displayed in Table 2.15 columns (1)-(4). On

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[11] See https://www.census.gov/naics/?58967?yearbck=2022 for North American Industry Classification System.

Table 2.14: Variable Definitions

Variables	Descriptions
Panel A: CEO pay	
Total Pay	Total CEO pay in thousands of dollars, which consists of salary, bonus, value of restricted stock granted, value of options granted, long-term incentive payout, and other compensation (EXECUCOMP_TDC1).
Cash Pay	Salary plus bonus in thousand in thousands of dollars (EXECUCOMPTOTAL_CURR).
Equity Pay	Value of restricted stock granted plus value of options granted in thousands of dollars (EXECUCOMP_RSTKGRNT+OPTION_AWARDS_BLK_VALUE).
Panel B: CEO characteristics	
General Ability Index	Factors combination of applying principal components analysis to five proxies of general managerial ability: past Number of Positions, Number of Firms, Number of Industries, CEO Experience Dummy, and Conglomerate Experience Dummy (BoardEx).
Number of Positions	Number of positions CEO has had based on past work experience in publicly traded firms (BoardEx).
Number of Firms	Number of firms where CEO has worked based on past work experience in publicly traded firms (BoardEx).
Number of Industries	Number of industries[two-digit standard industrial classification (SIC)]I n which CEO has worked based on past work experience in publicly traded, private, or quoted firms (BoardEx).
CEO Experience Dummy	Dummy variable that takes a value of one if CEO held a CEO position based on past work experience in publicly traded, private, or quoted firms, and zero otherwise (BoardEx).
Conglomerate Experience Dummy	Dummy variable that takes a value of one if CEO worked at multi-segment company based on past work experience in publicly traded , private, or quoted firms and zero otherwise (BoardEx).
CEO Age	Age of CEO in years (BoardEx).
External Appointing Dummy	Dummy variable that takes a value of zero if the CEO worked for the hiring firm one and half years continuously prior to being appointed or has three or more years of accumulated working experience in the hiring firm, and the dummy takes a value of one otherwise (BoardEx).
External Outsider Dummy	Dummy variable that takes a value of one if External Appointing Dummy takes a value of one and the CEO worked for the hiring firms less than three years(accumulated) in managerial roles(keywords in BoardEx database include: director, SD, senior, manager, board) and zero otherwise (BoardEx).
Independent Board Year	Cumulative years working as an independent board member in firms other than the hiring firm (BoardEx).
Independent Board Number	Number of firms other than the hiring firm in which the CEO worked as an independent board member (BoardEx).
Longest Serve In A Firm	The longest duration (in years) that a CEO works for one firm (BoardEx).
Total Career Work Year	The duration (in years) of a CEO's career (BoardEx).
Certificate Dummy	Dummy variable that takes a value of 1 if the CEO holds special certificates such as C.F.A, C.P.A, F.R.M, M.D, etc. It takes a value of 0 otherwise (BoardEx).
Board Dummy	Dummy variable that takes a value of 1 if CEO held board position previously, and takes a value of 0 otherwise (BoardEx).
Panel C: Firm characteristics	
Sales Over Net(Sales)	Sales in millions of dollars (Compustat SALE).
Tobin's Q	Sum of total assets plus market value of equity minus book value of equity divided by total assets [Compustat (AT+CSHOPRCC_F -CEQ)/AT)].
ROA	Earnings before interest and taxes divided by total assets (Compustat EBIT/AT)
Stock Returns	Stockreturn [Compustat (PRCC_F(t)/AJEX(t)+DVPSX_F(t)/AJEX(t))/(PRCC_F(t-1)/AJEX_F(t-1))].
Leverage	Total debt, defined as debt in current liabilities plus long-term debt, divided by total assets [Compustat (DLC+DLTT)/AT].
CASH	Cash and short-term investments divided by total assets (Compustat CHE/AT).
CAPEX	Capital expenditures divided by total assets (Compustat CAPX/AT).
ROE	Net income divided by total assets (Compustat NI/AT).
Annualized Volatility	Annualized standard deviation of monthly stock returns (Center for Research in Security Prices *(CRSP)* database).

Variable definition is following Table A1 ((Custódio et al., 2013))

Table 2.15: Robustness Check: Industry Classification and Time in Probit Model

Dependent Variable: External Dummy

	Change Industry Classfications				Appointment Year After 2009			
	Probit	IV	LPM	IV	Probit	IV	LPM	IV
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
General Ability Index	0.215***	0.370***	0.056***	0.101***	0.220***	0.370***	0.064***	0.115***
	(0.033)	(0.068)	(0.009)	(0.021)	(0.039)	(0.076)	(0.012)	(0.025)
LnSales t-1	-0.081***	-0.094***	-0.021***	-0.026***	-0.090***	-0.102***	-0.026***	-0.030***
	(0.019)	(0.019)	(0.005)	(0.006)	(0.022)	(0.023)	(0.006)	(0.007)
CEO Control Variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm Control Variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry & Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3206	3206	3206	3206	1834	1834	1834	1834
R^2	.	.	0.136	0.038	.	.	0.076	0.044
χ^2	312.432	314.277	.	.	243.468	238.788	.	.

Standard errors in parentheses. Standard errors are clustered to CEO-firm appointing. The dependent variable is the external dummy. The instrumented variable is General Ability Index at year $t-1$. CEO and firm control variables are the same as Table 2.3. In Columns (1) to (4), the industries are classified into 20 industries according to North American Industry Classification System(NAICS) code. In Columns (5) to (8), the years prior to 2010 are excluded, and industries are classified into 9 industries according to the SIC code. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

the other hand, according to Murphy and Zabojnik (2007); Frydman (2019); Custódio et al. (2013); Chen et al. (2021), the external hiring rate steadily increased while generalists were employed due to the change from firm-specific capabilities to general abilities before 2008. To observe the trend clearly over the past few years and exclude the abnormal period during the financial crisis and accompanying recession, columns (5)-(8) show the regressions using newly appointed CEO data after 2009.[12] The results are consistent with the baseline and instrumented results in Section 2.3,[13] which implies that there has been a trend during the past decade, from 2001 to 2020, for companies to hire from within while successors' general abilities are positively and significantly linked to external hiring.

2.5.3 Summary: General Ability Index By Gender and Certificate

Table 2.16 shows a summary of the internal and external hiring decisions, categorized by gender and whether or not the successor CEO holds a certificate, with different general ability levels.

2.5.4 Hiring Choice And Hiring Reasons

In this section, I examine whether a company's choice of CEO succession depends on the temporary appointment (hiring an interim CEO) or the reason for the previous CEOs' departure. According to available data, the reasons for the departure of previous CEOs are categorized as "Resign", "Retire", and "Unknown". Results are displayed in Table 2.17. There is no statistically significant association between temporary replacement and firms' internal/external recruiting decisions, as seen in columns (2) and (5) of Table 2.17. In comparison to firms whose prior CEOs' reasons for leaving are not clear, firms whose preceding CEOs have either retired or resigned are not statistically more likely to hire external or internal candidates, as seen in columns (3) and (6) of Table 2.17.

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[12] According to *the U.S. National Bureau of Economic Research (the official arbiter of U.S. recessions)* the recession began in December 2007 and ended in June 2009, spanning a total of eighteen months. https://www.nber.org/research/business-cycle-dating

[13] In the linear probability model, the Kleibergen-Paap rk Wald F statistic has a value of 270.527, where Stock-Yogo weak ID test critical value (10% maximal IV size) is 19.93. Hansen J statistic has a value of 0.001 with a corresponding $P-$ value of 0.980. The endogeneity test has a value of 5.499 and a corresponding $P-$ value of 0.019. In the Probit model, the weak IV Anderson-Rubin test $\chi^2(2)$ has a value of 29.39 with a corresponding $P-$value of 0.000; the overidentifying test has a value of 1.920 and $P-$value of 0.167; and the endogeneity test Wald $\chi^2(1)$ has a value of 5.21 with a corresponding $P-$value of 0.023.

Table 2.16: Internal and External Hiring Overview For Male/Female And Certificate/No Certificate At Different General Ability Level

Panel A: Gender and General Ability Index	Female			Male		
	Observations			Observations		
	Internal Promotion	External	External As % of Total	Internal Promotion	External	External As % of Total
General Ability Index						
General Ability Index$<=-1.8$	1	0	0.000%	37	9	19.565%
General Ability Index$(-1.8,-0.8]$	28	3	9.677%	567	108	16.000%
General Ability Index$(-0.8,0.2]$	44	9	16.981%	973	236	19.520%
General Ability Index$(0.2,1.2]$	48	13	21.311%	539	191	26.164%
General Ability Index$(1.2,2.2]$	9	9	50.000%	237	93	28.182%
General Ability Index>2.2	3	5	62.500%	52	35	67.307%

Panel B: Certificate and General Ability Index	With Certificate			Without Certificate		
	Observations			Observations		
	Internal Promotion	External	External As % of Total	Internal Promotion	External	External As % of Total
General Ability Index						
General Ability Index$<=-1.8$	2	1	33.333%	36	8	18.182%
General Ability Index$(-1.8,-0.8]$	44	12	21.429%	551	99	15.231%
General Ability Index$=(-0.8,0.2]$	72	22	23.404%	944	223	19.109%
General Ability Index$(0.2,1.2]$	47	15	24.193%	540	189	25.926%
General Ability Index$(1.2,2.2]$	15	7	31.818%	231	95	29.141%
General Ability Index>2.2	1	2	66.667%	54	38	41.304%

Table 2.17: External Hiring and Precedessor Departure Reasons IV Regressions Reduced Form

Dependent Variable: External Dummy	Probit			IV		
	(1)	(2)	(3)	(4)	(5)	(6)
General Ability Index	0.216***	0.137***	0.136***	0.343***	0.234***	0.127***
	(0.031)	(0.032)	(0.032)	(0.065)	(0.068)	(0.040)
LnSales t-1	-0.067***	-0.065***	-0.064***	-0.078***	-0.073***	-0.063***
	(0.018)	(0.018)	(0.018)	(0.019)	(0.019)	(0.018)
Temporary Appointing Dummy		-0.074			-0.084	
		(0.107)			(0.108)	
Resign Dummy			-0.019			-0.020
			(0.062)			(0.063)
Retire Dummy			-0.007			-0.007
			(0.109)			(0.109)
CEO Control Variables	Yes	Yes	Yes	Yes	Yes	Yes
Firm Control Variables	Yes	Yes	Yes	Yes	Yes	Yes
Industry ×Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3206	3206	3206	3206	3206	3206
χ^2	283.523	255.485	256.182	286.420	256.998	256.290

Standard errors in parentheses. Standard errors are clustered to CEO-firm appointing. The dependent variable is External Dummy at hiring year t. Other CEO and firm control variables are the same as Table 2.3. Industries are classified into nine industries according to the first two-digit SIC code. Temporary appointing dummy takes a value of 1 if the new CEO is replaced within one year; otherwise, it takes a value of 0. Resign and retire dummy take the value of 1 if the predecessor CEO resigned or retired, respectively, and take the value of 0 otherwise.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

2.5.5 Robustness Check: Nonlinear Relationship Between CEO Compensation and Firm Size

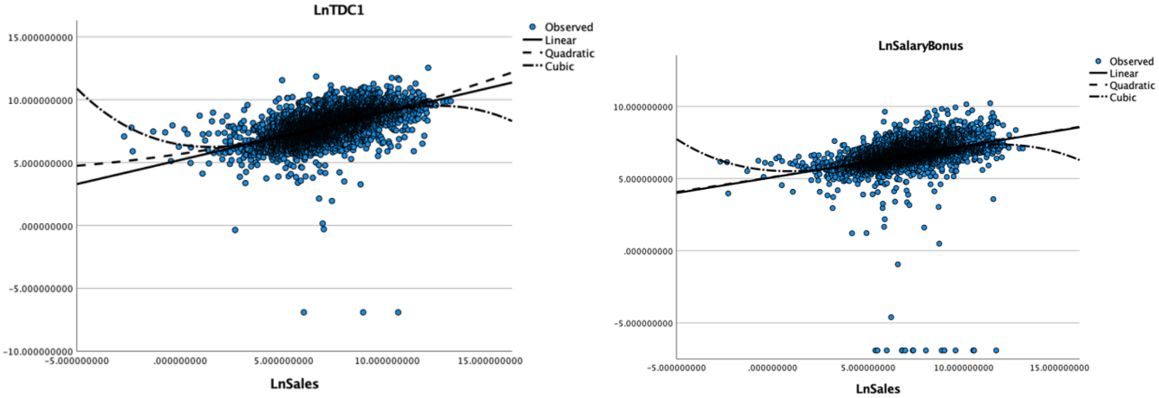

Figure 2.5: Curve Fit of CEO Cash Pay and Total Pay

Murphy and Zabojnik (2007) suggest that the relationship between CEO compensation and firm size is nonlinear in the labor market model. Curve fits of the regressions of CEO compensation on firm size, as shown in Figure 2.5, where the log of CEO both cash and total compensation are the dependent variable and the log of the *Sales Over Net* in COMPSTAT (firm size proxy) is the independent variable, also suggest that linear, quadric and cubic models are significant for both cash compensation and total compensation. I verify the monotonic relation between compensation and firm size using the following regressions with square and cubic terms of firm size for further testing:

$$Payment_{ijt} = \beta_0 + \beta_1 X_{it} + (\beta_2 Z_{jt} + \beta_3 Z_{jt}^2) + \beta_5 \theta_{jt} + \beta_6 \theta_{jt-1} + \beta_7 G_{it} + \gamma_t + \zeta_j + \eta_{ijt} \tag{11}$$

$$Payment_{ijt} = \beta_0 + \beta_1 X_{it} + (\beta_2 Z_{jt} + \beta_3 Z_{jt}^2 + \beta_4 Z_{jt}^3) + \beta_5 \theta_{jt} + \beta_6 \theta_{jt-1} + \beta_7 G_{it} + \gamma_t + \zeta_j + \eta_{ijt} \tag{12}$$

where all variables are defined identically to the linear regression in (10) and Z_{jt}^2 and Z_{jt}^3 represent the square and cubic terms of firm size, respectively. The results of the CEO cash and total compensation regressions are displayed in Table 2.18.

In particular, the non-linear estimates between firm size and CEOs' initial total compensation are displayed in columns (2) and (3), and the non-linear estimates between firm size and CEOs' initial cash compensation are displayed in columns (5) and (6). (6). However, column (2) indicates that the total compensation increases if the logarithm of sales ranges from 0 to 22.621, and column

(3) indicates that the total compensation increases if the logarithm of sales ranges from 0.022 to 13.745. In column (5), cash compensation increases if the logarithm of sales is between 0 and 23.142; in column (6), cash compensation increases if the logarithm of sales is between 2.391 and 11.851. Given that firm size (the logarithm of *Sales* in period t) falls between 2.47 and 11.395, all models (linear, square, and cubic) in Table 2.18 columns (1)-(6) imply that the initial total and cash compensation are monotonically increasing in firm size in the selected sample.

Therefore, there is no evidence to support the hypothesis that there are non-linear relationships between the initial total or cash compensation of CEOs and the sizes of the firms.

Table 2.18: CEO Compensation Nonlinearity Robustness Check

	(Total Pay)			(Cash Pay)		
	(1)	(2)	(3)	(4)	(5)	(6)
General Ability Index	0.098^{***}	0.100^{***}	0.099^{***}	0.019	0.020	0.020
	(0.021)	(0.021)	(0.020)	(0.020)	(0.020)	(0.020)
Age	-0.011^{***}	-0.011^{***}	-0.011^{***}	-0.002	-0.002	-0.002
	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.003)
LnSales	0.362^{***}	0.548^{***}	-0.795^{***}	0.219^{***}	0.324^{***}	-0.440
	(0.014)	(0.081)	(0.280)	(0.016)	(0.087)	(0.277)
LnSales^2		-0.012^{**}	0.181^{***}		-0.007	0.105^{**}
		(0.005)	(0.040)		(0.006)	(0.041)
LnSales^3			-0.009^{***}			-0.005^{***}
			(0.002)			(0.002)
Ratio Equity	1.336^{***}	1.341^{***}	1.356^{***}			
	(0.336)	(0.332)	(0.326)			
Constant	5.279^{***}	4.591^{***}	7.572^{***}	4.462^{***}	4.230^{***}	4.596^{***}
	(0.257)	(0.369)	(0.731)	(0.445)	(0.662)	(1.034)
CEO Control Variables	Yes	Yes	Yes	Yes	Yes	Yes
Firm Control Variables	Yes	Yes	Yes	Yes	Yes	Yes
Industry ×Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3139	3139	3139	3139	3139	3139
R^2	0.420	0.421	0.426	0.151	0.152	0.158

Standard errors in parentheses. Standard errors are clustered to CEO-firm appointing. The dependent variable is the logarithm of CEO total pay in Columns (1)-(3) and the logarithm of CEO cash pay in Columns (4)-(6) of the hiring year t. CEO and Firm control variables are the same as Table 2.11. Industries are classified into nine industries according to the first two-digit Standard Industrial Classification (SIC).

$^{*}\ p < 0.1$, $^{**}\ p < 0.05$, $^{***}\ p < 0.01$.

Chapter 3

Industry Collusion On Quality Disclosure Strategy

3.1 Introduction

There is an ongoing debate about the best way to regulate firms' disclosure of product information. The disclosure of product information is important to consumers' purchase decisions and hence consumer welfare. Examples include information about the nutritional worth and healthiness of food products, the environmental impact of manufacturing processes, and the geographical origins of components. If firms reveal information regarding the wholesomeness and nutritive value of their food products, for example, consumers can make more informed decisions about what they eat, which can lead to improved public health. Similarly, if firms disclose information about the environmental impact of their production processes, consumers will be able to make more environmentally conscious purchasing decisions, which could contribute to the reduction of environmental damage. Yet, the level of disclosure in informing consumers and influencing their behavior may depend on a variety of factors. For instance, consumers may lack the time, money, or expertise to completely absorb and apply the information offered by businesses.[1] However, firms may disclose incorrect or misleading information, which can lead to consumer confusion and reduce the effectiveness of disclosure. A recent class action lawsuit claims that Aveeno's "Active Naturals" products are fraudulent and/or misleading because they claim to consumers that the ingredients are natural when, in fact, they include unnatural, synthetic, and potentially harmful compounds. Hence,

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[1] Grunert et al. (2010) show that nutrition usage is more likely for health-related reasons and that nutrition knowledge is mostly related to the comprehension of nutrition information on food labels. Both are affected by demographic variables but in different ways.

a settlement fund in the amount of 675,000 (in U.S. Dollars) has been formed.[2]

Ideally, to ensure informed decisions by consumers, the regulatory authority may want to mandate the disclosure of quality information by firms. There indeed exist some such mandatory disclosure laws. An example cited by Gruère et al. (2008) is the Nutrition Labeling and Education Act (NLEA) in the US. European Union also has laws that require the clear labeling of genetically modified (GM) food and feed (Regulation (EC) No 1829/2003). Such laws, however, may be difficult and costly to enforce. Moreover, in some cases, consumers may not have a choice in the products they purchase. As a result of the mandatory labelling of genetically modified foods in the European Union, consumers are forced to purchase Non-GM foods regardless of their preferences, as GM producers cease selling (Gruère et al., 2008).

Previous studies have discussed the effects of mandatory and/or voluntary disclosure. Theoretically, market dynamics create incentives for sellers to reveal information even in the absence of mandatory disclosure Jovanovic (1982). Further, not all customers comprehend the seller's information. Hence, mandatory disclosure benefits only the informed while harming the seller (Fishman and Hagerty, 2003). Empirical research indicates that voluntary and mandated disclosure policies can have a variety of implications on customer behaviour and competitiveness and that firms can use disclosure strategically to differentiate themselves from competitors or control costs. Mathios (2000) shows that, in the salad dressing sector, disclosure on a voluntary basis is an important market mechanism, and compulsory labelling can alter consumer behavior and health, even in countries with low-cost disclosure mechanisms. Jin (2005) demonstrates that the rate of disclosure is lower in highly competitive markets when HMOs use voluntary disclosure to differentiate themselves from competitors. Bederson et al. (2018) discover that restaurants with a higher quality are less likely to disclose cleanliness information than restaurants with a lower quality.

Early studies suggest that firms will disclose information voluntarily if it is costless (Grossman and Hart, 1980; Grossman, 1981). Recent studies have demonstrated a great interest in the equilibria of quality disclosure in the context of price competition (Celik, 2014; Zhao et al., 2018;

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[2] Another example is Keurig's $10 million settlement for deceptive labelling. The lawsuit alleged that Keurig's "Have your cup and recycle it, too"-labeled K-Cup pods were not recyclable in several regions. Now, Keurig must properly label and advertise its recyclable products. Until March 21, 2021, the settlement will compensate pod purchasers between 2010 and 2020.

Koessler and Renault, 2012; Sun, 2011) and customer preferences (Zhang and Li, 2021; Zhao et al., 2020; Heyes et al., 2020).[3] Other literature examines the cases that prevent firms' full disclosure (Zhao et al., 2018; Fishman and Hagerty, 2003). Following Gabszewicz and Thisse (1979) model where production is at no cost, Board (2009), in line with Hotz and Xiao (2013) and Guo and Zhao (2009) who show that there is less disclosure under duopoly than under the monopoly proposed by Grossman and Hart (1980), demonstrates the existence of a partial equilibrium that may prevent firms from disclosing all information. In addition, Levin et al. (2009) discuss a costly disclosure model employing both horizontal and vertical differentiation under a duopoly and a cartel, where the expected disclosure is greater under a cartel than a duopoly.

In practice, some standards are set by industry associations and rely on self-enforcement.[4] Industry self-regulation widely employs quality certificates.[5] Examples include Sustainable Forestry Initiative (SFI), the Responsible Jewellery Council (RJC), and the Marine Stewardship Council (MSC).[6] In this chapter, we investigate how firms optimally set product labeling rules, in a model of duopoly. We adopt the vertical differentiation model of Gabszewicz and Thisse (1979), subsequently used by Board (2009) in his analysis of competition and disclosure. Like Board (2009), we assume that the firms cannot collude with each other on prices due to antitrust enforcement against such collusion. In contrast to Board (2009), however, we assume that the industry as a whole can

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[3] Celik (2014) presents an equilibrium in which a seller discloses information when buyer's preference is private information; Zhao et al. (2018) demonstrates an equilibrium in which an high-quality may decide not to hide its quality, while an low-quality may choose to act in the opposite manner; Koessler and Renault (2012) focus on the heterogeneity of consumer preferences; and Sun (2011) show that products with superior vertical quality are less prone to showing horizontal qualities. On the other hand, Zhang and Li (2021) show that symmetric firms are more likely to disclose when consumer loss aversion is present; consumers' comprehension of disclosed information is higher when there is signalling(Heyes et al., 2020); and Zhao et al. (2020) show that disclosure of intermediary product quality relies on customer tastes.

[4] Sharma et al. (2010) provide examples of the food industry's self-regulation on disclosure of product information. One such example is the so-called "Smart Choices" program, created by Keystone Center in collaboration with several major food companies. The Smart Choices Program involves the use of a green-and-white symbol with a check and the words "Smart Choices Program: Guiding Food Choices" on the front of food packaging, along with disclosure of calories information and designation of products that meet the "Smart Choices" criteria.

[5] While Viscusi (1978) claims that high-quality products quit the market when there is a quality certificate, Stahl and Strausz (2017) show it benefits sellers.

[6] Companies that meet SFI's responsible forestry guidelines are certified. SFI mandates companies to identify the source of their wood materials, the chemicals used in manufacturing, and their environmental impact. In the jewelry supply chain, RJC encourages ethical, social, and environmental principles. The RJC's certification program demands members to follow high human rights, labor, and environmental requirements. Wild-caught seafood is certified by MSC. The MSC compels firms to publish their fishing activities, including the type of fish harvested, the methods utilized, and the impact on the marine ecosystem.

commit to a scheme of information disclosure, with the goal of joint profit maximization. Specifically, an industry should only disclose the order of the products' qualities.

To recap, our aim in this chapter is to show how an industry will do if they could jointly set a disclosure strategy to maximize the joint profit. The rest of the chapter is organized as follows. Section 3.2 presents the theoretical model. Section 3.3 characterizes the industry's optimal strategy following Board (2009), where the high-quality product is always disclosed and the low-quality product is only disclosed if its quality falls in an intermediate ratio to the high-quality product. Section 3.4 describes the optimal industry disclosure strategies using product quality ratios. Section 3.5 concludes.

3.2 Model

Our model is adapted from that of Board (2009). Consider an industry with two firms, 1 and 2. They each produce, at zero costs, a product with an exogenously determined quality, denoted by s_1 and s_2, which are not observable to the consumers. It is common knowledge that they are independently drawn from the uniform distribution on $[0, 1]$. Before competing against each other in prices, firms may disclose quality in a costless and verifiable way. We depart from Board (2009), however, in that we assume the firms may come to an agreement on how to disclose information about s_1 and s_2 to consumers.[7]

Consumers are assumed to have heterogeneous preferences about quality, represented by a taste parameter θ that is uniformly distributed on $[0, 1]$. Each consumer can purchase either 0 or 1 unit of either good, but not both goods. The utility for a consumer with taste parameter θ who purchases 1 unit of product $i \in 1, 2$ at price p_i is:

$$u_i = \theta s_i - p_i.$$

Given that a consumer's utility is an affine function of product quality, a consumer's decision is determined by the difference in the expected quality of the two products. We directly borrow Board's

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[7] Price cannot reflect quality in our setting as pricing does not require supporting information and can be combined with disclosure in the first stage.

(2009) analysis of the consumer's purchase decision and firms' profits in equilibrium. Similar to Board (2009), we assume that firms know each other's quality and that all disclosure of information is public. Thus, conditional on the information disclosed, a consumer's expected value of each firm's product's quality is common knowledge. We first state a Lemma that directly follows from Board's (2009) analysis. Let x_1 and x_2 be a consumer's expected quality of firms 1 and 2's products conditional on the information disclosed, respectively.

Lemma 3.1. Consider the case $x_1 < x_2$. The equilibrium of the price competition between the firms can be characterized by:

$$\begin{aligned} p_1^* &= \frac{x_1(x_2 - x_1)}{4x_2 - x_1}, \quad p_2^* = \frac{2x_2(x_2 - x_1)}{4x_2 - x_1}; \\ D_1^* &= \frac{x_2}{4x_2 - x_1}, \quad D_2^* = \frac{2x_2}{4x_2 - x_1}; \\ \pi_1^* &= \frac{x_1 x_2 (x_2 - x_1)}{(4x_2 - x_1)^2}, \quad \pi_2^* = \frac{4{x_2}^2(x_2 - x_1)}{(4x_2 - x_1)^2}. \end{aligned}$$

where D_1^* and D_2^* are consumers' demands of products 1 and 2, and π_1^* and π_2^* are the profit of selling products 1 and 2, respectively. The joint profit of the industry is

$$\pi^*(x_1, x_2) = \pi_1^* + \pi_2^* = \frac{x_2(x_2 - x_1)(4x_2 + x_1)}{(4x_2 - x_1)^2}. \tag{13}$$

Note that the case $x_2 < x_1$ is analogous. On the other hand, if $x_1 = x_2$, we are in the case of Bertrand competition with no product differentiation, which leads to both firms earning zero profits. For joint profit shown in equation (13), the following proposition holds:

Proposition 3.1. Let $0 \leq x_1 \leq x_2 \leq 1$. The function π^* satisfies:

(1) **Monotonicity:** function $\pi^*(x_1, x_2)$ is strictly increasing in x_2 and strictly decreasing in x_1 when fixing the other variable.

(2) **Concavity:** function $\pi^*(x_1, x_2)$ is concave in both x_2 and strictly concave in x_1 when fixing the other variable.

Proof. For monotonicity, we verify the First-Order Conditions(FOCs) of joint profit regarding x_1

and x_2, respectively.

$$\begin{cases} \frac{\partial\pi^*(x_1,x_2)}{\partial x_2} = \frac{16x_2^3 - 12x_2^2x_1 + 10x_2x_1^2 + x_1^3}{(4x_2 - x_1)^3} > 0 \\ \frac{\partial\pi^*(x_1,x_2)}{\partial x_1} = \frac{-x_2^2(4x_2 + 11x_1)}{(4x_2 - y_1)^3} < 0 \end{cases}$$

And for concavity, we verify the Second-Order Conditions(SOCs) of joint profit regarding x_1 and x_2, respectively.

$$\begin{cases} \frac{(\partial)^2\pi^*(x_1,x_2)}{\partial x_2} = \frac{-2x_1^2(28x_2 + 11x_1)}{(4x_2 - x_1)^4} \leq 0 \\ \frac{\partial\pi^*(x_1,x_2)}{\partial x_1} = \frac{-x_2^2(28x_2 + 11x_1)}{(4x_2 - x_1)^3} < 0 \end{cases}$$

And $\nabla\pi^*(x_1, x_2)$ is Negative Semi-Definite.

□

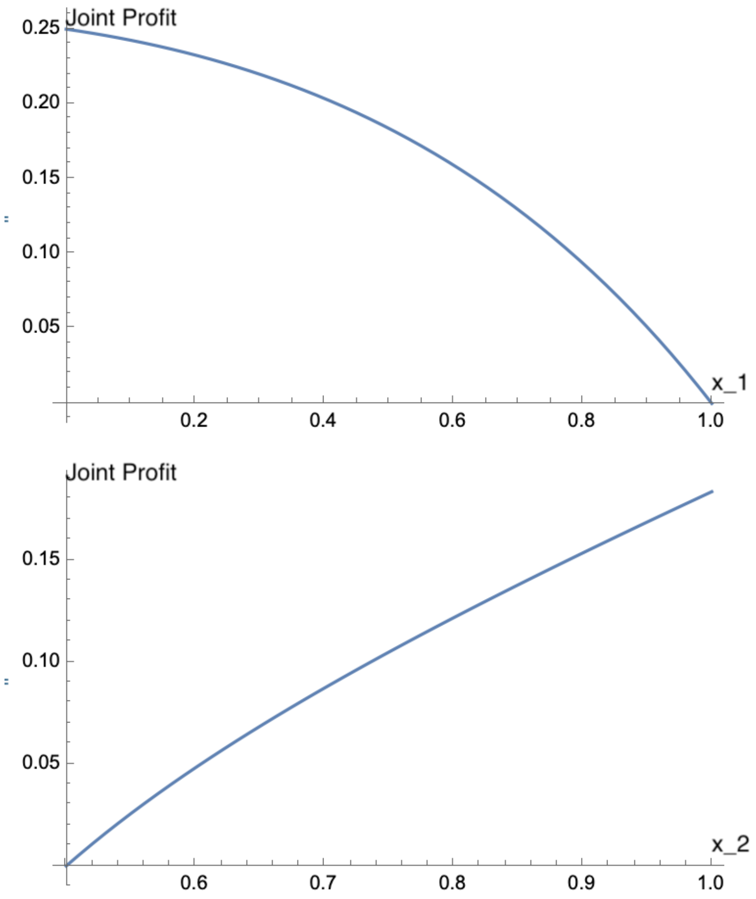


Figure 3.1: Joint Profit First-Order Conditions

Figure 3.1 displays two examples of FOCs of the joint profit. In the first graph in Figure 3.1,[8] we show that the joint profit decreases when the expected quality of the low-quality product, Product 1, increases. Consequently, it is not beneficial to raise consumers' expectations of Product 1's quality if Product 2's expected quality is fixed. In contrast, the second graph shows that the joint profit increases as the expected quality of the high-quality product (Product 2) increases.[9] Subsequently, it is beneficial to raise consumers' expected quality of Product 2 while keeping the expected quality of Product 1 constant. Jointly, the basic principle underlying the optimal disclosure policy is that products should be widely differentiated such that consumers would have high expectations for product 2's quality and low expectations for the product with inferior quality (Product 1). Figure 3.2 depicts the joint profit from different angles.[10]

Intuitively, given that the joint profit function in the study is concave, the incorporation of additional information may lead to a reduction in the dispersion of consumers' expectations regarding the qualities of Products 1 and 2, which may not benefit the joint profit or further lead to a decline.

3.3 A class of partial disclosure policy

We first consider a class of information disclosure policy that resembles the partial disclosure equilibrium characterized by Board (2009).[11] That is, the firm with the higher quality fully discloses its quality, while the one with the lower quality only discloses its quality in an intermediate range. Let us focus on the case $s_1 < s_2$. Then, s_2 is fully disclosed to the consumer and s_1 is disclosed if $s_1 \in [\underline{k}s_2, \overline{k}s_2]$.[12] Outside this range, Firm 1's quality is not disclosed. The joint profit obtained from selling the two products in this context is calculated as follows:

$$\pi = \pi_1 + \pi_2 = \int_0^1 \Big(\int_0^{\underline{k}s_2} \pi^*(x_1, s_2)\, ds_1 + \int_{\underline{k}s_2}^{\overline{k}s_2} \pi^*(s_1, s_2)\, ds_1 + \int_{\overline{k}s_2}^{s_2} \pi^*(x_1, s_2)\, ds_1 \Big)\, ds_2 \quad (14)$$

---

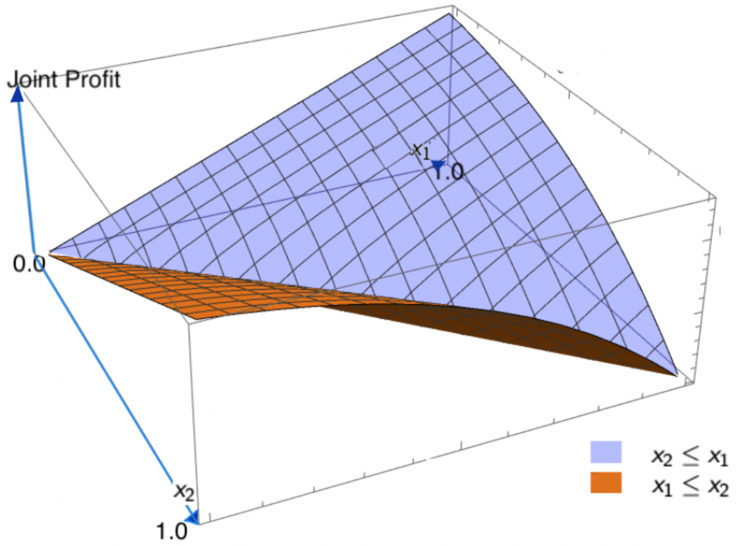
[8] We consider an example in which $x_2 = 1$ here.

[9] $x_1 = 0.5$ in this example.

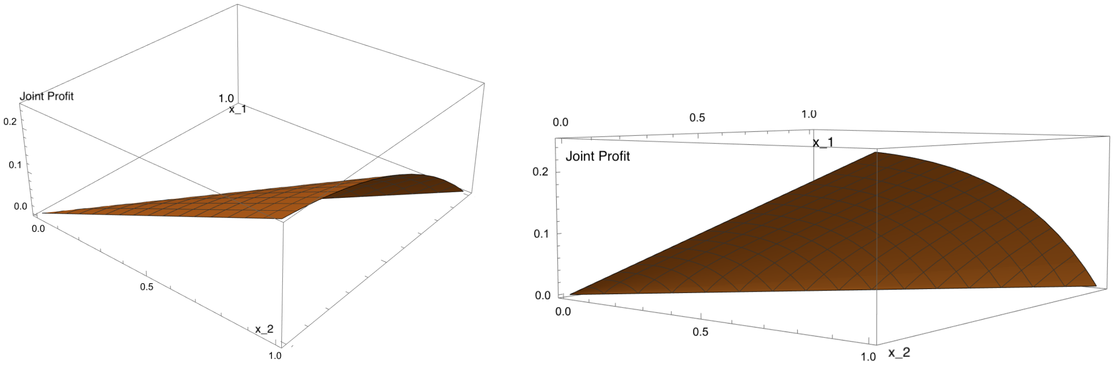
[10] Subfigure (a) in Figure 3.2 shows the joint profit including both cases when expected values $x_1 < x_2$ and $x_2 \leq x_1$. They are presented in orange and blue colors, respectively. Subfigures (b)-(d) show the joint profit in the case of $x_1 < x_2$ from different angles.

[11] In Board (2009), the equilibrium is derived when each firm maximizes its own profit following the assumption that consumers believe that the product disclosed is of high quality.

[12] $\underline{k}$ and $\overline{k}$ are endogenously determined in Board (2009).

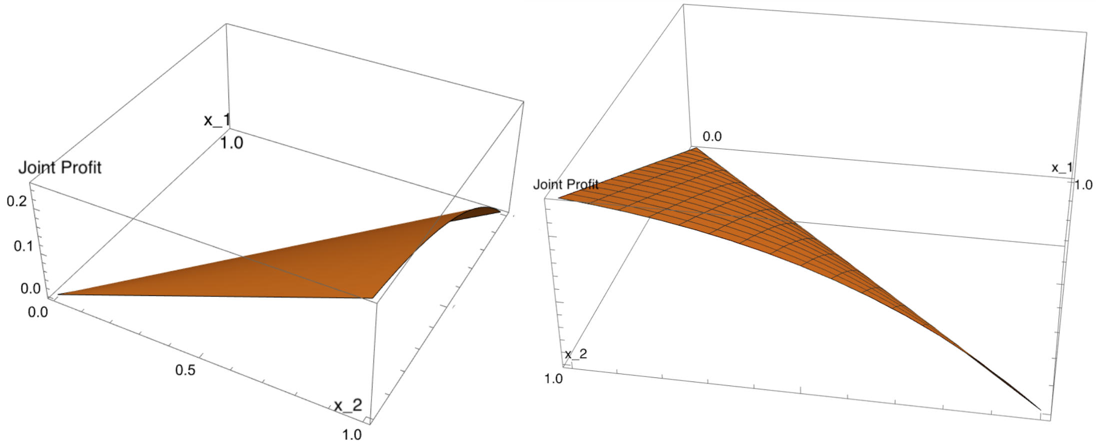


(a) Joint Profit



(b) Joint Profit: $x_1 < x_2$ (Angle 1)

(c) Joint Profit: $x_1 < x_2$ (Angle 2)



(d) Joint Profit: $x_1 < x_2$ (Angle 3)

(e) Joint Profit: $x_1 < x_2$ (Angle 4)

Figure 3.2: Joint Profit

where π^* is the joint profits expressions shown as equations (13).

In a partial-disclosure scenario, consumers only observe that the high-quality product s_2 has been disclosed. As a result, the expected quality of Product 1, x_1, when the quality of Product 1 is not disclosed, is calculated using conditional distribution. This distribution reflects the uncertainty that consumers have about the quality of product 1, given the information available to them. Given this information, they would form an expectation about the hidden quality of product 1, s_1. To do this, they would rationally expect that s_1 is uniformly distributed on the intervals $[0, \underline{k}s_2]$ and $[\overline{k}s_2, s_2]$, with a density of $1/(s_2 - \overline{k}s_2 + \underline{k}s_2)$. The expected quality is then described as following

$$x_1 = E(s_1 | s_1 \in [0, \underline{k}s_2] \cup [\overline{k}s_2, s_2]) = \frac{s_2(1 - \overline{k}^2 + \underline{k}^2)}{2(1 - \overline{k} + \underline{k})}. \tag{15}$$

Using the analysis of Board (2009), we may compute the joint profits of the firm. The following proposition characterizes the optimal one among the class of partial disclosure policies.

Proposition 3.2. Among the class of partial disclosure policy, $\underline{k} = \overline{k} \in [0, 1]$ maximizes the industry's joint profits. That is, only the higher quality is disclosed and the lower quality is not disclosed at all. This generates a joint profit of $3/49$.

Proof. First, we consider the case in which $\overline{k}$ is fixed. To elaborate, the current problem involves finding the optimal value of $\underline{k}$ that maximizes the joint profit,

$$\pi|_{\overline{k}=a} \tag{16}$$

where joint profit function is described in (13) and the value of $\overline{k}$ is fixed at $\overline{k} = a$. To obtain the joint profit in (16), first, note that the expected quality of Product 1 is

$$x_1 = E(s_1 | s_1 \in [0, \underline{k}s_2] \cup [as_2, s_2]) = \frac{s_2(1 - a^2 + \underline{k}^2)}{2(1 - a + \underline{k})}. \tag{17}$$

where s_2 is observed by consumers. Substituting (17) and (13) into (14) with $\overline{k} = a$, the joint profit

(16) can be expressed as:

$$\begin{aligned}\pi|_{\overline{k}=a} = \frac{1}{3}[(1-a+\underline{k})&\frac{(4+\frac{(1-a^2+\underline{k}^2)}{2(1-a+\underline{k})})(1-\frac{(1-a^2+\underline{k}^2)}{2(1-a+\underline{k})})}{(4-\frac{(1-a^2+\underline{k}^2)}{2(1-a+\underline{k})})^2} \\ &-(a-\underline{k}) - 11\ln(\frac{4-a}{4-\underline{k}}) - 24(\frac{1}{4-a}-\frac{1}{4-\underline{k}})]\end{aligned} \tag{18}$$

This is accomplished by first finding the interior solution, which is done by setting the first-order condition for the joint profit to 0 with respect to $\underline{k}$,

$$\frac{\partial\pi|_{\overline{k}=a}}{\partial\underline{k}} = 0,$$

regarding $\underline{k} \in (0, a)$. No value of $\underline{k}$ in $(0, a)$ satisfies this condition.

Apart from interior solutions, we then consider corner solutions, which occur when $\underline{k}$ takes on its boundary values of 0 or $\overline{k}$ such that the value of $\overline{k}$ is fixed at $\overline{k} = a$. The joint profits are as follows:

$$\begin{cases}\pi|(\overline{k} = a, \underline{k} = 0) < 3/49 \\ \pi|(\overline{k} = a, \underline{k} = a) = 3/49\end{cases}$$

where the joint profit of corner solution $(\overline{k} = a, \underline{k} = 0)$ is less than that of corner solution $(\overline{k} = a, \underline{k} = a)$.[13] □

Therefore, it is more incentive for the industry to not disclose the quality of product 1 (the low-quality product), i.e., $\overline{k} = \underline{k} = a$, for any value of a in the range [0,1], in order to maximize the joint profit from selling both products.

In order to provide a comparison, we evaluate the equilibrium in Board (2009) where $\overline{k}^* = 0.653$ and $\underline{k}^* = 0.486$ and the joint profit is 0.011. We also assess the joint profit that would result from a policy of full disclosure, in which customers would be informed of the qualities of both products, regardless of their actual qualities. Since there is no concealment of the product's quality from consumers, the industry could estimate the maximal joint profit of both products using the equation (23) in its decision-making process. Hence, the largest achievable profit under such a

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[13] The solution to FOC and joint profits in corner solutions are obtained with MATLAB.

disclosure policy is approximately 0.0548, which is less than the maximum possible profit of $3/49$ (approximately 0.0612) if the industry adopts the partial disclosure policy stated in Proposition 3.2. By disclosing additional information, specifically the particular value of Product 2's quality and that of Product 1's quality, both the expected quality of Product 1 and the difference between the expected qualities of Products 1 and 2 decrease. With the concavity of the joint profit function illustrated in Proposition 3.1, the gain from Product 1's low quality expectation is offset by the diminishing disparities between the expected qualities of Products 1 and 2.

3.4 Disclosing the ratio between the quality of products

We now turn our attention to a different class of disclosure policy. Here we consider an information disclosure policy that only tells the consumer full or partial information about the ratio between the quality levels. Again, we focus on the case $s_1 \leq s_2$. Let $\alpha = \{\alpha_1, \alpha_2, ..., \alpha_n\}$, where $n \geq 2$ and $0 \leq \alpha_1 \leq \alpha_2 \leq ... \leq \alpha_n = 1$. The industry only reveals information to consumers in the form of $0 \leq s_1 \leq \alpha_1 s_2$, $\alpha_i s_2 < s_1 \leq \alpha_{i+1} s_2$ for all $1 \leq i \leq n-1$.

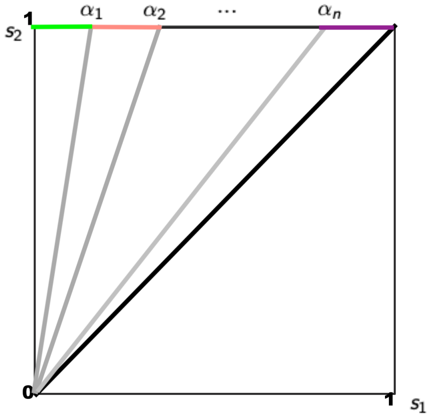

Figure 3.3: Disclosing the Ratios between Products Qualities

To compute the profits under this class of disclosure policy, the joint profit of the two firms is denoted as $(\pi_1 + \pi_2)_0$ when $s_1 \leq \alpha_1 s_2$, as $(\pi_1 + \pi_2)_i$ when $\alpha_i s_2 < s_1 \leq \alpha_{i+1} s_2$ (for all

$1 \leq i \leq n-1$).[14] In the absence of mandatory regulations, an industry can maximize its joint profit by finding the optimal cutoffs $\{\alpha_1^*, \alpha_2^*, ..., \alpha_n^*\}$ for quality disclosure through the following local optimization problem

$$\begin{aligned} \max_{\alpha=\{\alpha_1,\ldots,\alpha_n\}} \quad & \alpha_1(\pi_1+\pi_2)_0 + \sum_{i=1}^{n-1}(\alpha_{i+1}-\alpha_i)(\pi_1+\pi_2)_i \\ \text{s.t.} \quad & 0 \leq \alpha_1 \leq ... \leq \alpha_n = 1 \end{aligned} \tag{19}$$

In this case, the information that consumers have about the qualities of products 1 and 2 is limited to the information that the industry decides to disclose to them including $0 \leq s_1 \leq \alpha_1 s_2$, $\alpha_i s_2 < s_1 \leq \alpha_{i+1} s_2 \, (i = 1, \ldots, n-1)$. Depending on the relationship between the qualities s_1 and s_2, consumers will form expectations about the qualities of the two products based on the information they have been given. For example, if $0 \leq s_1 \leq \alpha_1 s_2$, then consumers would expect Product 1 to have lower quality than α_1 times the quality of Product 2. Specifically, the expectation of Product 1 is $\alpha_1/3$ if $0 \leq s_1 \leq \alpha_1 s_2$, is $(\alpha_{i+1}+\alpha_i)/3$ if $\alpha_i s_2 < s_1 \leq \alpha_{i+1} s_2$, whereas the expectation of Product 2 is $2/3$ regardless such relationship between the qualities s_1 and s_2. Thus, the industry's joint profit $(\pi_1+\pi_2)_0$ between cutoffs 0 and α_1 and $(\pi_1+\pi_2)_i$ between α_i and α_{i+1} can be obtained by substituting these expectations of Products 1 and 2 into equation(13) as following:

$$(\pi_1+\pi_2)_0 = \frac{2}{3} \cdot \frac{(2-\alpha_1)(8+\alpha_1)}{(8-\alpha_1)^2}, (\pi_1+\pi_2)_i = \frac{2}{3} \cdot \frac{(2-\alpha_i-\alpha_{i+1})(8+\alpha_i+\alpha_{i+1})}{(8-\alpha_i-\alpha_{i+1})^2}. \tag{20}$$

In order to make the analysis more straightforward, we will begin with a discussion about a single cutoff so that $n = 2$ and $\alpha_1 < \alpha_2 = 1$. Under these conditions, the industry achieves its goal of maximizing the joint profit

$$\alpha_1(\pi_1+\pi_2)_0 + (1-\alpha_1)(\pi_1+\pi_2)_1.$$

In this particular scenario, the only information that customers have access to on the quality of Products 1 and 2 is that which the industry chooses to make public, specifically $0 \leq s_1 \leq \alpha_1 s_2$ and $\alpha_1 s_2 < s_1 \leq s_2$. Consumers form expectations of Product 1 equal to $\alpha_1/3$ and $(\alpha_1+1)/3$

---

[14] Figure 3.3 illustrates an example of disclosing ratios between the qualities of products 1 and 2.

conditional on the relationships $0 \leq s_1 \leq \alpha_1 s_2$ and $\alpha_1 s_2 < s_1 \leq s_2$, respectively; nevertheless, the expectation of Product 2 remains the same at $2/3$ in both relationships. By plugging expectations into the calculation for the joint profit (20), we are able to determine that

$$(\pi_1 + \pi_2)_0 = \frac{2}{3} \cdot \frac{(2-\alpha_1)(8+\alpha_1)}{(8-\alpha_1)^2}, (\pi_1 + \pi_2)_1 = \frac{2}{3} \cdot \frac{(1-\alpha_1)(9+\alpha_1)}{(7-\alpha_1)^2}. \tag{21}$$

Solving the local optimizing problem (19) with joint profits shown in (21) yields $\alpha_1^* = 1$ and joint profit of $6/49$.[15]

Now we will extend our study to include the case where n is greater than 2. When calculating the joint profit with an additional cutoff between α_{n-1} and α_n, the majority of terms, specifically $(\pi_1 + \pi_2)_i \ \forall i = 1, 2, ..., n-1$, in the local maximizing problem (19) can be cancelled out. As a result, we will make the following claim:

Claim 3.1. $(\pi_1 + \pi_2)|_{n+1} \leq (\pi_1 + \pi_2)|_n \leq \frac{6}{49}$, where $n \geq 2$.[16]

Even if additional cutoffs are implemented, the overall amount of joint profits will not exceed its previous level. This finding is based on the function features of concavity and monotonicity; specifically, the joint profit is decreasing as consumers' quality expectations for Product 1 increase. In fact, introducing another cutoff point will result in a more spread-out distribution of the lower quality product (Product 1), while the expectation for the quality of Product 2 will remain unchanged with a value of $2/3$ in the context of this section. Hence, the discrepancy that previously existed between customers' expectations of Product 1 and 2's qualities has decreased somewhat. Hence, the joint profit will not improve. As a direct result, we could directly derive the following proposition from Claim 3.1:

Proposition 3.3. Among the class of disclosure policy that discloses ratios between the quality levels, $\alpha_1^* = \alpha_2^* = \ldots = \alpha_n^* = 1$ maximizes the industry's joint profits. That is, the disclosure policy only tells the consumers $s_1 \leq s_2$. This generates a joint profit of $6/49$.

The industry will not always disclose the quality of a high-quality product s_2 because the joint profit function is concave if $s_1 \leq s_2$ or vice versa.

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[15] The local optimizing problem is solved with Python local search optimization algorithms *scipy.optimize*

[16] $(\pi_1 + \pi_2)|_{n+1}$ denotes the joint profit in (19) when $\alpha = \{\alpha_1, \alpha_2, ..., \alpha_{n+1}\}$ and $(\pi_1 + \pi_2)|_n$ denotes the joint profit when $\alpha = \{\alpha_1, \alpha_2, ..., \alpha_n\}$.

The proposition has many implications for the business sector. Consider the label "handmade" in the craftsmanship industry, such as furniture making. In some cases, the "handmade" label is associated with a higher degree of quality, particularly if the product is constructed with greater care and attention to detail, i.e., it was created by skilled artisans using traditional techniques and premium ingredients or materials. These handcrafted items are frequently produced in small quantities and sold at local markets or specialty shops. They may command a premium price due to the notion that they are of higher quality or more unique than mass-produced goods. In the context of art, handcrafted artifacts may be seen as more valuable due to the fact that they are original, one-of-a-kind, and the artist has invested considerable time and skill in their creation. In this case, the handmade label promotes vertical differentiation by separating the piece of art from identical, mass-produced commodities and evaluating the two products based on their perceived quality, rarity, and artisanal craftsmanship. Customers who value artisanal craftsmanship and are willing to pay a premium for it may prefer the handcrafted brand over the mass-produced brand, whereas customers who place a priority on affordability may go for the more affordable option. A group of artisanal furniture makers can agree to label one type of product as "handmade" in order to differentiate their high-quality product from mass-produced furniture and to justify a higher joint profit.

Canadian organic labelling would be a counterexample. In the absence of regulation, food producers would collude to maximize their joint profits by strategically disclosing the quality of one product while concealing the quality of another. In this particular instance, one product may be branded "organic" while another is not. In Canada, however, "organic" labelling is voluntary, but specific delacaritions are governed by the *Canadian Food Inspection Agency*. Specifically, *Canadian Food Inspection Agency* set multiple cutoffs regarding products' qualities: "Only products with organic content greater than or equal to 95 percent may be labelled or advertised as 'organic' or bear the organic logo; Multi-ingredient products containing between 95 and 100 percent organic content may label 'X percent organic ingredients'; Multi-ingredient products containing between 70 and 95 percent organic content may label 'contains x percent organic ingredients'; Multi-ingredient products containing less than 70% organic content may not use the organic logo nor the claims 'organic' or 'contains x% organic ingredients'." [17] The rules prohibit industry collusion in disclosure strategies that merely rank qualities. By introducing extra cutoff points, the quality expectation for low-quality products, in this case defined as non-organic, will be fixed or improved, while the expectation for organic products will remain unchanged given the existing settings of the model. Thus, the difference between non-organic and organic customer expectations would expand, resulting in a (weakly) decline in joint profit.[18]

3.5 Conclusion

In this chapter, we analyze the quality disclosure strategies of an industry in an effort to maximize joint profits. In an environment where there is no regulation in place, we discuss the various classes of applicable disclosure strategies and then propose the optimal disclosure strategy for an industry in the vertical differentiation duopoly model. We demonstrate how an industry can jointly design an optimal disclosure policy of private information about product qualities in a price-competitive environment. While hiding the actual qualities, it is optimal for an industry to only disclose the order of the products' qualities to maximize its joint profit. Moreover, disclosing a product's quality range relative to another product, such as labeling products as "organic", "X percent organic ingredients", and "contains x percent organic ingredients", will not increase the industry's joint profit. Consequently, when an industry is permitted to freely reveal product quality in the absence of mandatory disclosure requirements, the industry will collude to disclose only the order of product qualities in order to maximize its joint profit. Furthermore, our disclosure theory shows that disclosure laws, both voluntary and mandatory, may have an essential role in the markets of the real world. For example, organic labelling in Canada specifies cutoffs in terms of organic ingredient percentages, such that more detailed information about a product's organic ingredient

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[17] The terms of the regulation can be found at https://inspection.canada.ca/food-labels/labelling/industry/organic-claims/eng/1623967517085/1623967517522

[18] We also relax our assumption of consumers' taste to be uniformly distributed on $[0, n]$, where n is a positive rational number. The profits of products 1 and 2 are both multiplied by n^2. Therefore, the joint profit shown in equation (13) is also multiplied by n^2. In the case of relaxed consumer preferences, the Propositions 3.1-3.3 remain valid.

would allow consumers to pay for a quality expectation that is closer to actual quality at the expense of the industry's joint profit. Further research could be conducted in a variety of profitable directions. For instance, one may consider conducting an analysis of the consumer surplus, which is a crucial factor in the process of designing disclosure regulations, as these policies are typically aimed at assisting customers in understanding the quality of the items. In attempting to replicate the multi-product market that exists in the real world, the disclosure strategy involves a variety of products that could be expanded beyond the duopoly model in this chapter.

3.6 Appendix C

3.6.1 Proof of Lemma 3.1

Recall that qualities s_1 and s_2 of products 1 and 2 are independently drawn from a uniform distribution on $[0,1]$, with $s_1 < s_2$ without loss of generality; consumers have different tastes for quality, with a taste parameter θ that is uniformly distributed on $[0,1]$; and the maximum purchase for each consumer is 1 unit. The utility for a consumer with taste parameter θ who purchases 1 unit of product i at price p_i is:

$$u_i = \theta * s_i - p_i.$$

Proof. It is assumed that consumers believe only high-quality products will be disclosed (Board, 2009) and three scenarios for the disclosure of the qualities of the two products are identified. Given any information set A, let $x_1 = E(s_1|A)$ and $x_2 = E(s_2|A)$ denote consumers' expected qualities of Products 1 and 2, respectively.

The utility for consumers who consume products 1 and 2 are, respectively,

$$u_1 = \theta * x_1 - p_1, \quad u_2 = \theta * x_2 - p_2.$$

To obtain the demand curve for each product, solving the equation while assuming $0 \leq p_1/x_1 \leq$

$(p_2 - p_1)/(x_2 - x_1) \leq 1$. So the demands for Products 1 and 2 are

$$D_1 = \frac{p_2 - p_1}{x_2 - x_1} - \frac{p_1}{x_1}; \quad D_2 = 1 - \frac{p_2 - p_1}{x_2 - x_1};$$

Note that it is assumed that there is no production cost. Thus, the profit of selling each product is simply described as $p_i D_i$. The unique equilibrium of the pricing game is then found by maximizing profits $p_i D_i$ $(i = 1, 2)$:

$$\begin{aligned} p_1^* &= \frac{x_1(x_2 - x_1)}{4x_2 - x_1}, \quad p_2^* = \frac{2x_2(x_2 - x_1)}{4x_2 - x_1}; \\ D_1^* &= \frac{x_2}{4x_2 - x_1}, \quad D_2^* = \frac{2x_2}{4x_2 - x_1}, ; \\ \pi_1^* &= \frac{x_1 x_2(x_2 - x_1)}{(4x_2 - x_1)^2}, \quad \pi_2^* = \frac{4x_2^2(x_2 - x_1)}{(4x_2 - x_1)^2}; \end{aligned}$$

where D_1^* and D_2^* are consumers' demands of products 1 and 2, and π_1^* and π_2^* are the profit of selling products 1 and 2, respectively. The assumption $0 \leq p_1/x_1 \leq (p_2 - p_1)/(x_2 - x_1) \leq 1$ is satisfied following the equilibrium in Lemma 3.1.

Hence, the joint profit is

$$\pi^* = \pi_1^* + \pi_2^* = \frac{x_2(x_2 - x_1)(4x_2 + x_1)}{(4x_2 - x_1)^2}. \tag{22}$$

(1) Disclose Qualities of Both Products

In this scenario, the qualities s_1 and s_2 of both products are observed by consumers. Therefore, $x_1 = s_1$ and $x_2 = s_2$. When the industry sells the two products with full disclosure of both product qualities, the joint profit is

$$\pi^* = \pi_1^* + \pi_2^* = \frac{s_2(s_2 - s_1)(4s_2 + s_1)}{(4s_2 - s_1)^2}. \tag{23}$$

(2) Disclose Only High-Quality Products

In this scenario, only the quality of product s_2 is disclosed to consumers, leading them to form an expectation of the quality of product s_1, $E(s_1 | s_1 < s_2)$. The pricing system in the model does not have a (positive)signal of the actual qualities, as the equilibrium profits are based on consumers' expected qualities and prices rather than the actual qualities (Board (2009)). Therefore, the assumption that consumers' expectations of the qualities are not impacted by prices is adopted. Therefore, the expected qualities of Products 1 and 2 are

$$x_1 = E(s_1 | s_1 < s_2); \quad x_2 = s_2$$

respectively. And the joint profit of the industry in the case of partial disclosure is determined by adding up the equilibrium profits of products 1 and 2.

$$\pi_P^* = \pi_1^* + \pi_2^* = \frac{s_2(s_2 - x_1)(4s_2 + x_1)}{(4s_2 - x_1)^2}. \tag{24}$$

(3) Disclose Neither

When assuming that consumers' prior beliefs about the qualities s_1 and s_2 of products 1 and 2 remain unchanged and equal, i.e. $E(s_1) = E(s_2)$, the unique pricing game equilibrium is $p_1^* = p_2^* = 0$ with corresponding profits $\pi_1^* = \pi_2^* = 0$. As a result, the total joint profit of the industry is 0.

□

3.6.2 Joint Profit in Full Disclosure

In the scenario where both product qualities are disclosed to consumers, the joint profit is calculated using equation(23):

$$\begin{aligned} \pi_1 + \pi_2 &= \int_0^1 \int_0^{s_2} \pi^* \, ds_1 \, ds_2 \\ &= \frac{11}{3} \ln(4/3) - 1 \\ &\approx 0.0548 \end{aligned} \tag{25}$$

3.6.3 Proof of Claim 3.1

Proof. First, $\pi_1 + \pi_2$ where $i = 2$, we have determined previously that the maximum values of both joint profit functions are $\frac{6}{49}$.

Second, for $i = n$ $(i > 2)$, suppose that $\alpha_n \in [\alpha_{n-1}, \alpha_{n+1}]$:

$$\begin{aligned}(\pi_1+\pi_2)|_{n+1} - (\pi_1+\pi_2)|_n \quad &= \alpha_1(\pi_1+\pi_2)_0 + \sum_{i=1}^{n-1}(\alpha_{i+1}-\alpha_i)(\pi_1+\pi_2)_i \\ &+ (1-\alpha_n)(\pi_1+\pi_2)_n - \alpha_1(\pi_1+\pi_2)_0 \\ &- \sum_{i=1}^{n-2}(\alpha_{i+1}-\alpha_i)(\pi_1+\pi_2)_i - (1-\alpha_{n-1})(\pi_1+\pi_2)_{n-1} \\ &= -(1-\alpha_{n-1})(\pi_1+\pi_2)_{n-1} + (\alpha_n-\alpha_{n-1})(\pi_1+\pi_2)_{n-1} \\ &+ (1-\alpha_n)(\pi_1+\pi_2)_n \\ &= \frac{2}{3}[\frac{(1-\alpha_n)^2(9+\alpha_n)}{(7-\alpha_n)^2} - \frac{(1-\alpha_{n-1})^2(9+\alpha_{n-1})}{(7-\alpha_{n-1})^2} \\ &+ \frac{(\alpha_n-\alpha_{n-1})(2-\alpha_n-\alpha_{n-1})(8+\alpha_n+\alpha_{n-1})}{(8-\alpha_n-\alpha_{n-1})^2}]\end{aligned} \tag{26}$$

Denote equation (26) as $G(\alpha_n)$ and consider α_{n-1} as a constant on interval $[0, 1]$. To Simplify the notation, let $x = \alpha_n$ and $a = \alpha_{n-1}$. Therefore,

$$G(x) = \frac{2}{3}[\frac{(x-a)(2-x-a)(8+x+a)}{(8-x-a)^2} + \frac{(1-x)^2(9+x)}{(7-x)^2} - \frac{(1-a)^2(9+a)}{(7-a)^2}] \tag{27}$$

Below we prove that $G(x)$ is a convex function on $[a, 1]$ where $a \in [0, 1]$.

First, the first-order derivative of $G(x)$ is

$$\begin{aligned}G^{'}(x) = \frac{2}{3}[&\frac{x^3+3ax^2-24x^2+3a^2x-4ax-80x+a^3+20a^2-48a+128}{(8-x-a)^3} \\ &+ \frac{(-x^3+21x^2+81x-101)}{(7-x)^3}]\end{aligned} \tag{28}$$

The first-order derivatives at points $x = a$ and $x = 1$ are as following:

$$\begin{cases} G^{'}(x)|_{x=a} & = \frac{2}{3}[\frac{8a^3-8a^2-128+128}{(8-2a)^3} + \frac{-a^3+21a^2+81a-101}{(7-a)^3}] \\ G^{'}(x)|_{x=1} & = \frac{2}{3}[\frac{-a^3+23a^2-49a+25}{(7-a)^3}] \end{cases} \tag{29}$$

As $a \in [0,1]$, the first-order derivatives at points $x = a$ and $x = 1$ satisfy:

$$\begin{cases} G^{'}(x)|_{x=a} < 0, \quad \forall a \in [0,1] \\ G^{'}(x)|_{x=1} > 0, \quad \forall a \in [0,1) \\ G^{'}(x)|_{x=1} = 0, \quad if \quad a = 1. \end{cases} \tag{30}$$

And

$$\begin{cases} G(x)|_{x=a} = 0, \quad \forall a \in [0,1] \\ G(x)|_{x=1} = 0, \quad \forall a \in [0,1]. \end{cases} \tag{31}$$

Therefore, no matter what is the value of constant a, $G(x)$ is decreasing at $x = a$ and non-decreasing at $x = 1$ where $G(x = a) = G(x = 1) = 0$.

Second, the second-order derivative of $G(x)$

$$\begin{aligned} G^{''}(x) = \frac{2}{3}[2(\frac{2(1-x)^2}{(7-x)^3} - \frac{2(1-x)}{(7-x)^2}) + \frac{2(2-a-x)}{(8-a-x)^2} + (\frac{6(2-a-x)}{(8-a-x)^4} - \frac{4}{(8-a-x)^3})(-a+x)(8+a+x) \\ + (\frac{6(1-x)^2}{(7-x)^4} - \frac{8(1-x)}{(7-x)^3} + \frac{2}{(7-x)^2})(9+x) + 2(\frac{2(2-a-x)}{(8-a-x)^3} - \frac{1}{(8-a-x)^2})(8+2x)], \end{aligned} \tag{32}$$

and the second-order derivative of $G(x) \geq 0$ always holds

$$G^{''}(x) \geq 0, \quad \forall x \in [a,1] \quad and \quad \forall a \in [0,1].$$

According to Mean-Value Theorem, for $\forall x \in (x_1, x_2) \supseteq [a,1], \exists \xi \in (x_1, x)$ and $\eta \in (x, x_2)$ s.t.

$$\begin{cases} G^{'}(\xi) = \frac{G(x)-G(x_1)}{x-x_1} \\ G^{'}(\eta) = \frac{G(x_2)-G(x)}{x_2-x}. \end{cases}$$

As $x_1 < \xi < x < \eta < x_2$ and $G^{''}(x) \geq 0$ always holds,

$$\Longrightarrow G^{'}(\xi) \leq G^{'}(\eta)$$

$$\Longrightarrow \frac{G(x)-G(x_1)}{x-x_1} \leq \frac{G(x_2)-G(x)}{x_2-x}. \tag{33}$$

Multiple $x_2 - x_1$ on both sides of inequality(8) and get

$$\Longrightarrow \frac{G(x) - G(x_1)}{\frac{x - x_1}{x_2 - x_1}} \leq \frac{G(x_2) - G(x)}{\frac{x_2 - x}{x_2 - x_1}}. \tag{34}$$

Let $\lambda = \frac{x_2 - x}{x_2 - x1}(\lambda \in (0, 1)$ and $1 - \lambda = \frac{x - x_1}{x_2 - x1}$ and substitute into inequality(9)

$$\Longrightarrow \frac{G(x) - G(x_1)}{1 - \lambda} \leq \frac{G(x_2) - G(x)}{\lambda} \tag{35}$$

$$\Longrightarrow \lambda(G(x) - G(x_1)) \leq (1 - \lambda)(G(x_2) - G(x)). \tag{36}$$

Note that $x = \lambda x_1 + (1 - \lambda)x_2$, substitute $x = \lambda x_1 + (1 - \lambda)x_2$ into inequality(11) and rearrange:

$$G(\lambda x_1 + (1 - \lambda)x_2) \leq \lambda G(x_1) + (1 - \lambda)G(x_2) \tag{37}$$

Therefore, the function $G(x)$ is convex. As the domain of x is $[a, 1]$, any point x between a and 1 can be represented as $x = \lambda \cdot a + (1 - \lambda) \cdot 1$, where $\lambda \in (0, 1)$. According to the definition of the convex function we have, for $\forall x \in (a, 1)$:

$$G(x) = G(\lambda \cdot a + (1 - \lambda) \cdot 1) \leq \lambda G(a) + (1 - \lambda)G(1). \tag{38}$$

Recall that $G(x = a) = G(x = 1) = 0$ always holds, so the above inequality implies for $\forall x \in [a, 1]$

$$G(x) = G(\lambda \cdot a + (1 - \lambda) \cdot 1) \leq \lambda G(a) + (1 - \lambda)G(1) = 0 \tag{39}$$

□

3.6.4 Proof of Proposition 3.3

Proof. First, consider an information disclosure policy that only tells the consumer full or partial information about the ratio between the quality levels and $n = 2$ for the $a = a_1, a_2, ..., a_n$. The industry only reveals information to consumers in the forms of $s_1 \leq \alpha s_2$ and $\alpha s_2 < s_1 \leq s_2$. The goal is to determine the optimal level of α that maximizes the joint profit $\pi_1 + \pi_2$. This is achieved by calculating the weighted average of the joint profit in each scenario, where $(\pi_1+\pi_2)_0$ represents the joint profit when $s_1 \leq \alpha s_2$ and $(\pi_1+\pi_2)_1$ represents the joint profit when $\alpha s_2 < s_1 \leq s_2$. The problem of joint profit maximization is expressed as follows:

$$\begin{aligned} \max_{\alpha} \quad & \alpha(\pi_1+\pi_2)_0 + (1-\alpha)(\pi_1+\pi_2)_i \\ \text{s.t.} \quad & 0 \leq \alpha \leq 1, \end{aligned} \tag{40}$$

It is important to note that consumers only have access to the information of whether s_1 is less than αs_2 or not. With this information, consumers develop expectations of the qualities of s_1 and s_2 in either of the following two cases:

Case (a). $s_1 \leq \alpha s_2$:

Given information $s_1 < s_2$, consumers form expectations about the qualities of products 1 and 2 as follows:

$$E(s_1|s_1 \leq \alpha s_2) = \frac{\alpha}{3}, E(s_2|s_1 \leq \alpha s_2) = \frac{2}{3}.$$

We then performed an additional calculation to determine the joint profits in a scenario where price competition is present:

$$\begin{aligned} (\pi_1+\pi_2)_0 = & \frac{E(s_2|s_1 \leq \alpha s_2)(E(s_2|s_1 \leq \alpha s_2) - E(s_1|s_1 \leq \alpha s_2))}{(4E(s_2|s_1 \leq \alpha s_2) - E(s_1|s_1 \leq \alpha s_2))^2} \\ & \times \frac{(4E(s_2|s_1 \leq \alpha s_2) + E(s_1|s_1 \leq \alpha s_2))}{4E(s_2|s_1 \leq \alpha s_2) - E(s_1|s_1 \leq \alpha s_2))^2} \end{aligned}$$

Substituting $E(s_2|s_1 \leq \alpha s_2)$ and $E(s_1|E(s_2|s_1 \leq \alpha s_2)$ into the equation above and obtain

$$(\pi_1+\pi_2)_0 = \frac{2}{3} \cdot \frac{(2-\alpha)(8+\alpha)}{(8-\alpha)^2}.$$

Case (b). $\alpha s_2 < s_1 \leq s_2$:

Given information $\alpha s_2 < s_1 \leq s_2$ in this case, consumers form expectations about the qualities of products 1 and 2 as follows:

$$E(s_1|\alpha s_2 < s_1 \leq s_2) = \frac{1+\alpha}{3}, E(s_2|\alpha s_2 < s_1 \leq s_2) = \frac{2}{3},$$

and the joint profit of price competition is then determined by

$$(\pi_1 + \pi_2)_1 = \frac{E(s_2|\alpha s_2 < s_1 \leq s_2)(E(s_2|\alpha s_2 < s_{12}) - E(s_1|\alpha s_2 < s_{12}))}{(4E(s_2|\alpha s_2 < s_1 \leq s_2) - E(s_1|\alpha s_2 < s_1 \leq s_2))^2}$$

$$\times \frac{(4E(s_2|\alpha s_2 < s_1 \leq s_2) + E(s_1|\alpha s_2 < s_1 \leq s_2))}{(4E(s_2|\alpha s_2 < s_1 \leq s_2) - E(s_1|\alpha s_2 < s_1 \leq s_2))^2}$$

Again, substituting $E(s_1|\alpha s_2 < s_1 \leq s_2)$ and $E(s_2|\alpha s_2 < s_1 \leq s_2)$ into the equation above and we get

$$(\pi_1 + \pi_2)_1 = \frac{2}{3} \cdot \frac{(1-\alpha)(9+\alpha)}{(7-\alpha)^2}$$

Hence, the industry's profit maximization problem is straightforward once the expected values of the products are obtained, which can be expressed in the following equation:

$$\begin{aligned} \max_{\alpha} \quad & \alpha((\pi_1 + \pi_2)_1) + (1-\alpha)(\pi_1 + \pi_2)_0 \\ & = \frac{2}{3} \cdot [\frac{\alpha(2-\alpha)(8+\alpha)}{(8-\alpha)^2} + \frac{(1-\alpha)^2(9+\alpha)}{(7-\alpha)^2}] \qquad (41) \\ \text{s.t.} \quad & 0 \leq \alpha \leq 1. \end{aligned}$$

The profit-maximizing outcome is achieved using python optimization when the optimal cutoff value α^* is 1. In this scenario, the profit is found to be the same value, which is $\frac{6}{49}$.

Now consider $n \geq 3$ for $\alpha = \{\alpha_1, \alpha_2, ..., \alpha_n\}$. Recall that a_i are assumed to be in non-decreasing order, with $0 \leq \alpha_1 \leq \alpha_2 \leq ... \leq \alpha_n = 1$. The industry only reveals information to consumers in the form of $s_1 \leq \alpha_1 s_2$ or $\alpha_i s_2 < s_1 \leq \alpha_{i+1} s_2$(for all $1 \leq i \leq n-1$).

The expectations about qualities products 1 and 2 given different cutoffs are illustrated in the following three cases:

Case (a)**.** $s_1 \leq \alpha_1 s_2$:

Given information $s_1 \leq \alpha_1 s_2$, consumers form expectations about the qualities of products 1 and 2 as follows

$$E(s_1|s_1 \leq \alpha_1 s_2) = \frac{\alpha_1}{3}, E(s_2|s_1 \leq \alpha_1 s_2) = \frac{2}{3};$$

And the joint profit is determined when price competition is presented as follows

$$(\pi_1 + \pi_2)_0 = \frac{E(s_2|s_1 \leq \alpha_1 s_2)(E(s_2|s_1 \leq \alpha_1 s_2) - E(s_1|s_1 \leq \alpha_1 s_2))}{(4E(s_2|s_1 \leq \alpha_1 s_2) - E(s_1|s_1 \leq \alpha_1 s_2))^2}$$

$$\cdot \frac{(4E(s_2|s_1 \leq \alpha_1 s_2) + E(s_1|s_1 \leq \alpha_1 s_2))}{4E(s_2|s_1 \leq \alpha_1 s_2) - E(s_1|s_1 \leq \alpha_1 s_2))^2}$$

Plugging $E(s_1|E(s_2|s_1 \leq \alpha_1 s_2)$ and $E(s_2|s_1 \leq \alpha_1 s_2)$ into the joint profit equation above and obtain

$$(\pi_1 + \pi_2)_0 = \frac{2}{3} \cdot \frac{(2 - \alpha_1)(8 + \alpha_1)}{(8 - \alpha_1)^2}.$$

Case (b)**.** $\alpha_i s_2 < s_1 \leq \alpha_{i+1} s_2 (1 \leq i \leq n-2)$: Given information $\alpha_i s_2 < s_1 \leq \alpha_{i+1} s_2 (1 \leq i \leq n-1)$, consumers form expectations about the qualities of products 1 and 2 as follows

$$E(s_1|\alpha_i s_2 < s_1 \leq \alpha_{i+1} s_2) = \frac{\alpha_i + \alpha_{i+1}}{3}, E(s_2|\alpha_i s_2 < s_1 \leq \alpha_{i+1} s_2) = \frac{2}{3};$$

And the industry's joint profit in a price-competitive environment is calculated as

$$(\pi_1+\pi_2)_i = \frac{E(s_2|\alpha_i s_2 < s_1 \le \alpha_{i+1}s_2)(E(s_2|\alpha_i s_2 < s_1 \le \alpha_{i+1}s_2) - E(s_1|\alpha_i s_2 < s_1 \le \alpha_{i+1}s_2))}{(4E(s_2|\alpha_i s_2 < s_1 \le \alpha_{i+1}s_2) - E(s_1|\alpha_i s_2 < s_1 \le \alpha_{i+1}s_2))^2}$$

$$\cdot \frac{(4E(s_2|\alpha_i s_2 < s_1 \le \alpha_{i+1}s_2) + E(s_1|\alpha_i s_2 < s_1 \le \alpha_{i+1}s_2))}{4E(s_2|\alpha_i s_2 < s_1 \le \alpha_{i+1}s_2) - E(s_1|\alpha_i s_2 < s_1 \le \alpha_{i+1}s_2))^2}$$

Substituting $E(s_1|E(s_2|\alpha_i s_2 < s_1 \le \alpha_{i+1}s_2)$ and $E(s_1|E(s_2|\alpha_i s_2 < s_1 \le \alpha_{i+1}s_2)$ into the profit equation above and obtain

$$(\pi_1+\pi_2)_i = \frac{2}{3} \cdot \frac{(2-\alpha_i-\alpha_{i+1})(8+\alpha_i+\alpha_{i+1})}{(8-\alpha_i-\alpha_{i+1})^2}.$$

Case (c)**.** $\alpha_{n-1}s_2 < s_1 \le \alpha_n s_2 = s_2$:

Again, given information $\alpha_{n-1}s_2 < s_1 \le \alpha_n s_2 = s_2$, consumers form expectations about the qualities of products 1 and 2 as follows

$$E(s_1|\alpha_{n-1}s_2 < s_1 \le \alpha_n s_2 = s_2) = \frac{1+\alpha_{n-1}}{3}, E(s_2|\alpha_{n-1}s_2 < s_1 \le \alpha_n s_2 = s_2) = \frac{2}{3};$$

Similar to previous cases, the industry's joint profit can be calculated as

$$(\pi_1+\pi_2)_{n-1} = \frac{E(s_2|\alpha_{n-1}s_2 < s_1 \le s_2)(E(s_2|\alpha_{n-1}s_2 < s_1 \le s_2) - E(s_1|\alpha_{n-1}s_2 < s_1 \le s_2))}{(4E(s_2|\alpha_{n-1}s_2 < s_1 \le s_2) - E(s_1|\alpha_{n-1}s_2 < s_1 \le s_2))^2}$$

$$\cdot \frac{(4E(s_2|\alpha_{n-1}s_2 < s_1 \le s_2) + E(s_1|\alpha_{n-1}s_2 < s_1 \le s_2))}{(4E(s_2|\alpha_{n-1}s_2 < s_1 \le s_2) - E(s_1|\alpha_{n-1}s_2 < s_1 \le s_2))^2}$$

And plugging $E(s_1|\alpha_{n-1}s_2 < s_1 < s_2)$ and $E(s_1|\alpha_{n-1}s_2 < s_1 < s_2)$ into the profit equation above and obtaining the joint profit function

$$(\pi_1+\pi_2)_{n-1} = \frac{2}{3} \cdot \frac{(1-\alpha_{n-1})(9+\alpha_{n-1})}{(7-\alpha_{n-1})^2}$$

The profit maximization problem for the industry has been simplified as follows by considering the three different cases described above and combining them.

$$\begin{aligned}\max_{\alpha=\{\alpha_1,\ldots,\alpha_n\}} \quad & \alpha_1(\pi_1+\pi_2)_0+\sum_{i=1}^{n-2}(\alpha_{i+1}-\alpha_i)(\pi_1+\pi_2)_i+(\alpha_n-\alpha_{n-1})(\pi_1+\pi_2)_{n-1} \\ & =\frac{2}{3}\cdot[\frac{\alpha_1(2-\alpha_1)(8+\alpha_1)}{(8-\alpha_1)^2}+\sum_{i=1}^{n-2}\frac{(\alpha_{i+1}-\alpha_i)(2-\alpha_i-\alpha_{i+1})(8+\alpha_i+\alpha_{i+1})}{(8-\alpha_i-\alpha_{i+1})^2} \\ & +\frac{(1-\alpha_{n-1})(9+\alpha_{n-1})}{(7-\alpha_{n-1})^2}] \\ \text{s.t.} \quad & 0\leq\alpha_1,\ldots,\leq\alpha_n=1\end{aligned} \tag{42}$$

When there are three cutoffs ($n = 3$), the profit-maximizing outcome is determined with Python optimization when the optimal cutoff values $\alpha = (\alpha_1^*, \alpha_2^*, \alpha_3^*)$ are either 0 or 1 while non-decreasing, i.e.,

$$\begin{cases}\alpha_i^*=\{0,1\}, \quad \forall i=1,2 \\ \alpha_1^*\leq\alpha_2^* \\ \alpha_3=1\end{cases}$$

To illustrate, the optimal $\alpha^* = (\alpha_1^*, \alpha_2^*, \alpha_2^*) = (1, 1, 1)$.In this scenario, the profit is found to be the same value at $\frac{6}{49}$.

Below we show that when relaxing to any situation in which $n \geq 3$ and n are finite, the maximal joint profit is not greater than $\frac{6}{49}$. Consider adding $\alpha_n^{'}$ $(n \geq 3)$ to cutoffs sequence$\{\alpha_1, ...\alpha_{n-1}, \alpha_{n+1}\}$ while fixing the values of cutoffs $\{\alpha_1, ...\alpha_{n-1}\}$ and letting $\alpha_{n+1} = 1$. Without loss of generality, assume that $\alpha_{n-1} \leq \alpha_n^{'} \leq \alpha_{n+1} = 1$, which allows setting any additional rational cutoff ranged between the greatest cutoff value below 1 and 1. We claim that the following inequalities hold for all $n \geq 3$ following Claim 3.1:

$$\frac{6}{49}\geq\pi_1+\pi_2)|_n\geq\pi_1+\pi_2|_{n+1},\forall i\geq 1,$$

where $\pi_1 + \pi_2|_n$ is the joint profit when $\alpha = \{\alpha_1, ...\alpha_n\}$ and $(\pi_1 + \pi_2)|_{n+1}$ is the joint profit when

$\alpha = \{\alpha_1, ..., \alpha_{n+1}\}$. Equivalently,

$$\begin{aligned}\frac{6}{49} &\geq \alpha_1(\pi_1+\pi_2)_0 + \sum_{i=1}^{n-2}(\alpha_{i+1}-\alpha_i)(\pi_1+\pi_2)_i + (1-\alpha_{n-1})(\pi_1+\pi_2)_{n-1} \\ &\geq \alpha_1(\pi_1+\pi_2)_0 + \sum_{i=1}^{n-1}(\alpha_{i+1}-\alpha_i)(\pi_1+\pi_2)_i + (1-\alpha_n)(\pi_1+\pi_2)_n\end{aligned} \tag{43}$$

When fixing the values of cutoffs $\{\alpha_1, ...\alpha_n\}$, the terms $\alpha_1(\pi_1+\pi_2)_0$ and $\sum_{i=1}^{n-2}(\alpha_{i+1}-\alpha_i)(\pi_1+\pi_2)_i$ can be canceled out in the LHS and RHS of the second inequality, see the Claim 3.1 above for proof. And corresponding optimal cutoff values $\alpha^* = (\alpha_1^*, \alpha_2^*, ..., \alpha_n^*)$ of the profit-maximizing outcome are either 0 or 1 while non-decreasing, i.e., α^* satisfies

$$\alpha_i^* = 1, \quad \forall i = 1, 2, ..., n$$

Thus, we can conclude that disclosing any quality cutoffs will not increase an industry's joint profit and it is optimal for them to only reveal the order of the qualities of products. $\square$

3.6.5 Flip Transformation

Here we can show that: in the case of

$$\begin{cases} A = A_1 \cup A_2 \\ A_1 = \{a_1 s_2 \leq s_1 \leq a_2 s_2\} \\ A_2 = \{b_1 s_1 \leq s_2 \leq b_2 s_1\} \end{cases}$$

where $0 \leq a_1 \leq a_2 \leq 1$ and $0 \leq b_1 \leq b_2 \leq 1$ for the symmetric transformation $A_2^{'}$ of info set A_2:

$$A_2^{'} = \{b_1 s_2 \leq s_1 \leq b_2 s_2\}$$

The joint profit conditional on $A^{'} = A_1 \cup A_2^{'}$ is always greater than or equal to the joint profit conditional on $A = A_1 \cup A_2$:

$$\pi(x_{2A'}, x_{1A'}) \geq \pi(x_{2A}, x_{1A})$$

Proof. **In the case of A_1**

$$\begin{cases} x_{1A_1} = E(s_1|A_1) = \frac{a_1+a_2}{3} \\ x_{2A_1} = E(s_2|A_1) = \frac{2}{3} \end{cases}$$

In the case of A_2

$$\begin{cases} x_{1A_2} = E(s_1|A_2) = \frac{2}{3} \\ x_{2A_2} = E(s_2|A_2) = \frac{b_1+b_2}{3} \end{cases}$$

In the case of $A_2^{'}$

$$\begin{cases} x_{1A_2^{'}} = E(s_1|A_2^{'}) = \frac{b_1+b_2}{3} \\ x_{2A_2^{'}} = E(s_2|A_2^{'}) = \frac{2}{3} \end{cases}$$

Therefore the joint profit conditional on A

$$\pi(x_{1A}, x_{2A}) = P(A_1|A)\pi(x_{1A_1}, x_{2A_1}) + P(A_2|A)\pi(x_{1A_2}, x_{2A_2})$$

Denote

$$\begin{cases} a = a_2 - a_1 \\ b = b_2 - b_1 \\ t = \frac{a}{a+b} = P(A_1|A) = P(A_1|A^{'}) \\ 1 - t = \frac{b}{a+b} = P(A_2|A) = P(A_2^{'}|A^{'}) \end{cases}$$

In the case of A$^{'}$

$$\begin{cases} x_{1A'} = E(s_1|A^{'}) = (P)(A_1|A^{'})E(s_1|A_1) + (P)(A_2^{'}|A^{'})E(s_1|A_2^{'}) = \frac{a(a_2+a_1)+b(b_2+b_1)}{3(a+b)}, \\ x_{2A'} = E(s_2|A^{'}) = (P)(A_1|A^{'})E(s_2|A_1) + (P)(A_2^{'}|A^{'})E(s_2|A_2^{'}) = \frac{2}{3} \end{cases}$$

Given $0 \leq a_1 \leq a_2 \leq 1$ $0 \leq b_1 \leq b_2 \leq 1$, we have $x_{1A'} \leq x_{2A'}$. Therefore, the joint profit $\pi(x_{2A'}, x_{1A'})$ is represented by

$$\pi(x_{2A'}, x_{1A'}) = \pi(\frac{2}{3}, \frac{a(a_1+a_2)+b(b_2+b_1)}{3(a+b)})$$

In the case of A

$$\begin{cases} E(s_1|A) = P(A_1|A)E(s_1|A_1) + P(A_2|A)E(s_1|A_2) = \frac{a(a_1+a_2)+2b}{3(a+b)}, \\ E(s_2|A) = P(A_1|A)E(s_2|A_1) + P(A_2|A)E(s_2|A_2) = \frac{2a+b(b_2+b_1)}{3(a+b)} \end{cases}$$

Given $0 \leq a_1 \leq a_2 \leq 1$ $0 \leq b_1 \leq b_2 \leq 1$, we have

$$\begin{cases} a_1 + a_2 \leq 2 \\ a_1 + a_2 \leq 2 \\ E(s_1|A) = P(A_1|A)E(s_1|A_1) + P(A_2|A)E(s_1|A_2) = P(A_1|A)\frac{a_1+a_2}{3} + P(A_2|A)\frac{2}{3} \leq 2/3 \\ E(s_2|A) = P(A_1|A)\frac{2}{3} + P(A_2|A)\frac{b_1+b_2}{3} \leq 2/3 \end{cases}$$

$$\Longrightarrow x_A = max\{E(s_1|A), E(s_2|A)\} \leq \frac{2}{3} = max\{E(s_1|A^{'}), E(s_2|A^{'})\} = x^{'}_A$$

Consider $y_A = min\{E(s_1|A), E(s_2|A)\}$:

If $y_A = E(s_1|A) = \frac{a(a_1+a_2)+2b}{3(a+b)}$, as $b_1 \leq b_2 \leq 1$

$$b_1 + b_2 \leq b \Longrightarrow y_{A'} = \frac{a(a_1+a_2)+b(b_1+b_2)}{3(a+b)} \leq \frac{a(a_1+a_2)+2b}{3(a+b)} = y_A.$$

Else if $y_A = E(s_1|A) = \frac{2a+b(b_2+b_1)}{3(a+b)}$, as $a_1 \leq a_2 \leq 1$

$$a_1 + a_2 \leq b \Longrightarrow y_{A'} = \frac{a(a_1+a_2)+b(b_1+b_2)}{3(a+b)} \leq \frac{2a+b(b_2+b_1)}{3(a+b)} = y_A.$$

To conclude, we have the following relations:

$$\begin{cases} x_{A'} \geq x_A \\ y_{A'} \leq y_A \end{cases}$$

As π is increasing in the expected value of the high-quality product and decreasing in the expected value of the low-quality product, we have

$$\pi(x_{2A'}, x_{1A'}) \geq \pi(x_{2A}, x_{1A}) \qquad \square$$

References

Acemoglu, D., V. M. Carvalho, A. Ozdaglar, and A. Tahbaz-Salehi (2012). The network origins of aggregate fluctuations. *Econometrica 80*(5), 1977–2016.

Acemoglu, D., A. Malekian, and A. Ozdaglar (2016). Network security and contagion. *Journal of Economic Theory 166*, 536–585.

Acemoglu, D., A. Ozdaglar, and A. Tahbaz-Salehi (2015). Systemic risk and stability in financial networks. *American Economic Review 105*(2), 564–608.

Adams, R., H. Almeida, and D. Ferreira (2009). Understanding the relationship between founder–CEOs and firm performance. *Journal of Empirical Finance 16*(1), 136–150.

Adams, R. B., A. C. Akyol, and P. Verwijmeren (2018). Director skill sets. *Journal of Financial Economics 130*(3), 641–662.

Adams, R. B. and D. Ferreira (2009). Women in the boardroom and their impact on governance and performance. *Journal of Financial Economics 94*(2), 291–309.

Al-Khazali, O. M., T. A. Zoubi, et al. (2005). Empirical testing of different alternative proxy measures for firm size. *Journal of Applied Business Research 21*(3).

Allen, F. and D. Gale (2000). Financial contagion. *Journal of Political Economy 108*(1), 1–33.

Alvarez, F. and G. Barlevy (2015). Mandatory disclosure and financial contagion. Technical report, National Bureau of Economic Research.

Amemiya, T. (1978). The estimation of a simultaneous equation generalized probit model. *Econometrica: Journal of the Econometric Society*, 1193–1205.

Amiti, M. and D. E. Weinstein (2018). How much do idiosyncratic bank shocks affect investment? evidence from matched bank-firm loan data. *Journal of Political Economy 126*(2), 525–587.

Anand, K., B. Craig, and G. Von Peter (2015). Filling in the blanks: Network structure and interbank contagion. *Quantitative Finance 15*(4), 625–636.

Baker, G. P., M. C. Jensen, and K. J. Murphy (1988). Compensation and incentives: Practice vs. theory. *The Journal of Finance 43*(3), 593–616.

Bamber, L. S., J. Jiang, and I. Y. Wang (2010). What's my style? the influence of top managers on voluntary corporate financial disclosure. *The Accounting Review 85*(4), 1131–1162.

Banerjee, R. N. and H. Mio (2018). The impact of liquidity regulation on banks. *Journal of Financial Intermediation 35*, 30–44.

Basel Committee (2013). Basel III: The liquidity coverage ratio and liquidity risk monitoring tools. Bank for International Settlements. https://www.bis.org/publ/bcbs238.htm.

Basel Committee (2014). Basel III: the net stable funding ratio. Bank for International Settlements. https://www.bis.org/bcbs/publ/d295.htm.

Bebchuk, L. A., J. Fried, and D. Walker (2002). Managerial power and rent extraction in the design of executive compensation.

Becker, G. S. (1962). Investment in human capital: A theoretical analysis. *Journal of Political Economy 70*(5, Part 2), 9–49.

Becker, G. S. (2009). *Human capital: A theoretical and empirical analysis, with special reference to education*. University of Chicago press.

Bederson, B. B., G. Z. Jin, P. Leslie, A. J. Quinn, and B. Zou (2018). Incomplete disclosure: Evidence of signaling and countersignaling. *American Economic Journal: Microeconomics 10*(1), 41–66.

Bernanke, B. S. (2001). Nonmonetary effects of the financial crisis in the propagation of the great depression. *International Library of Critical Writings in Economics 133*, 70–89.

Black, F. (1976). The pricing of commodity contracts. *Journal of Financial Economics 3*(1-2), 167–179.

Blume, L., D. Easley, J. Kleinberg, R. Kleinberg, and É. Tardos (2011). Which networks are least susceptible to cascading failures? In *2011 IEEE 52nd Annual Symposium on Foundations of Computer Science*, pp. 393–402. IEEE.

Blume, L., D. Easley, J. Kleinberg, R. Kleinberg, and É. Tardos (2013). Network formation in the presence of contagious risk. *ACM Transactions on Economics and Computation (TEAC) 1*(2), 1–20.

Board, O. (2009). Competition and disclosure. *The Journal of Industrial Economics 57*(1), 197–213.

Cabrales, A., P. Gottardi, and F. Vega-Redondo (2017). Risk sharing and contagion in networks. *The Review of Financial Studies 30*(9), 3086–3127.

Caprio, G. and D. Klingebiel (1996). *Bank insolvencies cross-country experience*. World Bank Publications.

Carter, M. E., F. Franco, and I. Tuna (2019). Matching premiums in the executive labor market. *The Accounting Review 94*(6), 109–136.

Castanias, R. P. and C. E. Helfat (1991). Managerial resources and rents. *Journal of Management 17*(1), 155–171.

Celik, L. (2014). Information unraveling revisited: Disclosure of horizontal attributes. *The Journal of Industrial Economics 62*(1), 113–136.

Chang, W.-J., R. M. Hayes, and S. A. Hillegeist (2016). Financial distress risk and new CEO compensation. *Management Science 62*(2), 479–501.

Chen, G. (2015). Initial compensation of new CEOs hired in turnaround situations. *Strategic Management Journal 36*(12), 1895–1917.

Chen, G., S. Huang, P. Meyer-Doyle, and D. Mindruta (2021). Generalist versus specialist CEOs and acquisitions: Two-sided matching and the impact of CEO characteristics on firm outcomes. *Strategic Management Journal 42*(6), 1184–1214.

Čihák, M. (2007). Introduction to applied stress testing.

Ciscel, D. H. and T. M. Carroll (1980). The determinants of executive salaries: An econometric survey. *The Review of Economics and Statistics*, 7–13.

Cohen, L., A. Frazzini, and C. J. Malloy (2012). Hiring cheerleaders: Board appointments of "independent" directors. *Management Science 58*(6), 1039–1058.

Cotter, J. F., A. Shivdasani, and M. Zenner (1997). Do independent directors enhance target shareholder wealth during tender offers? *Journal of Financial Economics 43*(2), 195–218.

Craig, B. and G. Von Peter (2014). Interbank tiering and money center banks. *Journal of Financial Intermediation 23*(3), 322–347.

Cuñat, V. and M. Guadalupe (2009a). Executive compensation and competition in the banking and financial sectors. *Journal of Banking and Finance 33*(3), 495–504.

Cuñat, V. and M. Guadalupe (2009b). Globalization and the provision of incentives inside the firm: The effect of foreign competition. *Journal of Labor Economics 27*(2), 179–212.

Custódio, C., M. A. Ferreira, and P. Matos (2013). Generalists versus specialists: Lifetime work experience and chief executive officer pay. *Journal of Financial Economics 108*(2), 471–492.

Custódio, C. and D. Metzger (2014). Financial expert CEOs: CEO's work experience and firm's financial policies. *Journal of Financial Economics 114*(1), 125–154.

Custódio, C. and D. Metzger (2013). How Do CEOs Matter? The Effect of Industry Expertise on Acquisition Returns. *The Review of Financial Studies 26*(8), 2008–2047.

Cziraki, P. and D. Jenter (2022). The market for CEOs. *European Corporate Governance Institute–Finance Working Paper* (831).

Dasgupta, A. (2004). Financial contagion through capital connections: A model of the origin and spread of bank panics. *Journal of the European Economic Association 2*(6), 1049–1084.

Dedman, E. and C. Lennox (2009). Perceived competition, profitability and the withholding of information about sales and the cost of sales. *Journal of Accounting and Economics 48*(2-3), 210–230.

Devers, C. E., A. A. Cannella Jr, G. P. Reilly, and M. E. Yoder (2007). Executive compensation: A multidisciplinary review of recent developments. *Journal of Management 33*(6), 1016–1072.

Dietrich, A., K. Hess, and G. Wanzenried (2014). The good and bad news about the new liquidity rules of basel iii in western european countries. *Journal of Banking and Finance 44*, 13–25.

Dranove, D. and G. Z. Jin (2010). Quality disclosure and certification: Theory and practice. *Journal of Economic Literature 48*(4), 935–63.

Drehmann, M. and N. Tarashev (2013). Measuring the systemic importance of interconnected banks. *Journal of Financial Intermediation 22*(4), 586–607.

Duchin, R., J. G. Matsusaka, and O. Ozbas (2008). When are outside directors effective. *Journal of Financial Economics 89*(1), 62–82.

Dungey, M., G. Milunovich, and S. Thorp (2010). Unobservable shocks as carriers of contagion. *Journal of Banking and Finance 34*(5), 1008–1021.

Edmans, A. and X. Gabaix (2011). The effect of risk on the CEO market. *The Review of Financial Studies 24*(8), 2822–2863.

Edmans, A., X. Gabaix, and D. Jenter (2017). Executive compensation: A survey of theory and evidence. *The handbook of the economics of corporate governance 1*, 383–539.

Edmans, A., X. Gabaix, and A. Landier (2009). A multiplicative model of optimal CEO incentives in market equilibrium. *The Review of Financial Studies 22*(12), 4881–4917.

Edmans, A., T. Gosling, and D. Jenter (2021). CEO compensation: Evidence from the field.

Eisenberg, L. and T. H. Noe (2001). Systemic risk in financial systems. *Management Science 47*(2), 236–249.

Faccio, M., M.-T. Marchica, and R. Mura (2016). CEO gender, corporate risk-taking, and the efficiency of capital allocation. *Journal of Corporate Finance 39*, 193–209.

Fahlenbrach, R., A. Low, and R. M. Stulz (2010). Why do firms appoint CEOs as outside directors? *Journal of Financial Economics 97*(1), 12–32.

Falato, A., D. Li, and T. Milbourn (2011). To each according to his ability? CEO pay and the market for CEOs. *Unpublished working paper, Washington University in St Louis*.

Falato, A., D. Li, and T. Milbourn (2015). Which skills matter in the market for CEOs? evidence from pay for CEO credentials. *Management Science 61*(12), 2845–2869.

Field, L. C. and A. Mkrtchyan (2017). The effect of director experience on acquisition performance. *Journal of Financial Economics 123*(3), 488–511.

Finkelstein, S. (1992). Power in top management teams: Dimensions, measurement, and validation. *Academy of Management Journal 35*(3), 505–538.

Fishman, M. J. and K. M. Hagerty (2003). Mandatory versus voluntary disclosure in markets with informed and uninformed customers. *Journal of Law, Economics, and Organization 19*(1), 45–63.

Freixas, X., B. M. Parigi, and J.-C. Rochet (2000). Systemic risk, interbank relations, and liquidity provision by the central bank. *Journal of Money, Credit, and Banking*, 611–638.

Friedrich, B. (2016). Internal labor markets and the competition for managerial talent. *Unpublished manuscript, Department of Economics, Yale University*.

Frydman, C. (2019). Rising through the ranks: the evolution of the market for corporate executives, 1936–2003. *Management Science 65*(11), 4951–4979.

Frydman, C. and D. Jenter (2010). CEO compensation. *Annual Review of Financial Economics 2*(1), 75–102.

Gabaix, X. and A. Landier (2008). Why has CEO pay increased so much? *The Quarterly Journal of Economics 123*(1), 49–100.

Gabaix, X., A. Landier, and J. Sauvagnat (2014). CEO pay and firm size: An update after the crisis. *The Economic Journal 124*(574), F40–F59.

Gabszewicz, J. J. and J.-F. Thisse (1979). Price competition, quality, and income disparities. *Journal of Economic Theory 20*(3), 340–359.

Gai, P., A. Haldane, and S. Kapadia (2011). Complexity, concentration, and contagion. *Journal of Monetary Economics 58*(5), 453–470.

Garicano, L. and E. Rossi-Hansberg (2006). Organization and inequality in a knowledge economy. *The Quarterly Journal of Economics 121*(4), 1383–1435.

Georg, C.-P. (2013). The effect of the interbank network structure on contagion and common shocks. *Journal of Banking and Finance 37*(7), 2216–2228.

Giannakas, K. and M. Fulton (2002). Consumption effects of genetic modification: what if consumers are right? *Agricultural Economics 27*(2), 97–109.

Glasserman, P. and H. P. Young (2015). How likely is contagion in financial networks? *Journal of Banking and Finance 50*, 383–399.

Grossman, S. J. (1981). The informational role of warranties and private disclosure about product quality. *The Journal of Law and Economics 24*(3), 461–483.

Grossman, S. J. and O. D. Hart (1980). Disclosure laws and takeover bids. *The Journal of Finance 35*(2), 323–334.

Gruère, G. P., C. A. Carter, and Y. H. Farzin (2008). What labelling policy for consumer choice? the case of genetically modified food in canada and europe. *Canadian Journal of Economics/Revue canadienne d'économique 41*(4), 1472–1497.

Grunert, K. G., J. M. Wills, and L. Fernández-Celemín (2010). Nutrition knowledge, and use and understanding of nutrition information on food labels among consumers in the uk. *Appetite 55*(2), 177–189.

Guan, X. and Y.-J. Chen (2017). The interplay between information acquisition and quality disclosure. *Production and Operations Management 26*(3), 389–408.

Guevara, C. A. (2018). Overidentification tests for the exogeneity of instruments in discrete choice models. *Transportation Research Part B: Methodological 114*, 241–253.

Guo, L. (2020). Upstream exploitation and strategic disclosure. *Marketing Science 39*(5), 923–938.

Guo, L. and Y. Zhao (2009). Voluntary quality disclosure and market interaction. *Marketing Science 28*(3), 488–501.

Haldane, A. G. (2013). Rethinking the financial network. In *Fragile stabilität–stabile fragilität*, pp. 243–278. Springer.

Hasman, A. (2013). A critical review of contagion risk in banking. *Journal of Economic Surveys 27*(5), 978–995.

Haubrich, J. G. (1990). Nonmonetary effects of financial crises: Lessons from the great depression in canada. *Journal of Monetary Economics 25*(2), 223–252.

Heyes, A., S. Kapur, P. W. Kennedy, S. Martin, and J. W. Maxwell (2020). But what does it mean? competition between products carrying alternative green labels when consumers are active acquirers of information. *Journal of the Association of Environmental and Resource Economists 7*(2), 243–277.

Ho, S. S., A. Y. Li, K. Tam, and F. Zhang (2015). CEO gender, ethical leadership, and accounting conservatism. *Journal of Business Ethics 127*, 351–370.

Hofer, C. W. (1980). Turnaround strategies. *Journal of Business Strategy*.

Hong, H., J.-Z. Huang, and D. Wu (2014). The information content of Basel III liquidity risk measures. *Journal of Financial Stability 15*, 91–111.

Hotz, V. J. and M. Xiao (2013). Strategic information disclosure: The case of multiattribute products with heterogeneous consumers. *Economic Inquiry 51*(1), 865–881.

Hubbard, R. G. and D. Palia (1995). Executive pay and performance evidence from the us banking industry. *Journal of Financial Economics 39*(1), 105–130.

Hull, J. (2012). *Risk management and financial institutions*, Volume 733. John Wiley and Sons.

Janssen, M. C. and S. Roy (2015). Competition, disclosure and signalling. *The Economic Journal 125*(582), 86–114.

Jensen, M. C. and K. J. Murphy (1990). Performance pay and top-management incentives. *Journal of Political Economy 98*(2), 225–264.

Jin, G. Z. (2005). Competition and disclosure incentives: an empirical study of HMOs. *The RAND Journal of Economics*, 93–112.

Jin, G. Z., M. Luca, and D. Martin (2015). Is no news (perceived as) bad news? an experimental investigation of information disclosure. Technical report, National Bureau of Economic Research.

Jin, G. Z., M. Luca, and D. Martin (2021). Is no news (perceived as) bad news? an experimental investigation of information disclosure. *American Economic Journal: Microeconomics 13*(2), 141–73.

Jovanovic, B. (1979). Job matching and the theory of turnover. *Journal of Political Economy 87*(5, Part 1), 972–990.

Jovanovic, B. (1982). Truthful disclosure of information. *The Bell Journal of Economics*, 36–44.

Kaplan, S. N., M. M. Klebanov, and M. Sorensen (2012). Which CEO characteristics and abilities matter? *The Journal of Finance 67*(3), 973–1007.

Khan, W. A. and J. P. Vieito (2013). CEO gender and firm performance. *Journal of Economics and Business 67*, 55–66.

Kindleberger, C. P., P. Manias, and A. Crashes (1996). History of financial crises.

Kiyotaki, N. and J. Moore (1998). Credit chains. *unpublished paper (London School of Economics)*.

Kleindorfer, P. R., Y. J. R. Wind, and R. E. Gunther (2009). *The network challenge: strategy, profit, and risk in an interlinked world*. Prentice Hall Professional.

Koessler, F. and R. Renault (2012). When does a firm disclose product information? *The RAND Journal of Economics 43*(4), 630–649.

Krishnamurthy, A. (2010). Amplification mechanisms in liquidity crises. *American Economic Journal: Macroeconomics 2*(3), 1–30.

Kroll, M., P. Wright, L. Toombs, and H. Leavell (1997). Form of control: A critical determinant of acquisition performance and CEO rewards. *Strategic Management Journal 18*(2), 85–96.

Lee, L.-F. (1982). Specification error in multinomial logit models: Analysis of the omitted variable bias. *Journal of Econometrics 20*(2), 197–209.

Lee, L.-F. (1992). Amemiya‘s generalized least squares and tests of overidentification in simultaneous equation models with qualitative or limited dependent variables. *Econometric Reviews 11*(3), 319–328.

Levin, D., J. Peck, and L. Ye (2009). Quality disclosure and competition. *The Journal of Industrial Economics 57*(1), 167–196.

Li, F. and M. Ueda (2005). CEO-firm match and principal-agent problem.

Loewenstein, G., C. R. Sunstein, and R. Golman (2014). Disclosure: Psychology changes everything. *Annual Review of Economics 6*(1), 391–419.

Malmendier, U. and G. Tate (2009). Superstar CEOs. *The Quarterly Journal of Economics 124*(4), 1593–1638.

Markopoulos, P. M. and K. Hosanagar (2018). A model of product design and information disclosure investments. *Management Science 64*(2), 739–759.

Mathios, A. D. (2000). The impact of mandatory disclosure laws on product choices: An analysis of the salad dressing market. *The Journal of Law and Economics 43*(2), 651–678.

Matthews, S. and A. Postlewaite (1985). Quality testing and disclosure. *The RAND Journal of Economics*, 328–340.

Milgrom, P. and J. Roberts (1986). Price and advertising signals of product quality. *Journal of Political Economy 94*(4), 796–821.

Milgrom, P. R. (1981). Good news and bad news: Representation theorems and applications. *The Bell Journal of Economics*, 380–391.

Mishel, L. and J. Kandra (2021). CEO pay has skyrocketed 1,322% since 1978: CEOs were paid 351 times as much as a typical worker in 2020.

Müller, J. (2006). Interbank credit lines as a channel of contagion. *Journal of Financial Services Research 29*(1), 37–60.

Murphy, K. J. (2002). Explaining executive compensation: Managerial power versus the perceived cost of stock options. *The University of Chicago Law Review*, 847–869.

Murphy, K. J. and J. Zabojnik (2004). CEO pay and appointments: A market-based explanation for recent trends. *American Economic Review 94*(2), 192–196.

Murphy, K. J. and J. Zabojnik (2007). Managerial capital and the market for CEOs. *Available at SSRN 984376*.

Newey, W. K. (1985). Generalized method of moments specification testing. *Journal of Econometrics 29*(3), 229–256.

Newey, W. K. (1987). Efficient estimation of limited dependent variable models with endogenous explanatory variables. *Journal of Econometrics 36*(3), 231–250.

Newey, W. K. (2009). Two-step series estimation of sample selection models. *The Econometrics Journal 12*, S217–S229.

Newey, W. K. and K. D. West (1987). Hypothesis testing with efficient method of moments estimation. *International Economic Review*, 777–787.

Niggle, C. J. (1987). Can "it" happen again? essays on instability and finance: By hyman p. minsky armonk, ny: Me sharpe, 1982, 301 pp., $25.00.

Oradi, J., K. Asiaei, and Z. Rezaee (2020). CEO financial background and internal control weaknesses. *Corporate Governance: An International Review 28*(2), 119–140.

Pan, Y. (2017). The determinants and impact of executive-firm matches. *Management Science 63*(1), 185–200.

Peters, F. S. and A. F. Wagner (2014). The executive turnover risk premium. *The Journal of Finance 69*(4), 1529–1563.

Roodman, D. (2011). Fitting fully observed recursive mixed-process models with cmp. *The Stata Journal 11*(2), 159–206.

Saeed, A. and M. Sameer (2017). Impact of board gender diversity on dividend payments: Evidence from some emerging economies. *International Business Review 26*(6), 1100–1113.

Sanders, W. G. and D. C. Hambrick (2007). Swinging for the fences: The effects of CEO stock options on company risk taking and performance. *Academy of Management Journal 50*(5), 1055–1078.

Sargan, J. D. (1958). The estimation of economic relationships using instrumental variables. *Econometrica: Journal of the Econometric Society*, 393–415.

Scholes, M. (1976). Taxes and the pricing of options. *The Journal of Finance 31*(2), 319–332.

Shaked, A. and J. Sutton (1982). Relaxing price competition through product differentiation. *The Review of Economic Studies*, 3–13.

Sharma, L. L., S. P. Teret, and K. D. Brownell (2010). The food industry and self-regulation: Standards to promote success and to avoid public health failures. *American Journal of Public Health 100*(2), 240–246.

Situation, W. E. and Prospects (2018). https://www.un.org/development/desa/dpad/publication/world-economic-situation-and-prospects-2018/, Last accessed on 2017-12-11.

Song, T. (2022). Quality disclosure and product selection. *The Journal of Industrial Economics 70*(2), 323–346.

Stahl, K. and R. Strausz (2017). Certification and market transparency. *The Review of Economic Studies 84*(4), 1842–1868.

Sun, M. (2011). Disclosing multiple product attributes. *Journal of Economics and Management Strategy 20*(1), 195–224.

Upper, C. (2007). Using counterfactual simulations to assess the danger of contagion in interbank markets.

Viscusi, W. K. (1978). A note on "lemons" markets with quality certification. *The Bell Journal of Economics*, 277–279.

Vivier-Lirimont, S. (2006). Contagion in interbank debt networks. *Unpublished Manuscript*.

Waldman, M. (1984). Job assignments, signalling, and efficiency. *The RAND Journal of Economics 15*(2), 255–267.

Yonker, S. E. (2017). Geography and the market for CEOs. *Management Science 63*(3), 609–630.

Zajac, E. J. and J. D. Westphal (1996). Who shall succeed? how CEO/board preferences and power affect the choice of new CEOs. *Academy of Management Journal 39*(1), 64–90.

Zhang, J. and K. J. Li (2021). Quality disclosure under consumer loss aversion. *Management Science 67*(8), 5052–5069.

Zhao, J., J. Qiu, Y.-W. Zhou, X.-J. Hu, and A.-F. Yang (2020). Quality disclosure in the presence of strategic consumers. *Journal of Retailing and Consumer Services 55*, 102084.

Zhao, M., C. Dong, and T. Cheng (2018). Quality disclosure strategies for small business enterprises in a competitive marketplace. *European Journal of Operational Research 270*(1), 218–229.