UNIVERSITY OF SOUTHAMPTON

FACULTY OF SOCIAL SCIENCES

Southampton Business School

Interface of Capacity Expansion, Capital Market, and Financial Constraints

by

Yingying Huang

Thesis for the degree of Doctor of Philosophy

February 2019

UNIVERSITY OF SOUTHAMPTON

ABSTRACT

FACULTY OF SOCIAL SCIENCES

Southampton Business School

Thesis for the degree of Doctor of Philosophy

INTERFACE OF CAPACITY EXPANSION, CAPITAL MARKET, AND FINANCIAL CONSTRAINTS

Yingying Huang

This thesis investigates the capacity expansion in the interaction between the operational and financial contexts. Estimating demand before a firm expands its capacity is a key activity in operations management, but it is difficult and unlikely to be observed by researchers and practitioners when the market is imperfectly competitive. This thesis uses the index share to identify demand, realising the simultaneity of matching demand with supply in the empirical capacity expansion. Moreover, the operating and financial performance effects of capacity expansion are also worth investigating, as these reflect the firm's profitability and financial reaction associated with capacity expansion. In this thesis, firm profit, stock return, and firm value are applied to measure the performance outcomes, and the influence of index share is also considered to build the interaction of capacity expansion and financial implication. In addition, as a significant expenditure in the process of capacity expansion, particularly in the semiconductor manufacturing sector, fixed cost plays a critical role in determining capacity policy; however, only few studies have investigated this due to the discontinuity and nonlinearity derived from the consideration of fixed cost. An economic structure is employed to figure out this issue and compare the models with and without fixed cost based on different measuring criteria. Therefore, the interactive relationships of capacity expansion decision with demand, firm performance, and fixed cost are well investigated in the thesis. To evaluate models, an empirical case of the semiconductor manufacturing sector is used for each topic, where data are obtained from US-listed semiconductor manufacturing firms in the iShares PHLX semiconductor ETF (SOX) from 2006 to 2010. Drawing on findings and outcomes specified in the empirical estimates and counterfactual analyses, many managerial implications are proposed; for example, the debtholder may prefer to invest in firms with small index share as they facilitate capacity expansion through fully utilising financial funding. This thesis contributes to the operations-finance interface in many ways. In general, the studies of interaction between operational and financial decisions, such as capacity expansion and debt, are advanced and

extended through building systematic frameworks of simultaneous determinates. Moreover, with the use of Bayesian estimation, the theoretical models are empirically examined; for instance, the important role of fixed cost on capacity expansion and supply chain coordination is verified by the case of the semiconductor manufacturing sector. Besides, the methodology proposed in this thesis can be extended to more general forms and is applicable in the empirical analyses for other sectors, including the automobile and chemical industries.

Table of Contents

List of Abbreviations

Abbreviation	Explanation
SOX	iShares PHLX semiconductor ETF
TSMC	Taiwan Semiconductor Manufacturing Company
TFT-LCD	thin film transistor-liquid crystal display
COGS	cost of goods sold
BLP	Berry, Levinsohn, and Pakes
MPEC	mathematical programming with equilibrium constraints
APT	arbitrage pricing theory
B/M	book to market
GMM	generalised method of moment
MLE	maximum likelihood estimation
MCMC	Markov Chain Monte Carlo
RMSE	root-mean-square error
AIC	Akaika information criterion
BIC	Bayesian information criterion
LMD	log marginal density
p.d.f.	probability density function
c.d.f.	cumulative density function
SQUAREM	Squared Polynomial Extrapolation Method
RW	Random-Walk
DAG	“directed acyclic” graph
i.i.d.	independent and identically distributed
ROA	return on asset
ROE	return on equity

Std.Dev.	Standard Deviation
EPS	earnings per share
SGA	sales, general and administrative cost
ROS	return on sales
CAPM	capital asset pricing model
EBITDA	earnings before interest, taxes, depreciation and amortisation
mean	mean values
ols	ordinary least squares
pls	partial least squares
pcr	principal component regression
lasso	lasso regression
ridge	ridge regression
rpart	recursive partitioning
rfot	randomForest
w/	with
w/o	without
CV	compensating value

Table of Tables

Table of Figures

Academic Thesis: Declaration of Authorship

I, Yingying Huang, declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

Title of thesis: Interface of Capacity Expansion, Capital Market, and Financial Constraints

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
4. Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
5. I have acknowledged all main sources of help;
6. Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
7. None of this work has been published before submission.

Signed: ....

Date: ....

Acknowledgements

I would like to express sincere gratitude to my supervisors, Dr Shu-Jung Sunny Yang, Professor Teck Yong Eng, Dr Ioannis Krasonikolakis and Dr Cheng Steve Chen, who provided professional guidance and kind support for my PhD study. I would also like to thank my parents Zong Zehuang and Aizhen Liu, my sister Jingjing Huang, my husband Dongjie Cai, and my friends Yanan Wang, Ying Wang, Mengsi Wang, Lin-Chih Wu, and Kun Duan for their meticulous care and attention.

Chapter 1 Introduction

1.1 Background

The decision concerning capacity expansion is arguably one of central activities of a firm's strategic planning and has been a critical topic in operational research. The *capacity* is typically defined as the maximum volume of products that a given set of equipment for a firm can provide in unit time (Buffa 1983, Martínez-Costa et al. 2014, Slack et al. 2010); the *capacity expansion* then refers to the additional capacity brought to the production for meeting demand and maintaining competitive advantage (Uzsoy et al. 2018). In the semiconductor manufacturing sector, the phenomena of capacity expansions are more significant with great demand. According to Gartner regarding overall forecast of world fab, global foundry capacity investment is expected to continue outgrowing with good long-term development at a 5.1 percent CAGR during the periods of 2017 to 2022 (Dieseldorff 2019). This trend is even spreading for US-listed firms where more fab capacity projects are planned. For instance, Taiwan Semiconductor Manufacturing Company (TSMC), a world's leading semiconductor foundries listed in US, built its first 12-inch wafer fab in Nanjing, China, which has attained 10,000 wpm since 2018 (TSMC 2017). From these findings, it is noticed that there exists the prevalence of capacity expansion in a firm's operational planning, especially for the semiconductor manufacturing sector, which is worth further investigation.

The capacity expansion decision typically occurs when a firm's productive resources reach their highest capacity, and varies depending on the key factors considered, such as size, location and timing of capacity expansion. For instance, Chen et al. (2013) and Luss (1982) consider how much and where new capacities should be installed through a trade-off between the economies of scale for large-capacity expansible plants and underutilisation risks of plants with small capacities, while Anderson and Yang (2015) investigate the impact of leading time on capacity expansion timing in a competitive setting. Many studies also discuss the decision regarding capacity expansion in the semiconductor manufacturing sector (e.g., Chen et al. 2013, Fowler et al. 2015, Geng et al. 2009, Lin et al. 2014, Swaminathan 2002). They carry out computational experiments and numerical simulations for the capacity expansion decision with real data from wafer fabs, semiconductor testing firms, or thin film transistor-liquid crystal display (TFT-LCD) manufacturers. Examples include Wang et al. (2007), which develop a resource portfolio model of capacity expansion planning and allocation problem using a case study of semiconductor testing facility, and Wang and Su (2015), which propose a deterministic MIP model of Taiwan LED firms' capacity expansion decisions by building multiple wafer fabrications, which is estimated by a numerical example.

Despite the abundance of capacity expansion studies in the analytical literature, few researchers have linked capacity expansion with financial implications, which however, commonly occurs in real-world practices; that debts issued for new capacity projects should be taken into account when firms make capacity expansion decisions, and the stock performance of corresponding capacity expansion may also impact firm's next expansion planning (Hennessy and Whited 2005). There indeed are some exceptions, such as Xu and Birge (2008), which illustrate the debt policy in influencing a firm's optimal decision to expand capacity, and Hendricks et al. (1995), which provide evidence of stock performance after the capacity expansion announcements. However, these studies lack either empirical applications or systematic modelling. More surprisingly, almost none of the related studies attempt to illustrate the relationship between capacity expansion and financial factors in the context of the semiconductor manufacturing sector. This may be due to the difficulty in building reasonable associations or in obtaining the complete data (Gaur et al. 2007). Consequently, an in-depth study of the operations-finance interface of capacity expansion and financial decisions is timely.

Three controversial issues related to the interactive capacity expansion and financial implications are identified. Firstly, estimating demand prior to firm's capacity expansion is a central activity in operations management (Syntetos et al. 2016), but it is difficult while the market is far away from perfect competition and demand is unlikely to be observed by most academics and practitioners (Hopp and Spearman 2011). A challenge in matching supply with demand in such a market lies in identifying an allocation mechanism using suitable indicators in the capital market, as well as other expert forecasts from different sources to represent the industry demand (Kilger and Wagner 2015). Secondly, another main concern of the capacity expansion decision is its effect on the operating and financial performance, reflecting a firm's profitability and financial market reaction associated with the expansion (Birge 2014). There are many accounting-based measures used to evaluate the performance impacts of capacity expansion, including return on asset and sales (e.g., Hendricks and Singhal 2008, Tsikriktsis 2007) and abnormal stock return (e.g., Hendricks and Signhal 2009). However, the value of the firm that implies a real evaluation of a firm's market value has rarely been applied in empirical studies due to the difficulty of specifying a form with measurable variables. Thirdly, as a major source of spending in the process of capacity expansion, fixed cost also plays an important role in determining the capacity planning (Chronopoulos et al. 2011). However, the discontinuous feature and incomplete information regarding fixed cost mean that investigation of fixed cost with empirical capacity expansion is likely to be extremely complex, requiring advanced approaches and tools to achieve this (Howell and Allenby 2015). In sum, the relationships of capacity expansion decisions with market demand, firm performance, and fixed cost are three primary issues addressed in the thesis.

These problems are even severe in the semiconductor manufacturing sector, as the construction of wafer fabrication facilities faces massive demand volatility, intensive capital investment, and large capacity expansion cost (Geng and Jiang 2009, Lin et al. 2014; Rastogi et al. 2011, Swaminathan 2000). Specifically, it is vital for semiconductor manufacturers to introduce extra fabs with the increase in demand forecast (Aytac and Wu 2013, Çatay et al. 2003), however, long lead time of equipment purchases and fabrications in semiconductor supply chains results in high uncertainty of demand (Mönch et al. 2012, Uzsoy et al. 2018). This indicates the bullwhip effect of the supply chain and drives the firm to implement the conservative capacity expansion planning. Moreover, because of the capacity-intensive feature in the semiconductor manufacturing sector, a small adjustment of capacity expansion decision is likely to achieve the prominent financial improvement, while the demand-capacity mismatch due to high demand variability may give rise to unsatisfying financial performance (Geng and Jiang 2009). Besides, firms that decide to build new fabs incur both large equipment and construction costs with high cycle time, which is critical to be estimated accurately due to the rapid evolution of technology (Hwang et al. 2016). Such a high fixed cost is noteworthy when considering the capacity expansion decision of a firm. Therefore, the case of the semiconductor manufacturing sector provides excellent empirical evidence to support this research on account of its significant characteristics in uncertain demand, diversified performance, and enormous cost expenditures.

In the light of these findings and research gaps, the interactive relationships between capacity expansion and financial factors are intended to be investigated so as to study, in depth, capacity expansion decision with the considerations of demand uncertainty, firm performance, and fixed cost by using the semiconductor data, which are main themes of this thesis.

1.2 Literature Review

Five streams of literatures are closely related to this thesis. Previous studies of capacity expansion decisions are first discussed from both theoretical and practical perspectives, particularly for the semiconductor manufacturing sector. Then, literature on the relationships of capacity expansion with demand allocation, firm performance, and fixed cost are specified, respectively. Note that the possible indicators that are suitable for estimating the demand allocation mechanism are reviewed, in which index share in the capital market is the most important factor. Moreover, firm profit and stock return are the main components of firm value, and are specifically illustrated in the discussion of the relationship between capacity expansion and firm performance. In addition, as an important expenditure in capacity expansion, the discontinuous fixed cost can be solved in a range of different approaches that are reported in the literature. Finally, modelling techniques, such as newsvendor model, discrete choice model, and asset pricing model, along with different estimation approaches including traditional statistical methods and Bayesian estimation, as well as Monte Carlo test are also reviewed in this section.

1.2.1 Capacity Expansion

Much of the literature in operations deals with the capacity planning problem at a strategic level, which has become an extremely important focus for a firm’s long-run development (e.g., Bihlmaier et al. 2009, Hax and Candea 1984, Lin et al. 2011, Olhager et al. 2001). Typically, capacity expansion is considered in a firm’s strategic capacity planning with the assumption of a non-decreasing global market over time (e.g., Ahmed and Sahinidis 2003, Hiller and Shapiro 1986, Julka et al. 2007). This is because most capacity decisions are irreversible once expansion takes place, meaning that they cannot be modified without a significant financial outlay (Pindyck 1988, Wu et al. 2005). This phenomenon is even more apparent in the semiconductor manufacturing sector since fixed costs for new facilities and equipment are extremely high (Karabuk and Wu 2003). To maintain identity with the above studies reviewed and satisfy the characteristics of the semiconductor manufacturing sector, this thesis investigates a firm’s strategic decisions only in the case of capacity expansion.

Regarding the research issues relating to capacity expansion, scholars and practitioners have conducted abundant investigations both in theory and reality. Manne (1961) proposes the first capacity expansion model with a single-site investment. The model analyses the economics of scale in capacity expansion problem through minimising the discounted cost of additional capacity. This is further developed into a multi-site expansion case by Manne (1967) and a dynamic version by Erlenkotter (1972). Subsequently, multiple capacity-related decisions with more advanced methods are provided, including size, location, timing, new technology, inventory, and financial applications (e.g., Li and Tirupati 1994, Luss 1984, Martínez-Costa et al. 2014, Shulman 1991, Syam 2000, Van Mieghem 2003). Among them, the interactive relationship of capacity expansion with financial implication has been a focus topic of either operations or financial management in recent years, which draws my attention. The operational and financial decisions are initially analysed separately in a perfect market based on the Modigliani-Miller theory (Modigliani and Miller 1958) which posits that firm value gained from operations is not affected by the financial structure. However, the operational decisions, particularly for capacity expansion, are closely related to the finance activities. For instance, operators may consider the amount of debts raised for capacity expansion planning, while investors in the financial market are supposed to alter their investment decision responses to the variations of the firm’s capacity and debt levels (Hennessy and Whited 2005). Failure to incorporate the operations and finance interactions in the model may result in distortions and biases of both actual operational- and financial-oriented viewpoints (Birge 2014). Therefore, this thesis attempts to construct an interface framework that links the financial considerations with the capacity expansion decision.

To date, the existing research on the interaction between capacity expansion and financial issues is not widely discussed. From an operational management viewpoint, exceptions mainly focus on the critical roles and distinction of capital structure on operations. For example, Lederer and Singhal (1994) jointly consider financing decisions and technology choices of investing in manufacturing. Buzacott and Zhang (2004) seek to use the asset-based financing option in deciding operational policies. Moreover, Xu and Birge (2004) investigate the impact of financial distress costs and tax treatments of debt on production decisions when the market is imperfect and frictional, which is further developed by Xu and Birge (2008) with the additional consideration of agency effects. From the financial perspective, researchers typically examine the financial impacts of operational decisions through using the reduced models. Some empirical findings related to this stream of research include Hennessy and Whited (2005), which illustrates the joint operational and financial decisions in an imperfect market with tax and distress cost, and Hendricks and Sighal (2008, 2009), which models the financial outcomes of supply chain disruptions and excess inventory, respectively. Only the study of Hendricks, et al. (1995) provides evidence on the relationship between capacity expansion decision and market value. However, there are no theoretical modelling and systematic analyses that specify this interaction; also these works do not consider the indirect impact of capacity expansion on the financial implication, such as whether the decision on capacity expansion may alter the demand allocation, which further leads to the variation of stock price in the financial market. It is an important research gap that is intended to deeply investigate in the thesis.

Considering the case of the semiconductor manufacturing sector, capacity expansion planning is particularly important due to its features of high demand uncertainty, capital-intensive nature and large cost of capacity increment (Geng and Jiang 2009). A range of literature studies the strategic capacity expansion in this sector. For example, Barahona et al. (2005) propose a stochastic model to analyse the capacity planning of wafer fabrication in the face of different demand scenarios. Yang et al. (2009) deal with the problem of resource portfolio and capacity planning in a semiconductor testing facility, while Chen and Lu (2012) describe a multi-site capacity planning model for TFT-LCD firms. However, although many issues of capacity expansion refer to the semiconductor manufacturing sector, the discussions concerning the application of financial considerations on the capacity expansion decision are extremely rare in this sector, except for a few studies of option valuation (e.g., Benavides et al. 1999). In this case, an in-depth investigation of the relationship between capacity expansion and financial factors, such as index share, debt level, stock return, and financial constraint, in the semiconductor manufacturing sector is imperative, representing the main goal of this thesis. This is particularly analysed in the following sections.

1.2.2 Capacity Expansion and Demand Allocation

The capacity expansion is typically determined with uncertain demand in numerous literature on operational research (e.g., Bean et al. 1992, Chen and Lu 2012, Erlenkotter et al. 1989, Lin et al. 2014). For example, Harrison and Van Mieghem (1999) model the stochastic demand using a geometric Brownian motion to solve the capacity expansion problem with multiple sites. Angelus and Porteus (2002) analyse the joint capacity expansion and production when there is an inversed-U shape demand change. Ryan (2004) consider both the exponential rise in demand and lead time for capacity expansion decision. Of note is that it is more essential and vital for semiconductor manufacturers to incorporate the demand uncertainty into their capacity expansion decision due to the high demand volatility and long lead time in this sector. Many studies have dealt with the capacity expansion problem in the semiconductor manufacturing firms with uncertain demand, including Swaminathan (2000), which uses discrete demand scenarios to describe the effect of demand on capacity expansion specified as tool purchasing, Christie and Wu (2002), which calibrates the stochastic demand as an input of the capacity expansion model to analyse the allocation of Microelectronics technologies, and Rastogi et al. (2011), which considers the correlation of uncertainty in demand for different products and its impact on capacity expansion decision in a semiconductor supply network. In sum, this stream of research about demand uncertainty is very important and much related to this thesis, which provides fundamental knowledge and understanding of how capacity expansion decisions are made under the stochastic demand, particularly in the semiconductor manufacturing sector.

Concerning the relationship between capacity expansion and demand, various researchers have proposed different points of views. Pindyck (1993) demonstrates that an increase in demand uncertainty can restrict the firm’s incentive to expand its capacity when the market is perfectly competitive. This is because the opportunity cost raised by uncertain demand is significantly higher than the value obtained from capacity expansion, leading to the wait-and-see strategy of the firm’s capacity expansion decision (Pindyck 1988, 1993). However, in an imperfect competition setting, such as when a high capacity expansion cost to enter the market exists (e.g., semiconductor manufacturing) (Wu et al. 2005) and the flexibility in realising control over the output (Anupindi and Jiang 2008), the impact of demand on capacity expansion is entirely different. Kulatilaka and Perotti (1998) find that high demand uncertainty may facilitate the expansion in capacity, while Van Mieghem and Rudi (2002) observe a decreased firm value for higher demand variability when assuming demand to follow a normal distribution. On the other side, demand may also vary depending on the capacity expansion decision, which results in the endogeneity in demand (Van Mieghem 2003). For example, Cachon and Lariviere (1999) incorporate capacity allocation schemes into the analysis of demand and show that demand is a decreasing function of capacity decision when individual needs are met. Ho et al. (2002) also consider the effect of capacity expansion planning on demand forecast through building a dynamic product diffusion model. Omitting such interaction between demand and capacity expansion can, however, lead to the estimation biases and forecast errors of using exogenous demand assumption provided by Paraskevopoulos (1991) and Olivares et al. (2008). My thesis intends to address this issue by specifying a suitable demand allocation mechanism that accounts for the capacity expansion decision.

To evaluate the allocation mechanism of demand, complete information of customers' purchasing preference, market structure, and rival firms' capacity expansion intent is required (Ghemawat 1984, Yang and Anderson 2014). However, it is unlikely that researchers and practitioners can fully obtain such historical data, such as historical demand of new products (Gaur et al. 2007). Therefore, demand-related data at firm level are more appropriate for indicating the demand allocation for a firm's capacity expansion decision. There are plenty of indicators available that are being used in a demand function. For example, cost of goods sold (COGS), inventory, and gross margin of each firm is able to forecast sales for retailers, which are useful firm-level indicators to specify the demand allocation mechanism (Kesavan et al. 2010). Moreover, firms typically share the industry demand in a competitive environment (Lieberman 1987, Serin 2007). Lippman and McCardle (1997) indicate that firms with competitive edges are allocated for huge excess demands, and apply a specific rule to split the industry demand into individual firms. In the light of this, aggregate sector-level data that reflect the relative competitiveness of each firm, such as index share in the capital market, may thus be a possible factor in evaluating the demand allocation mechanism for the determination of a firm's capacity expansion decision.

Two different explanations are given regarding why index share is used to model demand allocation of a firm's capacity expansion decision. The first is that index share adjustment slopes down the demand curve for firm stock, such as the redefinitions of the Toronto Stock Exchange 300 index and the MSCI global index (Hau et al. 2009, Kaul et al. 2000). It reflects a close association between index share and an individual firm's demand on stock. Moreover, as a leading indicator of the economic activity, the stock market makes predictions of future industrial production (Choi et al. 1999), output growth (Henry 2004), GDP, consumption, and investment (Aylward and Glen 2000). This means that demand in the stock market is able to predict the product demand. Therefore, the relationship between index share and product demand is built based on their connections to the stock market. Another explanation seems more intuitive; that is, index share is the weight of index fund, which is a sort of share in a given sector. For instance, the PHLX Semiconductor Sector (SOX) is a capitalisation-weighted index fund that is composed of the representative semiconductor companies primarily involved in the design, distribution, manufacture, and sale of semiconductors, and is designed to measure the overall sector performance. It implies the high consistency between the index share and product market share of a firm in a given sector. Many studies in the field of economic application apply a market-share approach to predict the future demand (Moschini 1995, Sirhan and Johnson 1971). Besides, some researchers consider using a discrete choice model for estimating the demand when they treat the demand as the aggregated share (Yang et al. 2003). Thus, a link between index share and demand is built due to the fact that index share is regarded as a kind of market share for individual firm. In this thesis, some sales forecasts and index share that incorporate capacity expansion are used to specify the demand allocation mechanism, so as to realise the simultaneity of matching demand and supply in the empirical capacity expansion.

1.2.3 Capacity Expansion and Firm Performance

Investigating a firm's performance outcomes following capacity expansion decision is one of the main concerns in operational research. Firm typically expects to obtain a positive impact from its expansion of capacity, prominently performing as higher profitability and better market reaction (e.g., Birge 2014, Birge and Xu 2011, Harrison and Van Mieghem 1999, Wu et al. 2005). This view is closely associated with the theory of efficient market hypothesis derived from the study of Tobin (1969). That is, the capacity expansion as new information entering the capital market can be accurately responded to, wherein the stock price would be adjusted accordingly. However, capacity expansion has a different effect on firm performance in an imperfect capital market context where frictions, such as tax benefits and information asymmetry, exist in the market. Xu and Birge (2008) shows that firm value firstly increases and then goes down with the rise in production level when considering tax rate, while Boyabatli and Toktay (2011) demonstrate a positive correlation between capacity expansion and performance of firm under different technology choices. Notice that the firm's performance outcome even becomes negative after its capacity expansion in a capital-intensive sector, such as semiconductor manufacturing. In the case of Micron Technology Inc., although its index share increased with new fabrications added from 2006 to 2008, both profit and stock returns drastically decreased. These findings reflect a mismatch of capacity expansion and the expected performance in the imperfect market, but lack further proof and empirical evidence, which is a research gap. Therefore, major emphasis in this thesis is to specify a reasonable model structure and appropriate evaluations of performance that fit reality in order to empirically explore the effect of capacity expansion on firm performance.

Various measures of firm performance in both operating and financial aspects are applied in the literatures of operational management. The operating outcomes of capacity expansion are firstly discussed. Some researchers compute the total cost incurred in capacity expansion, including produce and operating cost, expansion cost, maintenance cost for excess capacity as well as shortage cost when capacity cannot meet demand (e.g., Atamtürk and Hochbaum 2001, Chen et al.

2002, Huang and Ahmed 2009, Mitra et al. 2014, Rajagopalan and Soteriou 1994, Zhang et al. 2012). In these studies, the optimal capacity expansion level is determined through minimising the cost. Moreover, the net present value and the expected long-term profit are also used to specify a firm's operating performance. For example, Papageorgiou et al. (2001) develop a net present value maximisation model for capacity planning in the pharmaceutical sector. Chen et al. (2010) consider a multi-site capacity expansion decision with maximised profit for the TFT-LCD manufacturing firms. Other related literature applying firm profit in the semiconductor manufacturing sector include Chen and Lu (2012), Wang and Hou (2003), Wang and Lin (2002), and Wang et al. (2007). Among them, the budget constraint is also allowed in bounding the capacity expansion and profit level (Wang and Hou 2003). The cost minimisation and profit maximisation are indeed equivalent measures for a firm's operating outcomes; however, only a few studies have inferred their impacts on the capacity expansion from an empirical perspective. Besides, this body of literature regarding the effect of capacity expansion on operating performance does not consider the influence of factors in the capital market, such as index share, which is also be addressed in this thesis.

Moreover, financial performance measures is another concern that needs to be considered when a firm expands its capacity. Some studies in the financial community deal with the effect of operational decisions on financial outcomes, and their analyses are mainly based on the empirical results. For instance, Hendricks and Singhal (2009) discuss how excess inventory as a signal of demand-supply imbalance affects the stock market. Other related empirical papers involve that of Hendricks and Singhal (2009), which models the financial performance of supply chain disruptions, and that of Hendricks et al. (2009), which investigates the intermediate factors of operational slack, business and geographic diversifications, and vertical relatedness that influence the effect of supply chain disruptions on stock performance. Within these studies, only a few scholars consider the relationship between capacity expansion and financial outcomes. One exception is Hendricks et al. (1995) who examine the abnormal stock return after the firm's capacity expansion, and show the significantly improved performance on the day of expansion announcement. These models only regard the financial performance as exogenously determined, but financial outcomes, such as stock return, may also affect the capacity expansion decision through influencing the demand allocation mechanism, which leads to an endogenous relationship between capacity expansion and financial performance. This simultaneous issue is not considered in the studies reviewed, and will be discussed in depth in this thesis.

Indeed, the value of the firm is a key measure to evaluate the firm performance effect of capacity expansion, as it precisely implies the firm's market value. Many different ways can be used to calculate the firm value from both operational and financial viewpoints. Researchers in operations generally use accounting identities, such as the balances in payments of capacity expansion and in balance sheet, to determine the value of firm. Pindyck (1988) models the value of a firm when capacity expansion is irreversible with the consideration of the value of operating gains, profit generated by incremental capacity, and cost of capacity expansion. Besides, Xu and Birge (2008) apply cash flows to both debt-holders and equity-holders along with the initial expenditure of production to specify the firm value in an imperfect market, in which operational and financial decisions are made simultaneously. However, it is noted that it is difficult to empirically estimate the firm value in an operational setting, because most variables considered, including unit revenue and cost of capacity expansion, are often unavailable to researchers. To measure firm value from a financial perspective on behalf of the performance impact of capacity expansion can well address this issue. For example, Chod and Lyandres (2011) regard the stock return as the ratio of profit that deducing firm value to the firm value, in the sense that firm value can be identified using stock return and firm profit. It thus becomes feasible to calculate firm value in an empirical case with the use of accounting-based indicators that are stock return and firm profit. In this thesis, the performance of stock return and firm profit after capacity expansion are going to be modelled based on financial and operational decisions; accordingly, the value of the firm can be evaluated by incorporating both stock return and firm profit.

1.2.4 Capacity Expansion and Fixed Cost

Fixed cost plays an important role in determining a firm’s capacity expansion, particularly in the context of capital-intensive sectors (e.g., semiconductor manufacturing, petrochemical, and automobile). Firms in these sectors typically spend a large amount of fixed expenditures to expand their capacities (Geng et al. 2009, Wu et al. 2005). The significant fixed cost may drive the firm to employ a conservative capacity expansion strategy (Erkoc and Wu 2004). That is, capacity expansion only occurs when the firm achieves the full utilisation of capacity, reflecting a clearance policy in the product market (Goyal and Netessine 2007, Yang and Allenby 2014). In this case, the firm prefers to decrease the prices, sometimes below the capacity expansion costs, so as to match the production to its capacity level. Moreover, the exceedingly high fixed cost also makes the capacity expansion decision irreversible once it is implemented, because modifying it generally incurs even larger payment than the capacity expansion cost, which is very unlikely to be realised in the capital-intensive sector (Chronopoulos et al. 2011, Pindyck 1988). Besides, to some extent, a barrier to capacity expansion may be raised with the consideration of fixed cost due to relatively high pay-outs for excess capacity in a competitive setting (Rhim et al. 2003). Therefore, fixed cost has significant impacts on capacity expansion and it is essential that it is incorporated into the operational decision process.

The analytical studies of fixed cost and capacity expansion are widely discussed in operations (see Ahmed et al. 2003, Birge and Xu 2011, Boyabatli and Toktay 2011, Chen and Simchi-Levi 2004). To exhibit economies of scale, the fixed cost should be involved in the total cost for capacity expansion that is minimised to achieve the optimal capacity level. Some researchers use concave cost functions to specify the economies of scales; for example, Luss (1986) proposes a power cost function with the feature of strict concavity for a single-site case. Rajagopalan et al. (1998) further develop this into a dynamic version that also allows for technology innovation. Besides, there exists another cost function for economies of scale in determining a firm's capacity expansion, which is the fixed-charge cost function with a value of zero for no expansion. The related literature dealing with the tool procurement problem via fixed-charge cost form involves Ahmed and Garcia (2003), Ahmed and Sahinidis (2003), Ahmed et al. (2003), Huang and Ahmed (2009) and Geng et al. (2009). Moreover, the fixed cost of capacity expansion is often handled by the financial budget of firm, which affects the boundary decision of capacity level (Van Mieghem and Rudi 2002). However, the presence of fixed cost introduces additional complexity in modelling capacity expansion, such as discontinuity and nonlinearity. This is one of the main concerns that is addressed in this thesis, and is specifically discussed in the following part.

Frictions from fixed cost of capacity expansion typically create additional nonlinearity and discontinuity in determining the optimal capacity level. Three major issues are correlated to these difficulties when incorporating fixed cost into the capacity expansion decision. Firstly, considering fixed cost in model may lead to an increased region of inaction in a firm's capacity expansion policy (Abel and Eberly 1998). This reflects the fact that the firm prefers to maintain its original capacity level rather than expansion for a while due to high fixed cost expenditure, which is similar to the impact of fixed ordering cost for inventory. Secondly, the temporary large change of the capacity expansion decision also occurs when the fixed costs are allowed for (Van Mieghem and Rudi 2002). This is driven by the irreversible capacity expansion and economies of scale that produce the non-convexity in the fixed cost. Interestingly, the setting of a convex-concave production along with a convex capacity expansion cost is also equivalent to the non-convex fixed cost form proposed by Dixit (1995). Thirdly, there exists the non-differentiable boundary caused by the discontinuous fixed cost in the decision process of capacity expansion (Howell and Allenby 2015). The Lagrangian and Karush-Kuhn-Tucker first-order conditions are only applicable for the continuous function, which cannot be used for solving the boundary decision of capacity level that incorporates the fixed cost. In sum, issues related to fixed cost can be used to gain insight into a firm's capacity expansion problem by noting that fixed cost may cause an increase in the inaction region, occasionally great change of capacity expansion level, and non-differentiability of budget constraint.

To address these issues, researchers typically use the (s, S) policy to decide the optimal capacity expansion solution, in which lower and upper bounds are specified based on the fixed cost (e.g., Moon and Silver 2000, Yang and Anderson 2014). However, this method cannot be applied in determining the empirical capacity expansion decision with fixed cost due to the complicated nonlinear solution that consumes significant computational power and time. Therefore, another method suggested by Howell and Allenby (2015) is developed from an economic point of view. That is, the capacity expansion problem is divided into different sub-problems depending on the discontinuous point of fixed cost, which is usually the decision of whether to expand capacity or not. The optimal solution for each sub-problem is then figured out by using the continuous analysis. By selecting the best solution among sub-problems, the overall optimal capacity expansion decision that considers fixed cost is thus obtained. This thesis intends to employ the second method to deal with difficulties faced when considering the discontinuous fixed cost of capacity expansion decision.

Moreover, the fixed cost for capacity expansion also has a critical impact on supply chain planning due to its role in strategic network design (Meyr et al. 2015). As a major expenditure of expanding capacity for downstream portion, supply chain upstream firms would yield from selling equipment, which is a buyer-supplier procurement problem in the supply chain relationships (Bahinipati and Deshmukh 2012). This supply chain can be coordinated through contracts between suppliers and downstream firms, as well as planned decision systems where the total profit earned from joint activities exceeds that of all individuals in the uncoordinated supply chain (Cachon 2003, Snyder and Shen 2011). For example, the decision framework related to shared skills and human resources is used for structuring a collaboration between partners in a semiconductor supply chain (Bahinipati et al. 2009). In this thesis, the variation of fixed cost for capacity expansion exists a moderating effect on supply chain relationships that can be negotiated between buyer and supplier, which is also possible to build a form of coordination.

1.2.5 Modelling Techniques and Estimation Approaches

In this section, the models of capacity expansion, demand allocation, and stock return are discussed. Following this, both traditional statistical and Bayesian approaches in terms of estimation algorithm are also reviewed. I first investigate techniques used for modelling capacity expansion. There are different methods available to deal with the capacity expansion problem, including static capacity, neighbourhood search approaches (simulation-based and queuing models), and mathematical programming methods (linear programming and stochastic programming models) (Geng and Jiang 2009). Among them, stochastic programming, such as the newsvendor network approach, is probably the best fit for this research, since it can explicitly handle uncertainty in demand when finding the optimal decision of capacity expansion. The newsvendor network is typically generated via minimising the total cost or maximising the predicted profit, and solves the optimal capacity expansion policy through a trade-off of the excess capacity and the unsatisfied demand (Van Mieghem 2003). This approach also has extensive applications in capacity expansion decisions for the semiconductor manufacturing firms (e.g., Ahmed and Garcia 2003, Ahmed et al. 2003, Chen et al. 2013, Fleischmann et al. 2006). Therefore, a newsvendor network that is involved in the stochastic programming will be considered to model the capacity expansion problem when the demand is endogenously determined in this thesis, where the evaluation of demand is discussed in the next section.

Moreover, due to the limited amount of capital raised to support the capacity expansion in the real environment, budget constraints should also be taken into account in the capacity expansion model (see Barahona et al. 2005, Hood et al. 2003, Swaminathan 2002, Wang et al. 2007). For instance, Xu and Birge (2008) incorporate both financial boundary on produce process and risk-neutral equivalence of debt into the newsvendor model when allowing for the joint capacity expansion and financing decisions of firms in a complete market. This implies that the interactive capacity expansion and debt can be estimated through modelling the newsvendor network with a budget constraint. Besides, fixed cost is not only a major part of total cost that should be minimised to determine the optimal capacity expansion, but also affects the budget constraint because it consumes huge capital, particularly in the semiconductor manufacturing sector. The examples include Chakravarty (2005), which considers a budget constraint for the fixed cost to investigate the multi-site capacity expansion problem, and Boyabatli and Toktay (2011), which expand the capacity expansion model with fixed cost bounded by an investment budget in the imperfect capital market. Thus, in this research, the capacity expansion model will involve budget constraints for evaluating the relationship of capacity expansion with either financial decision or fixed cost.

To model demand allocation, multiple attributes of a firm including capacity expansion may be considered by investors so as to determine their own decisions of whether or not to purchase a firm’s stock, when market demand is regarded as the aggregated share of individual choices based on the previous explanations of index share. The idea is derived from the consumer demand theory that is typically evaluated by using the discrete-choice model (Yang et al. 2003). That is, the latent utility for linking the determinants to the discrete outcome is maximised (Rossi et al. 2012). Incorporating this into this study, one of the key factors that influences each investor’s utility is the capacity expansion, and the discrete outcome refers to the result generated by whether one firm’s stock in a given sector is being picked by investors or not. In this case, index share in the capital market is evaluated by aggregating all investors’ decisions with the consideration of capacity expansion. Due to the fact that the demand allocation mechanism specified by index share and some other forecasts is also an important input to solve for the optimal capacity expansion decision, the interactive relationship of capacity expansion with demand allocation is thus built, which realises the simultaneity of matching demand and supply in operations.

Although little research has employed the discrete-choice model to deal with the demand allocation of capacity expansion problem, there are several related applications in consumer demand theory. One of the representative cases is the random coefficient logit demand model proposed by Berry et al. (1995, BLP). It investigates the equilibrium price that is simultaneously determined by demand and supply, where the market-level demand is obtained from the discrete-choice logit distribution of consumer tastes. Moreover, Nevo (2000) and Train (2009) further develop the model through coordinating the individual characteristics, which enables us to better estimate the heterogeneity in individual preferences. In addition, the mathematical programming with equilibrium constraints (MPEC) approach proven by Su and Judd (2012) computationally improves the BLP model without repeatedly solving the demand equation by using the Contraction Mapping. However, these models do not consider the endogeneity of capacity expansion and demand allocation, in which index share plays a critical role. This advances an innovative spot and a possible application of discrete-choice model for the demand allocation prior to capacity expansion, and will be mainly discussed in the model section of this thesis.

In regard to the model of stock return, the individual firm's expected stock return in a given sector is closely related to the index share from a portfolio perspective, due to the positive correlation of stock return and return on the capitalisation-weighted market portfolio based on the arbitrage pricing theory (APT). Indeed, the stock return model that incorporates index share is initially developed by the modification of the Markowitz model proposed by Sharpe (1964), Lintner (1969), and Black (1972). Fama and French (1993) then extend it into a three-factor model that includes average returns related to size (e.g., market capitalisation), and price ratio (e.g., book to market (B/M) ratio). Moreover, proxies of expected profitability and investment are added to the three-factor model based on the research of Novy-Marx (2013) and Aharoni et al. (2013). Empirically, though, it is found that value factor is redundant in the five-factor model (Fama and French 2015). These models only consider stock return of each firm to be exogenously determined by index share; however, they should be related to each other in an endogenous manner. This is because index share, as the weight of a firm's stock return in a given sector, would be affected by its firm's attributes, such as stock return and capacity expansion, through altering investors' preferences of stock purchases as discussed in the demand allocation model, and then impacts the stock return. It also reflects an indirect effect of capacity expansion on stock return under the mediation of index share, and will be concretely analysed in this thesis.

Two different types of estimation algorithm are reviewed in this thesis – these are the conventional and Bayesian approaches. The conventional methods are based on the frequentist statistics, where repeatable evaluations are required to obtain the probability (Jeffreys 1998). This means that the stable results stem primarily from the large sample size (Gelman 2015). Many frequentist-based methods are widely used for the estimation of demand-supply simultaneity, such as the generalised method of moment (GMM, e.g., Berry et al. 1995, Nevo 2000) and maximum likelihood estimation (MLE, e.g., Train and Winston 2007, Villas-Boas and Zhao 2005). Apart from the frequentist methods, the Bayesian approach is another useful estimation for the model. It focuses on the posterior that is influenced by the prior information, which is better than the conventional methods in three ways. Firstly, Bayesian analysis allows for the investigation of small-sample events as it evaluates the probability with the knowledge about the measurement result (Rossi et al. 2012). It enables the evaluation of an empirical case in the semiconductor sector that only has limited applicable data. Secondly, the heterogeneity of preferences for investors is able to be implemented using the Bayesian hierarchical analysis of the random coefficient that is a more intuitive and straightforward method compared with the GMM and MLE approaches. Thirdly, although the MPEC method avoids the inner loop error of the NFP algorithm in the GMM estimation and speeds up the computation, the process can be much more simplified with the use of the Markov Chain Monte Carlo (MCMC) in the Bayesian estimation. The MCMC approach is typically completed by drawing parameters from the full conditional distribution instead of immediate integration of the unobserved variables based on the frequentist approach, where the calculation of integration would be an issue in finding the optimal solution. On the basis of merits mentioned above for the Bayesian method, in this thesis, a full-information Bayesian approach is thus used to estimate the model rather than conventional methods.

Besides, the simulation study of each model in the thesis is conducted by using the Monte Carlo test. It is a method that uses the generation of random sampling along with the corresponding probability to produce the distribution of each output variable (Jones 1972). This process can be repeated several times to estimate the parameters, such as means, standard deviations, and root mean square errors (Rossi et al. 2012). There are many advantages of Monte Carlo simulation over analytical methods and other simulation counterparts. One of significant merits is that it is much more straightforward and flexible to incorporate Monte Carlo test in dealing with the complicated framework system, such as models in this thesis, while various assumption limits should be made when using the analytical methods (Hopewell 2004). Moreover, the Monte Carlo simulation is able to evaluate the interaction between variables (Brooks et al. 2011), which provides a possible simulation method for the simultaneous structures in this thesis. Therefore, the Monte Carlo test is applied to simulate models proposed.

1.3 Research Questions

On the basis of the literature reviewed, three main research gaps are specified. The first one is that the demand allocation mechanism for capacity expansion is either randomly or exogenously determined without considering the influence of endogenous factors in the capital market, such as index share. However, a firm's capacity expansion is one of the important firm attributes that typically influences the stock-purchasing behaviour of investors. This in turn leads to the alternation of aggregated index share in a given sector, while – as a critical input in the demand allocation – index share would in turn determine the capacity expansion decision, realising the interaction relationship between capacity expansion and index share. Not allowing for index share in the demand allocation mechanism to evaluate capacity expansion decision would result in contradiction and conflict between estimation and reality. Thus, index share should be used to specify the demand allocation mechanism so as to decide the capacity expansion level, which is a research gap worth robust investigation.

Next, firm performance after capacity expansion occurs is not clearly measured from both operating and financial perspectives. Firm profit that is achieved through expanding its capacity is difficult to evaluate due to the uncertainty of demand and specifications of unit profit and costs caused by expansion. Most studies focus on the numerical simulation for the firm profit after capacity expansion to address these issues; however, few deal with the empirical analysis of it. As for the stock reaction of capacity expansion from a financial viewpoint, it is usually measured by using reduced models that does not consider systematic structure of modelling. What is more, the value of the firm that implies its real value in the marketplace is an important measure for firm performance effect of capacity expansion. There is still the lack of an empirical case with the use of formal and mathematical models that is able to evaluate the impact of capacity expansion on firm value. It is also noticed that capacity expansion and performance in both operating and financial aspects are related to each other; this is because financial factors, such as stock return, would conversely affect capacity expansion through the adjustment of index share that is aggregated from individual choices and composes the demand allocation mechanism. A simultaneity study regarding capacity expansion and firm performance is another gap of research that is discovered.

Besides, the fixed cost incurred when a firm expands the capacity indeed affects its operational decision, but is rarely taken into account in research of capacity expansion in operations. It is much more significant in the semiconductor manufacturing sector because a large amount of fixed charges are often required to expand capacities for firms in this sector, resulting in frictions that cause severe nonlinearity and discontinuity in obtaining the optimal capacity decision. The capacity expansion problem that incorporates fixed cost then has issues of increased inaction area, great fluctuation of expansion, and non-differential budget constraint, which are difficult to deal with. To solve these issues and find the effect of fixed cost on capacity expansion, economic views should be added into capacity expansion models and the managerial implications with supply chain cooperation also need further consideration. Therefore, to fill all these gaps, the research questions that require deep investigation are listed as follow:

- To what extent and how is the demand allocation for capacity expansion modelled?
- To what extent and how are the operating and financial performance impacts of capacity expansion evaluated?
- To what extent and how does the fixed cost affect capacity expansion and supply chain coordination?

In sum, the research objective of this thesis is to investigate the interface of capacity expansion, capital market, and financial constraint. According to research questions specified above, the issues of capacity expansion related to demand allocation, firm performance, and fixed cost are separately discussed in each chapter. The thesis framework with key constructs corresponding to the next three chapters is shown in Figure 1. Specifically, the demand allocation mechanism modelled by using index share prior to capacity expansion is first concerned in Chapter 2. Then, in Chapter 3, the effects of capacity expansion on both operating and financial performance, including firm profit, stock return, and the value of firm are examined. Finally, Chapter 4 illustrates the role of fixed cost on capacity expansion and its impact on supply chain coordination.

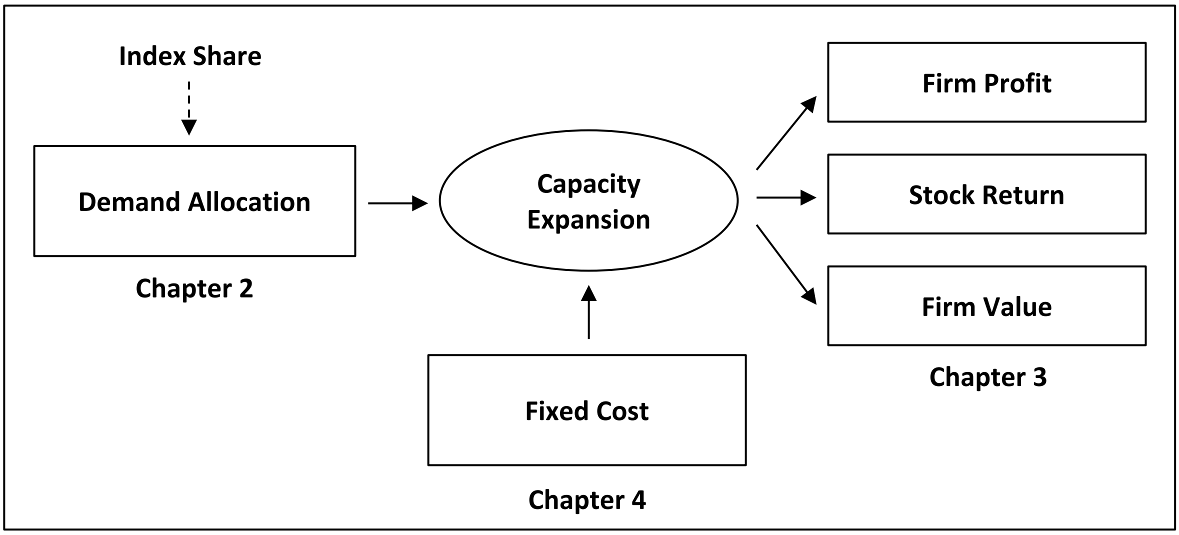


Figure 1 Thesis framework with key constructs

1.4 Methodology

To address the research problems, different modelling techniques along with estimation algorithms are proposed in the thesis. For the first research paper that models the demand allocation mechanism for a firm's capacity expansion, index share is specified by using a discrete choice model, which is an important factor of demand allocation. The capacity expansion is also considered by the index share via influencing the investors' stock purchasing behaviours. This model realises the evaluation of heterogeneity in demand allocation to capacity expansion with the use of a random coefficient in the model. On the other side, a simple supply-side model of capacity expansion is calibrated by maximising profit with a trade-off between unmet demand and excess capacity. It has a closed form of optimal capacity expansion level. Incorporating the demand allocation mechanism into the supply-side model facilitates analysis of the interactive relationship of capacity expansion with demand allocation, and captures important features of matching supply and demand for firms in a given sector. In addition, the methodology is applicable to a more general model. One possible extension shown in this thesis is a debt-financing consideration that explores the effect of debt on a firm's capacity expansion decision by developing the supply-side model with financial constraints.

In the study of performance impacts of capacity expansion, a simultaneous model under the mediator of index share is proposed to show how the capacity expansion impacts firm profit and stock return that are two critical parts of measuring firm value in a given sector. To be specific, a discrete choice model is used to evaluate demand allocation prior to capacity expansion, a capacity expansion model with financial constraints is developed for the profit maximisation, and a capital asset pricing model is discussed to specify the stock return in the financial market, in which index share plays an important role and fosters interaction among uncertain demand, capacity expansion, and firm performance. Firm profit as operating performance after capacity expansion is evaluated by allowing for the simultaneous capacity expansion and debt decisions, while the stock return that reflects a financial reaction of capacity expansion is determined through the rate of return on the sector index. The value of the firm is thus identified by incorporating both expected firm profit and stock return when the firm expands its capacity into the model, so as to realise the measure of firm value for the capacity expansion.

Regarding the methodology used to evaluate how fixed cost affects capacity expansion and corresponding supply chain coordination, a capacity expansion model bounded by the budget constraint that considers the discontinuous fixed cost are proposed. A discrete choice model for demand allocation is also specified, which is consistent with the previous modelling of demand allocation in capacity expansion. The setting of a budget boundary in the model is based on the assumption that cash outflows should be less than cash inflows to mitigate against bankruptcy, in which fixed and variable costs of capacity expansion are involved in the cash outflows. The cash inflows are constituted by the contribution from capacity expansion along with other financial incomes. Since there are missing data in fixed cost, I compare the root-mean-square error (RMSE) of eight different imputation methods including both traditional statistical regressions and machine learning techniques, and select the best one with the lowest RMSE to impute the missing fixed cost so as to implement the empirical study of capacity expansion and fixed cost.

The Bayesian estimation is used for all the studies in this thesis. That is, a technique of the MCMC algorithm is conducted to analyse the specific posterior of each estimator. The product of likelihood and prior information constitutes the posterior, in which joint densities of observations are obtained from assuming error terms in all models to follow normal distributions so as to specify the likelihood of the model. The Change-of-Variable Theorem is applied each time the density is transformed from error to observation, and the Contraction Mapping is required to obtain the mean utility of purchasing stock for investors in the given sector, which is based on the BLP model proposed by Berry et al. (1995). It is also noticed that the likelihood in the model that explores the impact of fixed cost on capacity expansion differs depending on whether a firm expands its capacity or not. This is because fixed cost is multiplied by an identity function to stand for the zero-fixed expenditure of no capacity expansion, leading to the discontinuity in error function specified by the supply-side model of capacity expansion, which is used for computing the likelihood. In addition, the Monte Carlo tests are carried out on all three studies to verify the validity of the models.

1.5 Research Outcomes

An empirical case of the semiconductor manufacturing sector is provided to evaluate the models specified for dealing with different research questions. The counterfactual analyses that are conducted by the changes of main variables are also given. Regarding the first empirical study of modelling demand allocation with index share for the capacity expansion, the results of the basic case without allowing for the financial constraints show that, with the increase of index share, demand for the capacity expansion is also raised, reflecting that index share is a positive signal for prospective demand. The interactive relationship between capacity expansion and index share is also discussed through analysing counterfactual results. That is, index share has a positive impact on capacity expansion, while the increased capacity expansion actually reduces a firm's index share in the sector. This means that firms with higher index shares intend to expand more capacities, however, their index shares are negatively influenced by the expansion in capacities, but ultimately, capacity expansion and index share will achieve equilibrium. When considering the financial constraints in the capacity expansion model, the joint decisions of capacity expansion and debt with the influence of index share are made. The counterfactual results present that debt level is negatively related to the capacity expansion for firms that own above-median index shares, while the increased amount of debt will facilitate expansion in capacity if firms' index shares are below the median level. This provides managerial implications of capacity expansion and financing strategy, whereby those debtholders who expect the funding to be fully utilised for expanding capacities should focus on firms with small index shares.

The second research question regarding the effect of capacity expansion on firm performance is also empirically evaluated. The parameters in demand allocation are almost the same as those in the first study, and the counterfactual analyses are specified by using the estimated parameters and alternating the amount of capacity expanded. The results indicate that both profit and value of firm firstly increase until they peak and then gradually reduce. When an effect of index share is considered in the firm's performance of capacity expansion, firms with below-median index shares have remarkably higher profits and firm values than those with index shares that are above the median level if the same capacities are expanded before reaching their optimal values. The case is the opposite with an insignificant difference being found for firms that have higher amounts of capacity expansions than peak values. Contrary to much received wisdom, it is found that capacity expansion has a negative impact on stock return for both groups of firms with different index shares. However, stock returns of firms that own above-median index shares are lower compared with those with below-median index shares for the same capacity expansion level, implying that great capacity expansion is not required for firms with large index shares as it may hurt their stock return. The managerial implication behind these findings is appealing, which is, investing in firms with small index share is a wise choice because their capacity expansions contribute to better firm performance including profit, stock return, and firm value compared with those of large-index-share firms when the expansion level lies in a suitable range.

For the results that evaluate how fixed cost affects capacity expansion, it is found that the capacity expansion model with fixed costs presents a better fit compared to the model without considering fixed costs, shown as lower values of the Akaika information criterion (AIC) and the Bayesian information criterion (BIC), as well as higher log marginal density (LMD) for the fixed cost model. Besides, the presence of fixed cost improves the estimation of capacity expansion, which leads to a good match between predictions of capacity expansions and data observations with lower RMSE. The impacts of fixed cost on capacity expansion and corresponding firm profit are analysed through counterfactuals, and the results show that with the increase of fixed cost, capacity expansion level remains nearly unchanged at the first stage and then goes up dramatically, while firm profit decreases with two inflection points that occur when the interior decision of capacity expansion equals to the corner solution and when demand and optimal capacity levels are the same, respectively. This emphasises the importance of fixed cost in determining capacity expansion and firm profit. When evaluating the impact of fixed cost on supply chain coordination, the compensating value that yields the same level of profits for the variation of fixed cost is also considered. It is noticed that the value to compensate the increased (decreased) fixed cost has a significantly positive (negative) relationship with fixed cost, meaning that if fixed costs of capacity expansions for downstream firms are increased (decreased) by suppliers, those firms with large expansion planning may obtain lower (higher) profit, which can be used to negotiate with their upstream suppliers. This represents a kind of supply chain coordination in operational research.

1.6 Contributions

The thesis contributes to the operations-finance interface in many ways. In general, the studies of interaction between operational and financial decisions, such as capacity expansion and debt, are advanced and extended through building systematic frameworks of simultaneous determinates. For example, the presence of index share are used to link the capacity expansion and debt, which is formed by a capacity expansion model with financial constraints, while a firm's stock return is modelled by the asset pricing model with the consideration of index share in the sector to evaluate the financial performance of capacity expansion. Moreover, models in this thesis are empirically examined by the use of Bayesian estimation, such as the important role of fixed cost on capacity expansion and supply chain coordination is verified by an empirical case of the semiconductor manufacturing sector. In addition, by conducting the counterfactual analyses with models and estimated parameters, many useful management practices in regard to the capacity expansion and financial implications are provided, including the debtholders that focus on capacity expansions are suggested to invest in small-index-share firms; compared to firms that own large index shares, much improved performance impacts of capacity expansion are obtained by small-index-share firms; a coordination between supply chain partners (suppliers and downstream firms) can be built by the variance of fixed cost of capacity expansion. Therefore, this thesis contributes to the interactive mechanism between operational decision and financial factors.

Concretely speaking, for the study of modelling demand allocation for capacity expansion, literature on strategic capacity investment is advanced by applying index share to make inferences about demand allocation among firms before capacity planning, which is ready for empirical examination. Moreover, the studies associated with operational decisions and financial implications are also analysed at a more macro level. (i.e. macro-level behaviour such as demand allocation and index share impacts micro-level decisions such as capacity expansion and financing, and vice versa), while previous research is mainly concerned with the firm-level operational and financial decisions, such as capacity and debt (see Birge (2014) for a recent view). Besides, the methodology specified in the study can be extended to more advanced supply-side models of capacity expansion. In the model extension, index share is shown to have a pronounced effect on the relationship between capacity expansion and debt financing by considering budget constraints, thereby complementing the simple analysis of direct impact of debt on capacity expansion without allowing for demand allocation via index share, which is proposed by Xu and Birge (2008). In conclusion, this study extends the operations literature in capacity expansion and its interaction with financial decisions.

Regarding the research that explores in depth the operating and financial performance impacts of capacity expansion, it contributes to the operational studies in three aspects. First, a systematic framework of simultaneous capacity expansion and performance outcomes is built, which extends the analysis that empirically tests financial performance of capacity expansion using only simple regressions (Hendricks et al. 1995). Second, literature linking the operations-finance interface is advanced by considering the firm value to precisely measure performance impact. This is rarely explored from both operational and financial perspectives in the extant studies. Third, this study also reveals an appealing managerial implication, which is, firms that own small index shares may obtain more advantage in capacity expansion, such as higher profit, stock return, and firm value within a reasonable range, compared with large-index-share firms. To conclude, the research explores the operating and financial performance impacts of capacity expansion and provides some useful insights into the management practice relating to the capacity expansion decision.

In addition, this research makes many contributions gained from the study of how fixed cost impacts the capacity expansion and corresponding supply chain coordination. What I postulate first is that the theoretical literatures regarding capacity expansion and fixed cost are extended by considering both operational decisions and financial matters. To be specific, the capacity expansion model is developed using a financial link of cash inflows and outflows to construct a boundary constraint that accounts for a firm’s fixed cost, and the discontinuity issue of fixed cost is addressed based on an economic framework. Next, the importance of fixed cost in determining the capacity expansion is verified by an empirical case; in which capacity expansion models with and without fixed costs are examined for firms in the semiconductor manufacturing sector, and it is found that a fixed cost model presents a much better fitting than when fixed cost is not considered. What is more, the presence of fixed cost builds a link between capacity expansion and supply chain coordination. That is, firms with large capacity expansion are able to negotiate with their upstream suppliers by adjusting the fixed cost, so as to achieve a win-win for supply chain partners. In sum, the model and empirical example in this study discuss the effect of fixed cost on capacity expansion decision and supply chain coordination, which complements the literature on operational research with the consideration of discontinuous fixed costs in empirical capacity expansion studies.

1.7 Thesis Structure

The thesis explores in great depth capacity expansion decisions that are associated with the demand allocation, firm performance, and fixed cost, which reflects the current research strand regarding the interface of capacity expansion, capacity market, and financial constraint. In the following sections, the study of modelling demand allocation for capacity expansion via index share is firstly discussed in Chapter 2. Then, in Chapter 3, the firm performance impacts of capacity expansion in both operating and financial aspects are investigated. Chapter 4 studies the effect of fixed cost on capacity expansion and supply chain coordination. The empirical case in the semiconductor manufacturing sector is used to evaluate models specified in each chapter. Chapter 5 concludes the thesis, identifies limitations, and makes suggestions for future research direction.

Chapter 2 Modelling Demand Allocation in Capacity Expansion using Index Share

2.1 Introduction

Numerous studies in the field of operations have focused on questions about how to optimise firm capacity to match product-market demand through either maximising firm profit or minimising losses (Angelus and Porteus 2002, Birge and Louveaux 2011). Of particular interest is the modelling of demand allocation for capacity expansion decisions in order to gain competitive advantage from potential time-compression diseconomies (Dierickx and Cool 1989, Yang and Allenby 2015) given the time required to increase capacity levels in large capital investments. This resonates with firms operating in the semiconductor manufacturing sector whereby capacity expansion would not only be done based on the expectation of uncertain demand, but also influences market demand from a financial view. For example, Samsung, one of the largest semiconductor manufacturers, expanded its capacity to meet demand uncertainty, but suffered from significant stock losses in the capital market during its first few years after expansion (Samsung 2016). These decreased stock returns of Samsung may be derived from the effect of capacity expansion on investors' preferences, which further leads to the reduction of market demand. Although firms' current decisions on capacity expansion would not fulfil unobserved market demand using a stochastic setting, past studies have shown that multiple financial factors (e.g., debt) are related to the current decision on capacity expansion (Xu and Birge 2004).

As such, modelling the determinants of demand that affect capacity expansion and its interaction with financial factors could provide insight into the study of capacity expansion to help firms to maximise profitability and optimise their decisions on capacity levels. The finance literature has widely documented empirical evidence that the stock market development plays a pivotal role in forecasting future economic growth (Henry et al. 2004, Levine and Zervos 1999). In other words, financial performance is demand-driven and, hence, index share as a leading indicator in capital market can serve as demand proxy for developing a plausible demand estimation model. This is consistent with the finance-led growth hypothesis proposed by Schumpeter (1911) in the theory of economic development; that an efficient financial system will serve as a catalyst for technological innovations through efficiency of resource allocation from unproductive sector to productive sector. It also matches the investment theory of the efficient market hypothesis that stock prices always incorporate and reflect all the information related to firm performance (Tobin 1969). As the weight of individual stock price in the financial market, index share therefore can be used to evaluate the demand allocation in empirical capacity expansion decision.

Operational models rarely incorporate financial factors into capacity expansion and consider that the operational decisions (e.g., capacity expansion) are separately determined by financial decisions in a perfect market (Modigliani and Miller 1958). However, financial implications of capacity expansion decision should be taken into account, as they are related to each other in reality. For example, operators may consider the amount of debts raised for capacity expansion plans (Lederer and Singhal 1994), while investors in the capital market are supposed to alter their investment decisions in response to the variations of firms' debt levels (Hennessy and Whited 2005). In this case, considering index share as an input of demand allocation to determine the capacity expansion and its reaction to debt is a way to evaluate the effect of financial factors on capacity expansion. On the other side, capacity expansion may also influence financial proxies in the capital market, such as index share; however, demand models typically evaluate index share by using expected utility with exogenous firm attributes without considering capacity expansion that is simultaneously determined by the demand allocation (Yang et al. 2003). Failure to account for operational endogeneity in a supply-and-demand matching relationship leads to estimation bias as shown in Olivares et al. (2008). Thus, this chapter attempts to address issues regarding interactive capacity expansion and demand allocation in the operations study.

The investigation of matching capacity expansion with market demand via index share is drawn from the interaction between operational and financial decisions. A demand allocation mechanism is proposed using the discrete choice model, and a supply-side model of capacity expansion is developed at a firm level. Index share that accounts for the endogenous capacity expansion is used to identify the demand allocation, which is a critical factor in determining the optimal capacity level. In addition, this chapter extends the basic model with simple supply-side specification of capacity expansion into a debt-financing application, which is modelled by allowing for financial constraints. It explores the effect of debt on a firm's capacity expansion decision. The data used for the empirical analyses are obtained from 64 listed semiconductor manufacturing firms in the SOX for the periods from 2006 to 2010 in a sector view. The evidence shows a significant role of index share in deciding capacity expansion and its interaction with debt financing. It also offers managerial implications on capacity expansion and financing strategy that debt holders should invest more in firms with smaller shares in the given sector than in those large-share firms.

The contributions are significant. Firstly, identifying demand allocation with the use of index share prior to capacity expansion advances the literature on strategic capacity planning. This is also applicable in a case of the semiconductor manufacturing sector, which provides evidence for the demand-and-supply match in empirical capacity expansion. Secondly, the interaction relationship between operational decisions and financial implications is also considered from a macro perspective. While previous studies are primarily concerned with the firm-level operational and financial decisions (e.g., Birge 2014), this research applies the macro-level proxy – index share – for the demand allocation to impact the capacity expansion decision of individual firms. Thirdly, more complicated supply-side models of capacity expansion can be provided based on the methodology specified in this chapter, and the proposed extension suggests the pronounced effect of index share in the interactive capacity expansion and debt financing, which extends the analysis that debt is directly related to capacity expansion without considering demand allocation (Xu and Birge 2008). In sum, the study in this chapter advances operations literature in capacity expansion and its interaction with financial decisions.

2.2 Model Development

This section illustrates the basic framework of matching supply with demand by applying the index share to study capacity expansion. The demand allocation before capacity planning is evaluated using index share that incorporates the endogenous capacity expansion. In the meantime, the optimal capacity expansion level is determined by demand allocation, in which the index share is regarded as one of the critical proxies. To model the interactive relationship, a discrete choice model is employed to determine the mechanism of demand allocation prior to capacity expansion. The utilities of each investor's stock purchase for firms in a given sector are maximised to obtain individual choice probabilities, and then are aggregated over investors to realise the heterogeneity in allocation of demand via index share. Moreover, a capacity expansion model is developed to solve the firm-level capacity expansion under the impact of demand allocation. By taking index share into account, firms pick the optimal capacity decisions that afford them the highest profits. In addition, the trade-off between the cost of excess capacity and the opportunity cost of unsatisfied demand is also allowed in the model. Figure 2 displays the interaction of capacity expansion with index share, reflecting that both are simultaneously determined.

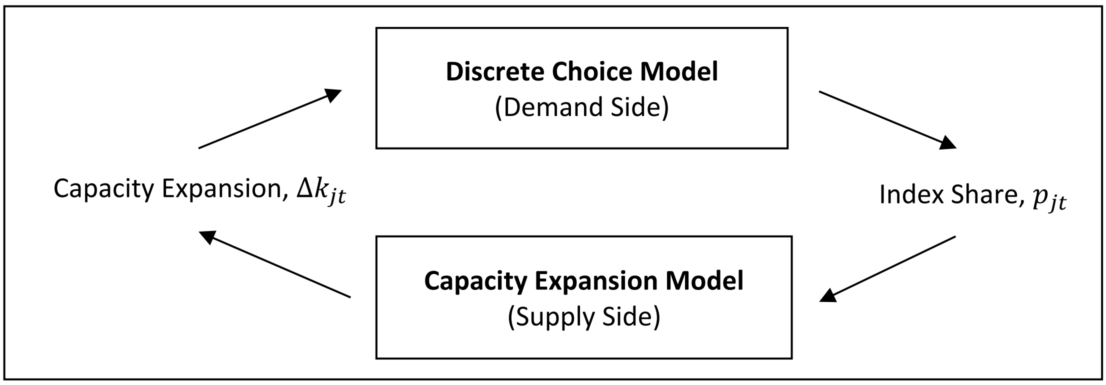


Figure 2 The interactive relationship between capacity expansion and index share

2.2.1 Demand Allocation

The demand allocation among firms in a given sector is affected by index shares that are weights of an index fund. The values of index shares are typically estimated by aggregating all investors' highest utilities of stock purchases that differ depending on firm-level attributes, expected returns, debts, and capacity expansion plans. Suppose that there are a total of J_t firms ($j \in \{1,..,J_t\} \equiv L(J_t)$) in a sector available to all I investors ($i \in \{1,..,I\} \equiv L(I)$) at period ($\in \{1,..,T\} \equiv L(T)$), where $L(\cdot)$ is an integer set from 1 to any positive number, $(\cdot)$. The utility of individual investor i purchasing firm j's stock at period t for $i \in L(I), j \in L(J_t), t \in L(T)$ is specified as,

$$U_{ijt} = \alpha_i^0 + \boldsymbol{\alpha}_i^x \mathbf{x}_{jt} + \alpha_i^r r_{jt} + \alpha_i^k \Delta k_{jt} + \alpha_i^d d_{jt} + \xi_{jt} + \varepsilon_{ijt}, \tag{1}$$

where $j = 0$ refers to no purchase of any J_t firms' stocks in a sector, and the corresponding utility is $U_{i0t} = \varepsilon_{i0t}$. Here, $\mathbf{x}_{jt}$ is the firm-level attributes, including firm size and financial features and r_{jt} is the expected return of firm j at period t. The terms Δk_{jt} and d_{jt} are the amounts of capacity and debt raised. The scalar ξ_{jt} is a firm-specific characteristic (i.e. a demand shock) that is observed by firms in a given sector, but is unknown by the researchers. The error term ε_{ijt} is an unobserved idiosyncratic shock that is distributed independently over investors, firms and periods. The intercept α_i^0 captures the utility of investing in an inside firm instead of outside firm. The parameter vector $\boldsymbol{\alpha}_i^x$ represents the investor i's preference for K attributes, and parameters α_i^r, α_i^k, and α_i^d reflect the marginal demand-side utilities of return, capacity expansion quantities, and debt for investor i.

In the financial market, all listed firms' stocks in a sector are possible to be selected by investors. However, it is often observed that investors purchase more than one firm's stock, which is a multi-variety choice problem. This issue can be solved by involving both corner and interior solutions in the utility optimisation, but results in the complexity of the evaluation regarding the index share equation, which is a further research direction. In this study, the assumptions of Yang et al. (2003) and Jiang et al. (2009) are followed that allows for the purchase of only one variety with the maximised utility for each individual, and develop the assumption as follows,

Assumption 1: Each investor chooses to purchase only one firm's stock that is able to obtain the highest utility.

To simplify the estimation, $\mathbf{X}_{jt} = (1, \mathbf{x}_{jt}, r_{jt}, \Delta k_{jt}, d_{jt})$ is set, which contains all firm-specific characteristics. Let random coefficient $\boldsymbol{\alpha}_i = (\alpha_i^0, \boldsymbol{\alpha}_i^x, \alpha_i^r, \alpha_i^k, \alpha_i^d)'$ be independently drawn from the normal distribution $F_\alpha(\boldsymbol{\alpha}_i; \overline{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha)$ with mean $\overline{\boldsymbol{\alpha}}$ and covariance matrix $\boldsymbol{\Sigma}_\alpha$. Then an identity for each investor's preference can be specified, which is $\boldsymbol{\alpha}_i = \overline{\boldsymbol{\alpha}} + \mathbf{v}_i$, where $\mathbf{v}_i \sim N(0, \boldsymbol{\Sigma}_\alpha)$, $i = 1, \dots, I$, so as to decompose the utility function into a mean utility and a deviation from that mean. If error term ε_{ijt} is assumed to follow the Type I extreme value distribution $F_{\varepsilon}(\varepsilon)$, index share of firm j at period t is then obtained by integrating all investors' choice probabilities over the distribution of $\boldsymbol{\alpha}_i$. It can be evaluated using a random coefficient mixed logit model, which is,

$$s_{jt}\left(\delta_{jt}^{\alpha}, \mathbf{X}_{jt}; \boldsymbol{\Sigma}_{\alpha}\right) = \int_{\left\{\boldsymbol{\alpha}_i, \varepsilon_{ijt} \middle| U_{ijt} \geq U_{ij't},\ \forall j' \neq j\right\}} dF_{\alpha}(\boldsymbol{\alpha}_i; \overline{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_{\alpha}) dF_{\varepsilon}(\varepsilon), \tag{2}$$

$$= \int \frac{\exp(\delta_{jt}^{\alpha} + \mathbf{X}_{jt}\mathbf{v}_i)}{1 + \sum_{j=1}^{J_t} \exp(\delta_{jt}^{\alpha} + \mathbf{X}_{jt}\mathbf{v}_i)}\, dF_{\alpha}(\mathbf{v}_i; \boldsymbol{\Sigma}_{\alpha}), \tag{3}$$

where $\delta_{jt} = \mathbf{X}_{jt}\overline{\boldsymbol{\alpha}} + \xi_{jt}$, capturing the 'linear' mean utility that is common to all investors, while the term $\mathbf{X}_{jt}\mathbf{v}_i$ is a heteroskedastic deviation from mean utility with random coefficients.

Often, integrals are estimated by Monte Carlo simulation with N_p draws of $\boldsymbol{\alpha}_i$ from the normal distribution, and the 'smooth simulator' becomes,

$$p_{jt}\left(\delta_{jt}, \mathbf{X}_{jt}; \boldsymbol{\Sigma}_{\alpha}\right) = \frac{1}{N_p} \sum_{i=1}^{N_p} \frac{\exp\left(\delta_{jt} + \mathbf{X}_{jt}\mathbf{v}_i\right)}{1 + \sum_{j=1}^{J_t} \exp\left(\delta_{jt} + \mathbf{X}_{jt}\mathbf{v}_i\right)}. \tag{4}$$

In the following sections, term $p_{jt}\left(\delta_{jt}, \mathbf{X}_{jt}; \boldsymbol{\Sigma}_{\alpha}\right)$ is written by p_{jt} to simplify notation.

2.2.2 Capacity Expansion

The amount of capacity for each firm can be evaluated through its profit maximisation under the specific demand allocation. Due to the heterogeneity of demand allocation, the demand w_{jt} is assumed to be lognormal distributed $w_{jt} \sim LN\left(\mu_{jt}, \tau\right)$ with probability density function (p.d.f.) ϕ_{jt} and cumulative density function (c.d.f.) $\boldsymbol{\Phi}_{\mathrm{jt}}$, where μ_{jt} is the firm-specific average demand that is related to index share p_{jt} and sales predictors $\mathbf{q}_{jt}$, τ is the standard deviation of lognormal distribution. Thus, the firm j's expected profit at period t is formulated with the consideration of both storage cost and shortage penalty, and the optimal capacity decision is then obtained by maximising its profit,

$$\max \quad u_{jt}\mathrm{E}\left[\min\left(w_{jt}, k_{jt}\right)\right] - h_{jt}\mathrm{E}\left[\left(k_{jt} - w_{jt}\right)^{+}\right] - l_{jt}\mathrm{E}\left[\left(w_{jt} - k_{jt}\right)^{+}\right] - c_{jt}k_{jt}, \tag{5}$$

where $x^{+} = \max(x, 0)$. Here, the production level is supposed to be equal to the amount of capacity, k_{jt}. This means that the firm can fully utilise its capacity for production, which is reasonable in the semiconductor manufacturing sector. The parameters u_{jt}, h_{jt}, l_{jt}, and c_{jt} are price, unit storage cost, unit shortage penalty, and unit production cost of firm j at period t, respectively.

Since the demand is stochastic, the expected firm profit can be rewritten as,

$$\pi_{jt} = \int_0^{k_{jt}} \left[u_{jt}w_{jt} - h_{jt}\left(k_{jt} - w_{jt}\right)\right] d\boldsymbol{\Phi}_{jt}\left(w_{jt}\right) + \int_{k_{jt}}^{\infty} \left[u_{jt}k_{jt} - l_{jt}\left(w_{jt} - k_{jt}\right)\right] d\boldsymbol{\Phi}_{jt}\left(w_{jt}\right)$$

$$-c_{jt}k_{jt}. \tag{6}$$

Differentiating the profit with respect to capacity gives the first-order condition,

$$\frac{\partial \pi_{jt}}{\partial k_{jt}} = \left(u_{jt} + l_{jt} - c_{jt}\right) - \left(u_{jt} + l_{jt} + h_{jt}\right)\boldsymbol{\Phi}_{jt}\left(k_{jt}\right) = 0. \tag{7}$$

Therefore, the optimal capacity policy for firm j at period t is,

$$k_{jt}^* = \boldsymbol{\Phi}_{jt}^{-1}\left(\frac{u_{jt} + l_{jt} - c_{jt}}{u_{jt} + l_{jt} + h_{jt}}\right) = \mu\left(p_{jt}\left(k_{jt}^*\right), \mathbf{q}_{jt}\right) \times \exp\left(\tau \mathbf{Z}^{-1}\left(\frac{u_{jt} + l_{jt} - c_{jt}}{u_{jt} + l_{jt} + h_{jt}}\right)\right), \tag{8}$$

where $\mathbf{Z}^{-1}(\cdot)$ is the inverse c.d.f. of a standard normal distribution.

In the empirical specification, the unit profit margin of each firm can be decomposed into a set of observed profit shifters, the vector $\mathbf{w}_{jt}$, and an unobserved component η_{jt}, which is a firm-specific linear function written as,

$$\frac{u_{jt} + l_{jt} - c_{jt}}{u_{jt} + l_{jt} + h_{jt}} = \mathbf{w}_{jt}\boldsymbol{\gamma} + \eta_{jt}, \tag{9}$$

where $\boldsymbol{\gamma}$ is a vector of parameters for profit shifters.

For simplicity of the capacity expansion model, mean demand $\mu\left(p_{jt}, \mathbf{q}_{jt}\right)$ is assumed to be an exponential linear function, which is $\mu_{jt} = \exp\left(\mu_1 p_{jt} + \mathbf{q}_{jt}\boldsymbol{\mu}_2\right)$, where μ_1 and $\boldsymbol{\mu}_2$ are parameters in the mean demand. $\Delta k_{jt}^* = k_{jt}^* - k_{j,t-1}$ is set to specify the amount of capacity expansion, where $k_{j,t-1}$ is the observed capacity level in the last period. By substituting the optimal capacity policy into the expression for unit profit margin, the capacity expansion equation that depends only on the index shares, equilibrium capacity expansion vector and observed covariates is obtained,

$$\mathbf{Z}\left(\frac{1}{\tau}\left(\ln\left(\Delta k_{jt}^* + k_{j,t-1}\right) - \mu_1 p_{jt}\left(\Delta k_{jt}^* + k_{j,t-1}\right) - \mathbf{q}_{jt}\boldsymbol{\mu}_2\right)\right) = \mathbf{w}_{jt}\boldsymbol{\gamma} + \eta_{jt.} \tag{10}$$

2.3 Statistical Specification

In this section, the likelihood and Bayesian estimation are discussed in great detail. A technique of the MCMC algorithm is used to facilitate the analysis of each Bayes estimator in the models. Besides, a Monte Carlo test is conducted to simulate models and verify their validities.

2.3.1 Likelihood

In order to specify the likelihood, shocks in the utility function (1) and profit margin function (9) are assumed to be independently distributed across firms with identical variances,

$$\xi_{jt} \sim N(0, \sigma_d^2), \tag{11}$$

$$\eta_{jt} \sim N(0, \sigma_s^2), \tag{12}$$

where σ_d^2 is the variance of ξ_{jt} and σ_s^2 is the variance of η_{jt}.

Under the inter-firm demand allocation mechanism, the joint density of index shares at period t with the use of the Change-of-Variable Theorem is specified as,

$$\pi_1(\mathbf{P}_t | \mathbf{X}_t, \overline{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha, \sigma_d^2) = \left(J_{(\mathbf{P}_t \to \boldsymbol{\xi}_t)}\right)^{-1} \times \left(\prod_{j=1}^{J_t} \phi_d\left(\left(p_{jt}^{-1}(P_{jt}, \mathbf{X}_{jt}; \boldsymbol{\Sigma}_\alpha) - \mathbf{X}_{jt}\overline{\boldsymbol{\alpha}} \right) \middle| \sigma_d^2 \right) \right), \tag{13}$$

where $\mathbf{P}_{1t} = (P_{1t}, \ldots, P_{J_t t})'$ and $\mathbf{X}_t = \left(\mathbf{X}_{1t}', \ldots., \mathbf{X}_{J_t t}'\right)'$ are vectors of observed index shares and firm-specific characteristics at period t, respectively. $\overline{\boldsymbol{\alpha}}$ and $\boldsymbol{\Sigma}_\alpha$ are the mean and covariance matrix of random coefficient $\boldsymbol{\alpha}_i$, and $\boldsymbol{\xi}_t = (\xi_{1t}, \ldots\ \xi_{J_t t})'$, as the aggregate shock among firms in the utility function at period t, has the normal density of ϕ_d. $p_{jt}^{-1}(P_{jt}, \mathbf{X}_{jt}; \boldsymbol{\Sigma}_\alpha)$ captures the mean utility δ_{jt} that can be computed through the use of the BLP Contraction Mapping. Its details are discussed in sub-section 2.3.1.1. $\left(J_{(\mathbf{P}_t \to \boldsymbol{\xi}_t)}\right)^{-1}$ is the inversed determinant of Jacobian matrix used to transform from $\mathbf{P}_t$ to $\boldsymbol{\xi}_t$.

In the case of intra-firm capacity expansion decision, the joint density of capacity expansion quantities at period t can be obtained by using the Change-of-Variable Theorem,

$$\pi_2(\Delta\mathbf{k}_t | \mathbf{X}_t, \mathbf{q}_t, \mathbf{w}_t, \boldsymbol{\varphi}, \sigma_s^2, \boldsymbol{\Sigma}_\alpha) = J_{(\boldsymbol{\eta}_t \to \Delta\mathbf{k}_t)} \tag{14}$$

$$\times \left(\prod_{j=1}^{J_t} \phi_s\left(\left(\mathbf{Z}\left(\frac{1}{\tau}\left(\ln(\Delta k_{jt} + k_{j,t-1}) - \mu_1 p_{jt}(\delta_{jt}, \mathbf{X}_{jt}; \boldsymbol{\Sigma}_\alpha) - \mathbf{q}_{jt}\boldsymbol{\mu}_2 \right) \right) - \mathbf{w}_{jt}\boldsymbol{\gamma} \right) \middle| \sigma_s^2 \right) \right),$$

where $\Delta\mathbf{k}_t = \left(\Delta k_{1t}, \dots, \Delta k_{J_t t}\right)'$, $\mathbf{q}_t = \left(\mathbf{q}'_{1t}, \dots, \mathbf{q}'_{J_t t}\right)'$, and $\mathbf{w}_t = \left(\mathbf{w}'_{1t}, \dots, \mathbf{w}'_{J_t t}\right)'$ are vectors of observed capacity expansion levels, financial sales predictors, and profit shifters at period t, respectively. $\boldsymbol{\eta}_t = (\eta_{1t}, \dots, \eta_{J_t t})'$, as the aggregate shock among firms in the profit margin function at period t has the normal density of ϕ_s. $\delta_{jt} = \mathbf{X}_{jt}\overline{\boldsymbol{\alpha}} + \xi_{jt}$ captures the mean utility of firm j at period t. The parameter vector that is required to be estimated in the capacity expansion equation involves $\boldsymbol{\varphi} = (\mu_1, \boldsymbol{\mu}_2, \iota, \boldsymbol{\gamma})'$, where μ_1 and $\boldsymbol{\mu}_2$ are parameters in the mean demand $\mu\left(p_{jt}, \mathbf{q}_{jt}\right)$, ι is the per cent of last-period asset, and $\boldsymbol{\gamma}$ is the parameter vector for profit shifters. $J_{(\boldsymbol{\eta}_t \to \Delta\mathbf{k}_t)}$ is the determinant of Jacobian matrix used to transform from $\boldsymbol{\eta}_t$ to $\Delta\mathbf{k}_t$.

Therefore, the likelihood for all parameters is specified as,

$$L\left(\overline{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha, \boldsymbol{\varphi}, \sigma_d^2, \sigma_s^2\right) = \prod_{t=1}^{T} \left(\pi_1\left(\mathbf{P}_t | \mathbf{X}_t, \overline{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha, \sigma_d^2\right) \times \pi_2(\Delta\mathbf{k}_t | \mathbf{X}_t, \mathbf{q}_t, \mathbf{w}_t, \boldsymbol{\varphi}, \sigma_s^2, \boldsymbol{\Sigma}_\alpha)\right). \quad (15)$$

The specific calculations for determinants of Jacobian matrices, $J_{(\boldsymbol{\eta}_t \to \Delta\mathbf{k}_t)}$ and $J_{(\mathbf{P}_t \to \boldsymbol{\xi}_t)}$, are illustrated in Appendix A.

2.3.1.1 Contraction Mapping

To obtain the mean utility δ_{jt} used for computing the shock in the utility function, the index share p_{jt}, calculated by using the discrete-choice model, is assumed to equal to the share observation P_{jt} based on the BLP model proposed by Berry et al. (1995), which is $p_{jt}\left(\delta_{jt}, \mathbf{X}_{jt}; \boldsymbol{\Sigma}_\alpha\right) = P_{jt}$. By inverting the above equation, mean utility function is obtained, which is,

$$\delta_{jt} = p_{jt}^{-1}\left(P_{jt}, \mathbf{X}_{jt}; \boldsymbol{\Sigma}_\alpha\right). \quad (16)$$

The nested fixed point of δ_{jt} can be found by iterating the BLP Contraction Mapping recursively, so that the distance between predicted index share and share observation is minimised. The iterative scheme proved by Berry (1994) for $j \in L(J_t)$ and $t \in L(T)$ is,

$$\delta_{jt}^{r+1} = \delta_{jt}^{r} + \ln\left(P_{jt}\right) - \ln\left(p_{jt}\left(\delta_{jt}, \mathbf{X}_{jt}; \boldsymbol{\Sigma}_\alpha\right)\right). \quad (17)$$

When δ_{jt}^{r+1} and δ_{jt}^{r} are sufficiently close to each other through successive iterations, the stopping rule is satisfied,

$$\left\|\delta_{jt}^{r+1} - \delta_{jt}^{r}\right\| \leq \mathrm{tol}, \quad (18)$$

where $r + 1$ is the iteration number and tol refers to the tolerance level that can be a small number, like 10^{-8} or 10^{-12}.

Since the nested-fixed point iteration and numerical root-finding are equivalent mathematically, the BLP Contraction Mapping for solving the fixed-point problem can therefore be reformulated as an indirect approach by using nonlinear rootfinding algorithms. For example, both the BB spectral gradient method and the derivative-free spectral algorithm for nonlinear equation proposed by La Cruz et al. (2006) are rootfinding methods that significantly improve speed, robustness and quality compared to the BLP Contraction Mapping when non-linear optimisation problems are on a large scale. Besides, alternative methods like the Squared Polynomial Extrapolation Method (Roland and Vardhan 2005, Roland et al. 2007, Varadhan and Roland 2008, SQUAREM) are also introduced to speed up the convergence procedure in a fixed-point formulation without changing the algorithm of Contraction Mapping.

2.3.2 Estimation

A full-information Bayesian approach is used to estimate the model rather than conventional methods, such as GMM, MLE, and MPEC (Berry et al. 1995, Su and Judd 2012, Train and Winston 2007). This is because Bayesian analysis allows for the investigation of small-sample events, and the random coefficient used in the Bayesian hierarchical model is much more intuitive and straightforward compared with the GMM and MLE approaches. Besides, the evaluation process can be simplified when using the MCMC in the Bayesian estimation.

To implement the Bayesian estimation, the independent priors of $\overline{\alpha}$, φ, σ_d^2, and σ_s^2 are,

$$\overline{\boldsymbol{\alpha}} \sim N\left(\overline{\overline{\boldsymbol{\alpha}}}, \mathbf{V}_{\overline{\alpha}}^{-1}\right), \tag{19}$$

$$\boldsymbol{\varphi} \sim N\left(\overline{\boldsymbol{\varphi}}, \mathbf{V}_{\varphi}^{-1}\right), \tag{20}$$

$$\sigma_d^2 \sim v_{d0} s_{d0}^2 / \chi_{v_{d0}}^2, \tag{21}$$

$$\sigma_s^2 \sim v_{s0} s_{s0}^2 / \chi_{v_{s0}}^2. \tag{22}$$

For the covariance matrix of investors' preference, each element of the Cholesky root for $\boldsymbol{\Sigma}_\alpha$ is estimated; there are a total of $R(R+1)/2$ elements. In order to ensure the positivity of variances, diagonal elements are reparameterised as exponential terms and prior is given by,

$$\boldsymbol{\Sigma}_\alpha = U'U \;\text{ for } U = \begin{bmatrix} e^{\theta_{11}} & \dots & \theta_{1R} \\ \vdots & \ddots & \vdots \\ 0 & \dots & e^{\theta_{RR}} \end{bmatrix}, \tag{23}$$

$$\theta_{jl} \sim N\left(0, \sigma_{\theta_{jl}}^2\right) \text{ for } j, l = 1, \dots, R, j < l. \tag{24}$$

The joint posterior based on the above likelihood and priors is,

$$\pi\left(\bar{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha, \boldsymbol{\varphi}, \sigma_d^2, \sigma_s^2 \middle| \{\Delta\mathbf{k}_t, \mathbf{P}_t, \}_{t=1}^T\right) \propto L\left(\bar{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha, \boldsymbol{\varphi}, \sigma_d^2, \sigma_s^2\right) \times \prod_{j=1}^{J_t} \left(\pi\left(\bar{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha, \boldsymbol{\varphi}, \sigma_d^2, \sigma_s^2\right)\right), \quad (25)$$

where $\pi\left(\bar{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha, \boldsymbol{\varphi}, \sigma_d^2, \sigma_s^2\right)$ is the product of individual priors, $\pi(\bar{\boldsymbol{\alpha}})$, $\pi(\boldsymbol{\theta})$, $\pi(\boldsymbol{\varphi})$, $\pi\left(\sigma_d^2\right)$, and $\pi(\sigma_s^2)$. $\boldsymbol{\theta} = (\theta_{11}, \dots, \theta_{jl}, \dots, \theta_{RR})'$ is the vector of elements in Cholesky root for $\boldsymbol{\Sigma}_\alpha$.

The conditionals of parameters used to implement the MCMC algorithm is,

$\bar{\boldsymbol{\alpha}} \mid \boldsymbol{\theta}, \sigma_d^2$	mean of heterogeneity in index share equation,	(26)
$\boldsymbol{\theta} \mid \boldsymbol{\varphi}, \bar{\boldsymbol{\alpha}}, \sigma_d^2$	covariance of heterogeneity in index share equation,	(27)
$\boldsymbol{\varphi} \mid \sigma_s^2, \boldsymbol{\theta}$	parameters in capacity expansion equation,	(28)
$\sigma_d^2 \mid \bar{\boldsymbol{\alpha}}, \boldsymbol{\theta}$	variance of error in index share equation,	(29)
$\sigma_s^2 \mid \boldsymbol{\varphi}$	variance of error in capacity expansion equation.	(30)

Here, the shocks are assumed to be conditionally independent.

The draws for both $\boldsymbol{\theta}$ and $\boldsymbol{\varphi}$ are much more complicated since the Jacobian terms in the likelihood function involve these parameters. Thus, the Random-Walk (RW) Metropolis algorithm is used to draw $\boldsymbol{\theta}$ and $\boldsymbol{\varphi}$, respectively. Moreover, the conditional draws for $\bar{\boldsymbol{\alpha}}$ and σ_d^2 can be easily accomplished by using a pure Gibbs sampler with standard natural conjugate Bayes analysis, as they are parameters in the univariate regression when mean utility δ_{jt} is computed by the BLP Contraction Mapping with a given $\boldsymbol{\theta}$. Besides, parameter σ_s^2 is drawn from the inverted gamma distribution. The detailed draws of parameters are provided in Appendix B.

The MCMC algorithm can also be presented by using the "directed acyclic" graph (DAG), which is displayed in Figure 3.

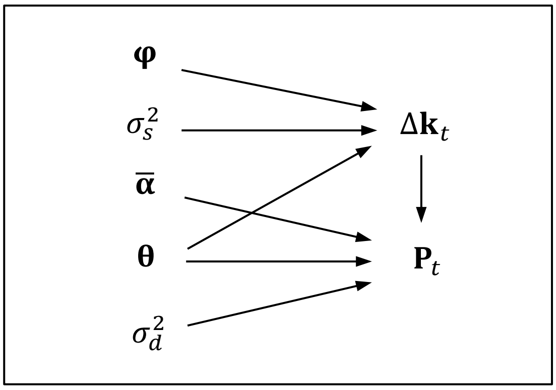


Figure 3 The DAG for basic model

2.3.3 Simulation Study

To simulate models regarding the relationship between capacity expansion and index share, a Monte Carlo test is conducted with the specific simulation settings. On the basis of the typical empirical application proposed by Jiang et al. (2009), a small sample of simulated data is considered with $J = 15$ firms in a sector available to all $I = 50$ investors in each period for a total periods of $T = 3$. In this situation, it is ensured that the Jacobian term in the index share equation is finite. There are $nA = 3$ observed firm attributes $\mathbf{x}_{jt}$ being generated by,

$$\begin{bmatrix} x_{jt}^1 \\ x_{jt}^2 \\ x_{jt}^3 \end{bmatrix} \sim N\left(\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 1 & -0.8 & 0.3 \\ -0.8 & 1 & 0.3 \\ 0.3 & 0.3 & 1 \end{bmatrix}\right), \tag{31}$$

which is consistent with the setting of Dubé et al. (2012). In addition, the values of stock return and debt are all simulated by the independent and identically distributed (i.i.d.) uniform draws.

Random coefficients $\boldsymbol{\alpha}_i = \left(\alpha_i^0, \boldsymbol{\alpha}_i^x, \alpha_i^r, \alpha_i^d, \alpha_i^k\right)'$ (an intercept, $nA = 3$ attributes, stock return, capacity expansion and debt) are set diffusely and the corresponding parameter vectors of mean $\overline{\boldsymbol{\alpha}}$ and covariance matrix $\boldsymbol{\Sigma}_\alpha$ are given by,

$$\overline{\boldsymbol{\alpha}} = (-2, -3, -4, -5, -6, -7), \tag{32}$$

$$\boldsymbol{\Sigma}_\alpha = \begin{bmatrix} 3 & & & & & \\ & 4 & & & & \\ & & 4 & & & \\ & & & 3 & & \\ & & & & 2 & \\ & & & & & 5 \end{bmatrix}, \tag{33}$$

where only variances of random coefficients are considered, consistent with the simulation settings of Jiang et al. (2009). Here, the largely negative effect of capacity expansion implies that when firms decide to expand capacities, there is a high probability that investors will not buy their stocks.

In addition, the convergence tolerance used to terminate the Contraction Mapping in the index share equation is set to 10^{-10}, and SQUAREM is applied to implement the BLP Contraction Mapping.

For covariates in the capacity expansion equation, $nQ = 3$ sale predictors $\mathbf{q}_{jt}$ and $nW = 3$ profit shifters $\mathbf{w}_{jt}$ are simulated by,

$$\begin{bmatrix} q_{jt}^1 \\ q_{jt}^2 \\ q_{jt}^3 \end{bmatrix} \sim N\left(\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 1.2 & -0.7 & 0.2 \\ -0.7 & 1.2 & 0.2 \\ 0.2 & 0.2 & 1.2 \end{bmatrix}\right), \tag{34}$$

$$\begin{bmatrix} w_{jt}^1 \\ w_{jt}^2 \\ w_{jt}^3 \end{bmatrix} \sim N\left(\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 1.1 & -0.2 & 0.1 \\ -0.2 & 1.1 & 0.1 \\ 0.1 & 0.1 & 1.1 \end{bmatrix}\right). \quad (35)$$

Variances of errors in both index share and capacity expansion equations are set to be a very small value of 0.01, and the parameter vector in the capacity expansion equation $\boldsymbol{\varphi}$ is,

$$\boldsymbol{\varphi} = (-0.1, -0.2, -0.3, -0.5, 0.2, 0.2, 0.3, 0.5), \quad (36)$$

where all parameters in the mean demand have negative signs, while the coefficients on profit margins are positive.

There is one identification concern in the capacity expansion equation. That is, it is possible that the optimal capacity remains unchanged when scaling it by a positive constant of c, which is $f(k_{jt}^*) = f(ck_{jt}^*)$. This implies a normalisation problem with the cross-term interference of the standard deviation of demand distribution and coefficients on mean utility, μ_1/τ and $\boldsymbol{\mu}_2/\tau$. The identification can be achieved by restricting the standard deviation of demand distribution to a fixed value, such as 1.

A total of 80,000 posterior draws are taken for the simulation study, and Markov chain rapidly converges after 3,000 iterations. Convergence is evaluated by inspecting the sequence plot of posterior outputs, which is suggested by Rossi et al. (2012). Values of log-likelihood are displayed in Figure 4, which remain stable after burning in.

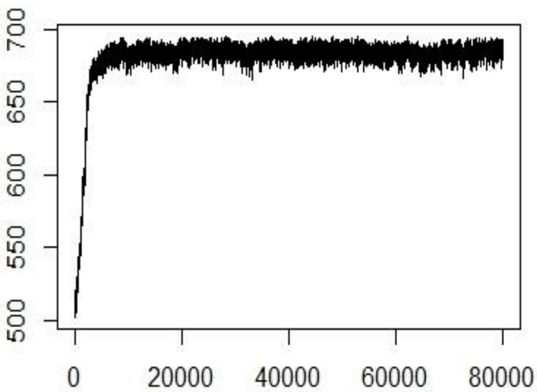


Figure 4 Values of the posterior log-likelihood for basic model

Upon convergence, draws are used to estimate the means and standard errors of the model parameters, and RMSE and bias are calculated for each element of coefficient vectors, which are shown in Table 1. It is found that all Bayes estimators are extremely closes to true values given in the simulation settings, with low standard errors, RMSEs, and biases. This verifies the high accuracy and significant efficiency of the models achieved by using the Bayesian approach.

Table 1 Posterior means, standards errors, RMSEs, and biases of parameters for basic model

Parameter	Variable	True	Mean	RMSE	Bias
$\bar{\boldsymbol{\alpha}}$	Firm Attributes	-2	-2.0492 (0.0791)	0.0932	-0.0492
		-3	-3.0696 (0.0701)	0.0988	-0.0696
		-4	-4.0229 (0.0581)	0.0625	-0.0229
	Stock Return	-5	-4.8767 (0.0899)	0.1526	0.1233
	Capacity Expansion	-6	-6.0736 (0.0505)	0.0893	-0.0736
	Leverage Ratio	-7	-6.8279 (0.0906)	0.1945	0.1721
$\boldsymbol{\Sigma}_{\alpha}$	Firm Attributes	3	2.9195 (0.1689)	0.1871	-0.0805
		4	4.2078 (0.1983)	0.2872	0.2078
		4	4.0364 (0.0991)	0.1056	0.0364
	Stock Return	3	2.8175 (0.1532)	0.2383	-0.1825
	Capacity Expansion	2	2.1042 (0.0708)	0.1260	0.1042
	Leverage Ratio	5	4.3024 (0.4320)	0.8205	-0.6976
$\boldsymbol{\varphi}$	Index Share	-0.1	-0.0712 (0.1069)	0.1107	0.0288
	Sales Forecasts	-0.2	-0.2003	0.0068	-0.0003

			(0.0068)		
		-0.3	-0.2905 (0.0095)	0.0134	0.0095
		-0.5	-0.4958 (0.0069)	0.0081	0.0042
	Profit Shifters	0.2	0.2009 (0.0031)	0.0032	0.0009
		0.2	0.1946 (0.0066)	0.0085	-0.0054
		0.3	0.3002 (0.0114)	0.0114	0.0002
	Last-Period Asset	0.5	0.4959 (0.0082)	0.0092	-0.0041
σ_d^2	Error in Index Share Equation	0.01	0.0100 (0.0025)	0.0025	0.0000
σ_s^2	Error in Capacity Expansion Equation	0.01	0.0109 (0.0109)	0.0109	0.0009

2.4 Empirical Application

In this section, the models previously described are empirically examined using the observational data in the semiconductor manufacturing sector, and counterfactual analyses for the estimation results are also provided.

2.4.1 Data

The identification of demand allocation using index share is investigated to study capacity expansion for firms that design, manufacture, pack, and sell semiconductors in the SOX from a sector-specific view. The data cover 64 US-listed semiconductor manufacturing firms during the periods of 2006 to 2010 with a total of 207 observations, including Intel, Texas Instruments, Micron Technology and On Semiconductor. Variables involve amounts of capacity expansion, index shares, stock returns, debt levels, firm-specific attributes, sales forecasts, and profit shifter.

Specifically, firm size, strategic holdings, asset efficiency, return on asset (ROA), and inventory turnover are chosen to estimate firm attributes. Gross margin, accounts payable to inventory, sales growth and inventory performance are used to forecast sales at the firm level. Moreover, operating profit margin and return on equity (ROE) are regarded as proxies of profit shifters. The detailed descriptions of data sources and variable definitions are specified in Appendix C.

Table 2 Sample description

	Number of Firm	Firm with Capacity Expansion (%)	Firm with Debt (%)	Firm with Positive Stoke Return (%)
2006	51	13.7255%	66.6667%	56.8627%
2007	44	6.8182%	59.0909%	61.3636%
2008	38	10.5263%	68.4211%	36.8421%
2009	47	10.6383%	63.8298%	0.0000%
2010	27	22.2222%	70.3703%	100.0000%

Table 2 displays the sample categorised by three main factors: capacity expansion, debt, and stock return. As shown in the table, over 20% of firms in the SOX index fund expanded their capacities in 2010, which is much higher than in previous years, while there are similar percentages of firms raising debts in each year, within a narrow range from 59% to 71%. Besides, the ratio of firms with positive stock return has reduced rapidly since 2008, and even fallen to 0% in 2009. This reflects the significant impact of economic crisis on the financial market and is also considered in this research. More interestingly, it is found that the majority of firms with capacity expansions typically have high debt levels. This may be due to the fact that large amounts of debts raised are mainly used to build new fabrications and purchase equipment in the semiconductor manufacturing sector.

The descriptive statistics and correlation matrices of variables are presented in Table 3. It is found that the change in capacity expansion values is extremely large with standard deviation of 33992.5788, while its mean value is only 7626.8496, which is about five times less than the standard deviation. To control for the variance of capacity expansion, I normalise it with the standard normal distribution, and the smoothness of the variable increases. Conversely, another two variables, stock return and debt, are relatively stable with difference values of around 5 and 1.5, respectively. Furthermore, variables in the categories of firm attributes, sales forecasts, and profit shifters are comparatively independent from each other and can be regarded as proper proxies.

Table 3 Summary statistics

Panel A: Descriptive Statistics					
Variable	Mean	Median	Std.Dev.	Maximum	Minimum
Capacity Expansion	7626.8496	0.0000	33992.5788	274500.00	0.0000
Stock Return	0.1322	-0.0248	0.7245	4.2114	-0.8634
Leverage Ratio	0.1365	0.0336	0.2225	1.4202	0.0000
Firm Size	3.5676	3.5563	0.5367	4.9736	2.3404
Strategic Holdings	0.2308	0.2000	0.1574	0.8100	0.0000
Asset Efficiency	0.6991	0.6950	0.2196	1.3201	0.2070
ROA	0.0936	0.0999	0.1703	0.8285	-0.8571
Inventory Turnover	3.9874	3.6815	1.8335	13.3309	0.8089
Gross Margin	0.5449	0.5331	0.1136	0.8270	0.2397
Accounts Payable to Inventory	0.6057	0.4882	0.3905	2.4113	0.0834
Sales Growth	0.1159	0.0328	0.3708	2.9056	-0.5659
Inventory Performance	0.1336	0.1197	0.0678	0.6016	0.0328
Operating Profit Margin	0.1168	0.1297	0.1738	0.5160	-1.0079
ROE	-0.0410	0.1194	1.7473	1.8582	-22.0692

Panel B: Correlation Matrices					
	FS	SH	AE	ROA	IT
Firm Size	1.0000	-0.1367	0.2665	-0.0343	0.1295
Strategic Holdings		1.0000	-0.0693	0.0653	0.1395
Asset Efficiency			1.0000	0.2185	0.2467
ROA				1.0000	-0.0422
Inventory Turnover					1.0000
	GM	API	SG	IP	
Gross Margin	1.0000	-0.2528	0.0572	-0.3652	

Accounts Payable to Inventory	1.0000	0.0233	-0.4329
Sales Growth		1.0000	-0.0962
Inventory Performance			1.0000

	OPM	ROE
Operating Profit Margin	1.0000	0,1060
ROE		1.0000

2.4.2 Estimates

There are 80,000 iterations in the Bayesian evaluation. Means and standard errors of model parameters are obtained by using draws after chains burn in, and empirical results are provided in Table 4.

It is noticed that mean utility levels on three variables – capacity expansion, stock return, and leverage ratio – are all negatively related and precise enough at reasonable significance levels. This is in accordance with the realistic situations of firms in the semiconductor manufacturing sector (Uzsoy et al. 2018, Wu et al. 2005). The negative coefficients on capacity expansion and debt reflect the trend that firms with large expansions on capacities and amounts of debts raised suffer from high risks, which would influence investors' purchases of their stocks. Moreover, growing stock returns are unstable and may thus reduce probability that investors would buy them. This shows a negative reaction of stock return on the investors' stock-purchasing behaviours. In addition, the means associated with the firm size and ROA are positive and significantly different from zero, while the estimates of constant, strategic holdings, asset efficiency, and inventory turnover have negative effects on the mean utility of individual investors. To be specific, firms with large sizes benefit from the economy of scale (Manne 1961). This may constantly bring down the average cost with the increase in output and, accordingly, investors are more likely to purchase these firms' stocks. Besides, since high earning power may predict the better stock performance of the firm from a financial point of view (Hendricks and Singhal 2008), investors thus prefer to buy the firm's stock with high profitability, which can be estimated by a widely used financial indicator, ROA. On the contrary, when there is an increase in the ratio of the firm's non-tradable shares, evaluated by an index of strategic holdings, its stock is less likely to be bought by investors as it would reduce the stock liquidity in the financial market (Bodie et al. 2011). Similarly, the higher the asset efficiency and inventory turnover, the greater the asset liquidity of the firm; this means that the firm finds it more difficult to control operational risk (Van Mieghem 2003), and therefore it lowers the amount of stock purchased. On the other side, standard deviations of the marginal utility distribution for all variables in the index share equation are estimated to be insignificantly close to 0.01, a tiny number. The failure of precise evaluations on standard deviations may be due to the fact that the data are not rich or substantial enough for empirical analysis. In addition, the variance value of shock in the index share equation is small and significant with little standard error.

When allowing for the optimal capacity policy for the semiconductor manufacturers under the influence of demand allocation, the parameter of index share is estimated precisely with a positive value of 0.4482. This reflects that when a firm's share in the index increases, more capacity is required to expand so as to realise the optimal capacity decision. The index share thus acts as a positive market signal for the prospective demand. Regarding the evaluations of sales forecasts, it is reasonable that gross margin, accounts payable to inventory, and sales growth have negative effects on the mean demand, and inventory performance is positively related due to the fierce competition in the semiconductor manufacturing sector. When firms' new wafers after expansions are put into the market with high profit, mass sales, and low inventory, other competitors typically tend to fast respond with the increased capacities and force the firm-specific demands to decrease significantly (Lieberman 1987, Yang and Anderson 2014). Moreover, 13.77% of last-period asset is used to estimate the capacity level in the last period. Besides, the proxy of profit shifter – operating profit margin – is significantly positively correlated with the optimal capacity level, while another one – ROE – has a slight negative impact on the capacity decision with the parameter value close to zero. It seems that operating profit margin is much more representative in evaluating profit shifters than ROA is due to it allows for the effect of fixed cost in a scale economy view (Anderson and Yang 2015). In addition, the variance of error in the capacity expansion equation is 0.7421, which is small, and this ensures the small variation in the supply shock regarding capacity expansion.

Table 4 Empirical results for basic model

Parameter	Variable	Mean
$\bar{\alpha}$	Constant	-5.3392 (0.4600)
	Firm Size	1.3085 (0.1260)
	Strategic Holdings	-1.4568 (0.3800)
	Asset Efficiency	-0.6249

		(0.2805)
	ROA	1.3722
		(0.3585)
	Inventory Turnover	-0.0601
		(0.0322)
	Stock Return	-0.2292
		(0.0833)
	Capacity Expansion	-0.1739
		(0.0709)
	Leverage Ratio	-0.3302
		(0.2764)
$\boldsymbol{\Sigma_\alpha}$	Constant	0.0094
		(0.0134)
	Firm Size	0.0076
		(0.0110)
	Strategic Holdings	0.0089
		(0.0128)
	Asset Efficiency	0.0104
		(0.0147)
	ROA	0.0102
		(0.0144)
	Inventory Turnover	0.0031
		(0.0042)
	Stock Return	0.0109
		(0.0152)
	Capacity Expansion	0.0112
		(0.0160)
	Leverage	0.0103
		(0.0138)

$\boldsymbol{\varphi}$	Index Share	0.4482 (0.0153)
	Gross Margin	-0.1704 (0.0258)
	Accounts Payable to Inventory	-0.1018 (0.0196)
	Sales Growth	-0.1689 (0.0121)
	Inventory Performance	0.1150 (0.0146)
	Last-Period Asset	0.1377 (0.0058)
	Operating Profit Margin	0.2560 (0.0237)
	ROE	-0.0713 (0.0120)
σ_d^2	Error in Index Share Equation	0.6259 (0.0623)
σ_s^2	Error in Capacity Expansion Equation	0.7421 (0.1065)

2.4.3 Discussion

The observed data of the semiconductor manufacturing sector specified in Figure 5, show that firms with high shares remain expand their capacities. However, their index shares typically fall after capacity expansions in the real-life situation. This reflects an interactive relationship between capacity expansion and index share when matching supply with demand in the semiconductor manufacturing sector; that is, the increase of index share facilitates capacity expansion and index share is then reduced after the firm decides to expand the capacity. In the light of these findings, it is therefore hypothesised that index share has a positive effect on the capacity expansion, but conversely, it is negatively influenced by the capacity expansion.

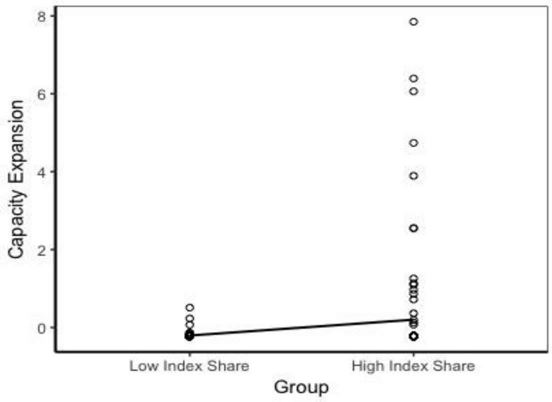


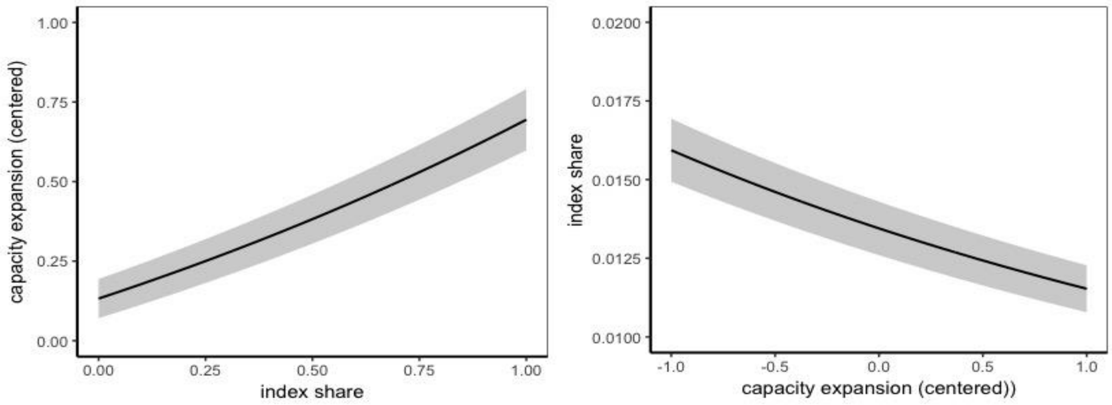
Figure 5 The relationship between capacity expansion and index share of real data

To test these hypotheses, the counterfactual analyses are conducted by using the models and estimated parameters. The simulation study consists of $I = 50$ investors and $J = 20$ firms available at periods $T = 15$, which is illustrated on the basis of a single-sector index. Values of firm attributes, sales forecasts, and profit shifters are fixed to their means, and the specific algorithm for computing the counterfactual equilibrium is given in Appendix D.

The relationship of capacity expansion with index share is provided in Figure 6. Curves and shadows in the plots show mean values and confidence intervals of the simulation results. To be specific, the plot in Figure 6 (a) displays the impact of index share on the individual firm's capacity expansion by using the capacity expansion model given in equation (10). That is, the index share of a firm for a given sector affects its demand allocation, and further influences the optimal capacity expansion level through seeking the maximised profit. As shown in the figure, a positive effect of index share on the capacity expansion is found, meaning that the amount of capacity expansion would increase with a concurrent increase in index share. This outcome is consistent with findings from the observed data, which is that firms with large index shares will continue to expand their capacities. This may be due to the fact that those firms that have already owned large index shares intend to hold on to their shares by implementing the capacity expansion strategy. On the other hand, the discrete choice model is applied to estimate the influence of capacity expansion on the index share. The capacity expansion, as one of the considerations for investors to buy the firm's stock in a given sector, would impact index share that is aggregated from investors' choices. Figure 6 (b) shows a significantly negative relationship and demonstrates that firms with more capacity expansions would reduce their index shares in the financial market. It is because that firms with capacity expansion discourage investors from purchasing their stocks, thus leading to the reductions of firms' index shares, which is often observed in real-world practices (Hendricks et al. 1995). In sum, there is an interaction between capacity expansion and index share, which is that firms with higher index shares intend to expand more capacities to prevent the losses of their shares; however, those increased capacity expansions will actually reduce firms' index shares based on investors' stock purchasing behaviours. Finally, capacity expansion and index share would reach their equilibria. Based on these findings, two propositions are proposed, which are,

Proposition 1. *The increase of a firm's index share facilitates its capacity expansion, ceteris paribus.*

Proposition 2. *The expansion of a firm's capacity level reduces its index share, ceteris paribus.*



(a) The effect of index share on capacity expansion (b) The effect of capacity expansion on index share

Figure 6 The relationships between capacity expansion and index share of counterfactuals

2.5 Model Extension

The relationship of capacity expansion with debt is investigated when extending the supply-side model of capacity expansion with financial constraints to jointly determine a firm's optimal capacity expansion and debt policies. The Bayesian approach is used to evaluate the models, and the corresponding estimates and counterfactual analyses are also specified.

2.5.1 Model Development

Debt, as one of the critical financial attributes of a firm, may impact investor's preference of stock purchase in a given sector. On the basis of the inter-firm demand allocation mechanism, debt would further affect index share which is one of the influence factors in the demand to determine the capacity expansion level. This reflects that debt has an effect on the capacity expansion decision when considering index share as a mediator. Besides, intuitively, the usual way that a firm deals with the large expenditures on building new fabrications and equipment is to borrow fund from banks or other organisations by issuing debt. In this case, the main concern of the firm is how much it can take by debt financing to support its capacity expansion. This represents the need for scholarship to study the impact of capacity expansion on debt. Moreover, when allowing for the financial boundary of debt on the cost of capacity expansion, the link of capacity expansion to debt is built. Therefore, the relationship between capacity expansion and debt can be well discussed if the capacity expansion and debt levels are determined simultaneously, where the debt is one financing means that a firm provides to expand its capacity.

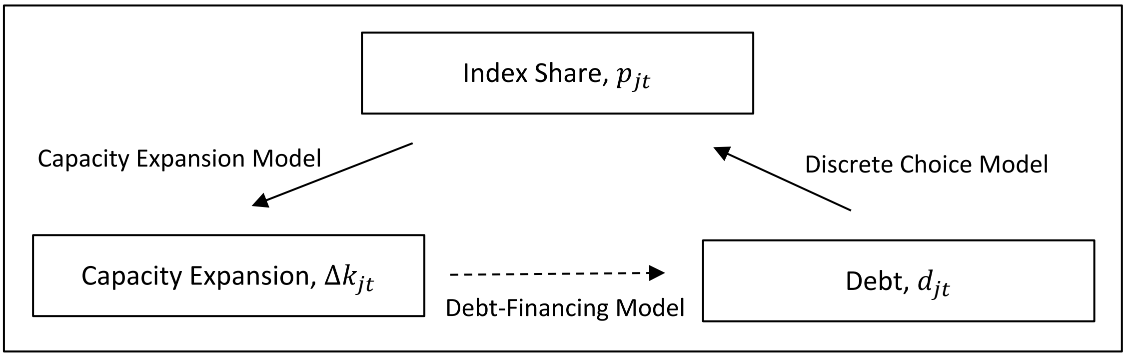


Figure 7 The interactive relationship between capacity expansion and debt

The pattern of how the capacity expansion interacts with the debt under the influence of demand allocation is displayed in Figure 7. There are two different types of interaction; one is the impact of debt on capacity expansion through the mediation of index share. The role of index share here is both the outcome of investor's preference on the stock purchases and the input of demand in determining the optimal capacity level. The other one is the direct influence of capacity expansion on the debt; which is the consequence of setting the upper bound for the cost of capacity expansion. To model these interactions, the same discrete choice model mentioned in section 2.2.1 is applied to evaluate the demand allocation for the correlation between debt and index share, while the capacity expansion model suggested in section 2.2.2 is extended by considering a financial constraint to connect capacity expansion with debt.

The budget that a firm can afford to expand its capacity includes the initial cash position and debt raised from the debtholder. Since the initial cash position is strongly related with the firm-specific financial characteristics via various studies in the finance field, this study assumes that financial constraint for the cost of capacity expansion is constituted by a firm's debt quantity d_{jt} and its initial cash position, which is a linear function of financial characteristics $\mathbf{z}_{jt}\mathbf{g}$. Moreover, in a financial setting, the debt raised for supporting firms' capacity expansions is typically assumed to be held as a one-period heterogeneous zero-coupon bound with face value of $d_{jt}(1+i_{jt})$, where i_{jt} is the interest rate. When the revenue is just sufficient to pay for the face value of debt in full, the firm reaches its bankruptcy point, which is $w_{jt}^b = \frac{d_{jt}(1+i_{jt})}{u_{jt}}$. Thus, the end-of-period payoff to debtholder is given as,

$$Y_d = \begin{cases} d_{jt}\left(1+i_{jt}\right) & \text{if } w_{jt} \geq w_{jt}^b \\ u_{jt}w_{jt} & \text{if } w_{jt} < w_{jt}^b \end{cases}. \tag{37}$$

This means that if the demand is greater than the bankruptcy point, the firm is able to pay back all the debt at face value; however, if the market-level demand cannot exceed the bankruptcy point, the firm would only pay its revenue to the debtholder at the end of the period.

In view of the equivalent risk-neutral measure concerning debt proposed by Dotan and Ravid (1985), the expected value of promised payments to debtholders must be equal to the price of zero-coupon bond in order for debt to have a zero net present value, which effectively reflects the fair pricing of debt and information symmetry in the perfect-competition financial market. The interest rate paid for debt then satisfies,

$$d_{jt} = \int_0^{w_{jt}^b} u_{jt} w_{jt} d\mathbf{\Phi}_{jt}(w_{jt}) + \int_{w_{jt}^b}^{\infty} d_{jt}(1 + i_{jt}) d\mathbf{\Phi}_{jt}(w_{jt}). \tag{38}$$

Therefore, the optimal capacity and debt decisions can be obtained by maximising the expected firm profit with both the financial constraint and the risk-neutral equivalence; that is,

$$\max \quad u_{jt}\mathrm{E}[\min(w_{jt}, k_{jt})] - h_{jt}\mathrm{E}\left[(k_{jt} - w_{jt})^+\right] - l_{jt}\mathrm{E}\left[(w_{jt} - k_{jt})^+\right] - c_{jt}k_{jt}, \tag{39}$$

$$\text{s.t.} \quad 0 \le c_{jt}k_{jt} \le d_{jt} + \mathbf{z}_{jt}\mathbf{g}, \tag{40}$$

$$d_{jt} = \int_0^{w_{jt}^b} u_{jt} w_{jt} d\mathbf{\Phi}_{jt}(w_{jt}) + \int_{w_{jt}^b}^{\infty} d_{jt}(1 + i_{jt}) d\mathbf{\Phi}_{jt}(w_{jt}). \tag{41}$$

By using the Lagrangian and Karush-Kuhn-Tucker first-order conditions, the optimal capacity and debt policies are

$$k_{jt}^* = \mu(p_{jt}(k_{jt}^*, d_{jt}^*), \mathbf{q}_{jt}) \times \exp\left(\tau \mathbf{Z}^{-1}\left(\frac{u_{jt} + l_{jt} - c_{jt}}{u_{jt} + l_{jt} + h_{jt}}\right)\right), \tag{42}$$

$$c_{jt}k_{jt}^* = d_{jt}^* + \mathbf{z}_{jt}\mathbf{g}. \tag{43}$$

The detailed calculations of solving the above optimisation problem in terms of the firm profit maximisation with constraints are specified in Appendix E.

Following the similar empirical specification for the unit profit margin shown in equation (9), the unit cost of each firm is set as a linear function of observable cost shifters $\mathbf{s}_{jt}$, and a stochastic shock ζ_{jt}. Since the unit cost is part of unit profit margin, the error term in the unit cost function ζ_{jt} should be correlated with that in the function of unit profit margin η_{jt}, and the unit cost function is,

$$c_{jt} = \mathbf{s}_{jt}\boldsymbol{\rho} + \zeta_{jt}, \tag{44}$$

where $\boldsymbol{\rho}$ is a vector of parameters for cost shifters.

To maintain consistence with the capacity expansion model specified in equation (9), the same assumptions are used to simplify mean demand and set the amount of capacity expansion. Therefore, the capacity expansion and debt equations are obtained by substituting the optimal capacity and debt policies into the expressions for unit profit margin and cost. They rely only on the index shares, equilibrium capacity expansion and debt, as well as observed covariates, which are

$$\mathbf{Z}\left(\frac{1}{\tau}\left(\ln\left(\Delta k_{jt}^{*}+k_{j,t-1}\right)-\mu_1 p_{jt}\left(\Delta k_{jt}^{*}+k_{j,t-1},d_{jt}^{*}\right)-\mathbf{q}_{jt}\boldsymbol{\mu}_2\right)\right)=\mathbf{w}_{jt}\boldsymbol{\gamma}+\eta_{jt}, \quad (45)$$

$$\left(d_{jt}^{*}+\mathbf{z}_{jt}\mathbf{g}\right)/\left(\Delta k_{jt}^{*}+k_{j,t-1}\right)=\mathbf{s}_{jt}\boldsymbol{\rho}+\zeta_{jt}. \quad (46)$$

2.5.2 Statistical Specification

To specify likelihood for the extension model, shocks of η_{jt} and ζ_{jt} are assumed to be jointly distributed with covariance matrix $\boldsymbol{\Sigma}_s$ due to the existence of correlation,

$$\begin{pmatrix}\eta_{jt}\\ \zeta_{jt}\end{pmatrix}\sim N\left(\begin{pmatrix}0\\0\end{pmatrix},\boldsymbol{\Sigma}_s=\begin{bmatrix}\sigma_{11} & \sigma_{12}\\ \sigma_{21} & \sigma_{22}\end{bmatrix}\right), \quad (47)$$

where $\boldsymbol{\Sigma}_s$ is the covariance matrix of $(\eta_{jt},\zeta_{jt})'$.

As for the case that the amounts of capacity and debt raised are simultaneously determined by maximising firm profit with the financial constraint and risk-neutral equivalence, the joint density of both capacity expansion quantities and debt levels at period t can be obtained on the basis of the Change-of-Variable Theorem, which is,

$$\pi_3(\Delta\mathbf{k}_t,\mathbf{d}_t\,|\mathbf{X}_t,\mathbf{q}_t,\mathbf{w}_t,\mathbf{z}_t,\mathbf{s}_t,\boldsymbol{\varphi},\boldsymbol{\varphi}',\boldsymbol{\Sigma}_s,\boldsymbol{\Sigma}_\alpha)=J_{(\boldsymbol{\eta}_t,\boldsymbol{\zeta}_t\rightarrow\Delta\mathbf{k}_t,\mathbf{d}_t)} \quad (48)$$

$$\times\left(\prod_{j=1}^{J_t}\phi_s'\left(\left[\begin{matrix}\mathbf{Z}\left(\frac{1}{\tau}\left(\ln\left(\Delta k_{jt}+k_{j,t-1}\right)-\mu_1 p_{jt}\left(\delta_{jt},\mathbf{X}_{jt};\boldsymbol{\Sigma}_\alpha\right)-\mathbf{q}_{jt}\boldsymbol{\mu}_2\right)\right)-\mathbf{w}_{jt}\boldsymbol{\gamma}\\ \left(d_{jt}+\mathbf{z}_{jt}\mathbf{g}\right)/\left(\Delta k_{jt}+k_{j,t-1}\right)-\mathbf{s}_{jt}\boldsymbol{\rho}\end{matrix}\right]\middle\|\boldsymbol{\Sigma}_s\right)\right),$$

where $\mathbf{d}_t=\left(d_{1t},\ldots,d_{J_t t}\right)'$, $\mathbf{z}_t=\left(\mathbf{z}_{1t}',\ldots.,\mathbf{z}_{J_t t}'\right)'$, and $\mathbf{s}_t=\left(\mathbf{s}_{1t}',\ldots.,\mathbf{s}_{J_t t}'\right)'$ are vectors of observed debt levels, financial characteristics, and cost shifters at period t, respectively. ϕ_s' is the multivariate normal density of $\left(\eta_{jt},\zeta_{jt}\right)'$. $\boldsymbol{\varphi}'$ is the parameter vector that is required to be estimated in the debt equation $(\mathbf{g},\boldsymbol{\rho})'$, where $\mathbf{g}$ is the parameter vector in the financial constraint and $\boldsymbol{\rho}$ is a vector of parameters for cost shifters. $J_{(\boldsymbol{\eta}_t,\boldsymbol{\zeta}_t\rightarrow\Delta\mathbf{k}_t,\mathbf{d}_t)}$ is the determinant of Jacobian matrix used to transform from $\boldsymbol{\eta}_t, \boldsymbol{\zeta}_t$ to $\Delta\mathbf{k}_t, \mathbf{d}_t$, where $\boldsymbol{\zeta}_t = (\zeta_{1t,} \dots, \zeta_{J_t t})'$. Its calculation is specifically illustrated in Appendix F.

Therefore, the likelihood of all parameters is specified as,

$$L(\overline{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha, \boldsymbol{\varphi}, \boldsymbol{\varphi}', \sigma_d^2, \boldsymbol{\Sigma}_s) \tag{49}$$

$$= \prod_{t=1}^{T} \left(\pi_3(\Delta\mathbf{k}_t, \mathbf{d}_t \,|\mathbf{X}_t, \mathbf{q}_t, \mathbf{w}_t, \mathbf{z}_t, \mathbf{s}_t, \boldsymbol{\varphi}, \boldsymbol{\varphi}', \boldsymbol{\Sigma}_s, \boldsymbol{\Sigma}_\alpha) \times \pi_1\big(\mathbf{P}_t|\mathbf{X}_t, \overline{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha, \sigma_d^2\big)\right).$$

To obtain the posterior, the additional independent priors, $\boldsymbol{\varphi}'$ and $\boldsymbol{\Sigma}_s$, are required to be set, which are shown as,

$$\boldsymbol{\varphi}' \sim N\left(\overline{\boldsymbol{\varphi}}', \mathbf{V}_{\varphi'}^{-1}\right), \tag{50}$$

$$\boldsymbol{\Sigma}_s \sim IW(\mathbf{V}_{s0}, \mathbf{S}_{s0}). \tag{51}$$

Thus, the joint posterior based on the above likelihood and priors is,

$$\pi\big(\overline{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha, \boldsymbol{\varphi}, \boldsymbol{\varphi}', \sigma_d^2, \boldsymbol{\Sigma}_s \big| \{\Delta\mathbf{k}_t, \mathbf{d}_t, \mathbf{P}_t, \}_{t=1}^{T}\big) \tag{52}$$

$$\propto L\big(\overline{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha, \boldsymbol{\varphi}, \boldsymbol{\varphi}', \sigma_d^2, \boldsymbol{\Sigma}_s\big) \times \prod_{j=1}^{J_t} \left(\pi\big(\overline{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha, \boldsymbol{\varphi}, \boldsymbol{\varphi}', \sigma_d^2, \boldsymbol{\Sigma}_s\,\big)\right),$$

where $\pi\big(\overline{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha, \boldsymbol{\varphi}, \boldsymbol{\varphi}', \sigma_d^2, \boldsymbol{\Sigma}_s\,\big)$ is the product of individual priors, $\pi(\overline{\boldsymbol{\alpha}})$, $\pi(\boldsymbol{\theta})$, $\pi(\boldsymbol{\varphi})$, $\pi(\boldsymbol{\varphi}')$, $\pi\big(\sigma_d^2\big)$, and $\pi(\boldsymbol{\Sigma}_s)$. $\boldsymbol{\theta} = (\theta_{11}, \dots, \theta_{jl}, \dots, \theta_{RR})'$ is the vector of elements in the Cholesky root for $\boldsymbol{\Sigma}_\alpha$.

To implement the MCMC algorithm, the conditionals of parameters in the index share equation do not change, while conditionals in the capacity expansion and debt equations become,

$\boldsymbol{\varphi}\|\boldsymbol{\Sigma}_s, \boldsymbol{\theta}$	parameters in capacity expansion equation,	(53)
$\boldsymbol{\varphi}'\|\boldsymbol{\varphi}, \boldsymbol{\Sigma}_s, \boldsymbol{\theta}$	parameters in debt equation,	(54)
$\boldsymbol{\Sigma}_s\|\boldsymbol{\varphi}, \boldsymbol{\varphi}', \boldsymbol{\theta}$	covariance of errors in capacity expansion and debt equations.	(55)

The draws for $\boldsymbol{\theta}$, $\boldsymbol{\varphi}$, $\overline{\boldsymbol{\alpha}}$, and σ_d^2 are the same as those shown in section 2.3.2. The parameter vector $\boldsymbol{\varphi}'$ can be drawn from Gibbs sampler for a linear model with error that is related to error in capacity expansion function. As for $\boldsymbol{\Sigma}_s$, it is drawn from the inverted Wishart distribution. The detailed draws of parameters for the extension case are provided in Appendix G.

The DAG for the extension model are,

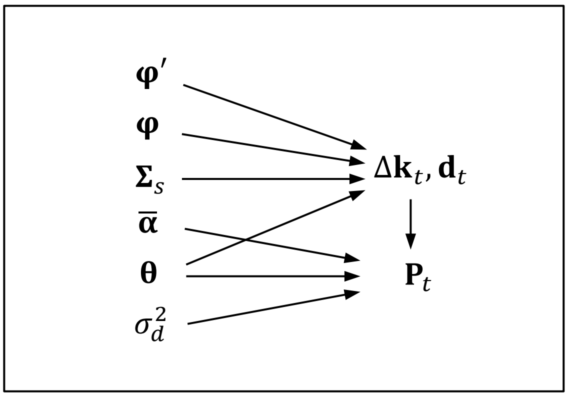


Figure 8 The DAG for extended model

A Monte Carlo test is also done for the extension model. To simulate covariates in the debt equation, covariance matrices of $nZ = 3$ financial characteristics $\mathbf{z}_{jt}$ and $nS = 3$ cost shifters $\mathbf{s}_{jt}$ are specified as follows,

$$\begin{bmatrix} z_{jt}^1 \\ z_{jt}^2 \\ z_{jt}^3 \end{bmatrix} \sim N\left(\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 1.1 & -0.1 & 0.4 \\ -0.1 & 1.1 & 0.4 \\ 0.4 & 0.4 & 1.1 \end{bmatrix}\right), \tag{56}$$

$$\begin{bmatrix} s_{jt}^1 \\ s_{jt}^2 \\ s_{jt}^3 \end{bmatrix} \sim N\left(\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 1.2 & -0.3 & 0.5 \\ -0.3 & 1.2 & 0.5 \\ 0.5 & 0.5 & 1.2 \end{bmatrix}\right). \tag{57}$$

The error in debt equation should be correlated with that in the capacity expansion due to the fact that unit cost is a component of unit profit margin. Thus, they are drawn by the multivariate normal distribution with zero means and a covariance matrix $\mathbf{\Sigma}_s$, which is,

$$\mathbf{\Sigma}_s = \begin{bmatrix} 0.04 & -0.01 \\ -0.01 & 0.04 \end{bmatrix}. \tag{58}$$

The parameter vector that is required to be estimated in the debt equation $\boldsymbol{\varphi}'$ is,

$$\boldsymbol{\varphi}' = (-0.1, -0.2, 0.3, 0.1, 0.3, 0.1), \tag{59}$$

A total of 80,000 posterior draws are taken, and the Markov chain burns in after 10,000 draws. The values of log-likelihood for the extension model are displayed in Figure 9, which remain stable after burning in.

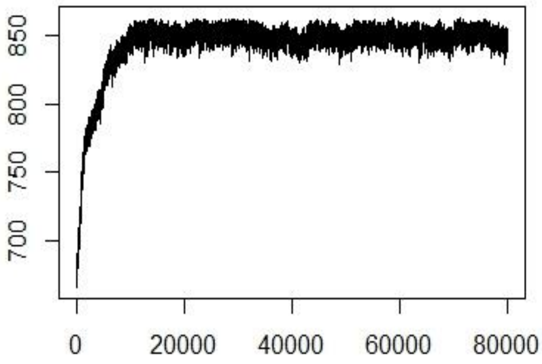


Figure 9 Values of the posterior log-likelihood for extended model

Table 5 shows the means, standard errors, RMSEs, and biases of model parameters upon convergence. It is found that all Bayes estimators are extremely close to the true values given in the simulation settings, with low standard errors, RMSEs, and biases. Compared with the simulation result of the basic model, the case that allows for joint capacity expansion and debt policies presents much more precise values of the means and standard deviations of random coefficients on capacity expansion and debt. This reflects that the model is more convincing if the simultaneity among capacity expansion, index share and debt are considered.

Table 5 Posterior means, standards errors, RMSEs, and biases of parameters for extended model

Parameter	Variable	True	Mean	RMSE	Bias
$\bar{\alpha}$	Firm Attributes	-2	-2.0749 (0.0776)	0.1079	-0.0749
		-3	-3.0753 (0.0763)	0.1072	-0.0753
		-4	-3.9899 (0.0495)	0.0505	0.0101
	Stock Return	-5	-4.9595 (0.0638)	0.0756	0.0405
	Capacity Expansion	-6	-6.0186 (0.0439)	0.0477	-0.0186
	Leverage Ratio	-7	-7.0388 (0.0462)	0.0603	-0.0388

$\mathbf{\Sigma}_\alpha$	Firm Attributes	3	3.0510 (0.0579)	0.0772	0.0510
		4	4.1705 (0.0911)	0.1933	0.1705
		4	4.0510 (0.0727)	0.0888	0.0510
	Stock Return	3	2.9415 (0.1439)	0.1553	-0.0585
	Capacity Expansion	2	2.0159 (0.0898)	0.0912	0.0159
	Leverage Ratio	5	5.1505 (0.1441)	0.2084	0.1505
$\boldsymbol{\varphi}$	Index Share	-0.1	-0.1559 (0.0394)	0.0684	-0.0559
	Sales Forecasts	-0.2	-0.1843 (0.0142)	0.0212	0.0157
		-0.3	-0.2983 (0.0166)	0.0167	0.0017
		-0.5	-0.4939 (0.0166)	0.0177	0.0061
	Profit Shifters	0.2	0.2009 (0.0011)	0.0014	0.0009
		0.2	0.1944 (0.0177)	0.0186	-0.0056
		0.3	0.3029 (0.0155)	0.0158	0.0029
	Last-Period Asset	0.5	0.4857 (0.0189)	0.0237	-0.0143
$\boldsymbol{\varphi}'$	Financial Characteristics	-0.1	-0.1039	0.0057	-0.0039

			(0.0042)		
		-0.2	-0.2019 (0.0028)	0.0034	-0.0019
		0.3	0.3036 (0.0053)	0.0064	0.0036
	Cost Shifters	0.1	0.0800 (0.0186)	0.0273	-0.0200
		0.3	0.2856 (0.0270)	0.0306	-0.0144
		0.1	0.1126 (0.0214)	0.0248	0.0126
σ_d^2	Error in Index Share Equation	0.01	0.0114 (0.0027)	0.0030	0.0014
$\mathbf{\Sigma}_s$	Error in Capacity Expansion Equation	0.04	0.0405 (0.0097)	0.0097	0.0005
	Covariance of Errors	-0.01	-0.0145 (0.0075)	0.0087	-0.0045
	Covariance of Errors	-0.01	-0.0145 (0.0075)	0.0087	-0.0045
	Error in Debt Equation	0.04	0.0406 (0.0094)	0.0094	0.0006

2.5.3 Estimates

The relationship between capacity expansion and debt is empirically analysed using the observed data in the SOX sector. The same variables in the basic model are considered, while covariates in the debt equation are likewise allowed for to evaluate the extended model, which are firm-level financial characteristics and cost shifters. Specifically, financial characteristics are measured by financial activities, earnings per share (EPS), cash flow margin, and Tobin's Q, while sales, general and administrative cost (SGA)/asset ratio and COGS/asset ratio are used to evaluate cost shifters. The detailed descriptions of additional data and variable definitions are given in Appendix C.

A total of 80,000 iterations are taken in the empirical study. Means and standard errors of model parameters are given for draws after chains converge. The empirical results are provided in Table 6. It is found that the values of means $\bar{\boldsymbol{\alpha}}$ and deviations $\boldsymbol{\Sigma}_{\alpha}$ of the random coefficients, along with the variance of shock σ_d^2 in the index share equation, are very similar with the results for the basic model. This reflects the consistency and stability of specifying index share for two models.

Considering the coefficients of financial characteristics and cost shifters in the debt equation, they are estimated linearly given the value of last-period capacity. The empirical results of these coefficients are significant with the precise evaluations of financial activities, cash flow margin, and COGS/Asset ratio. It is found that firms with many financial activities contribute to the debt financing, while high cash flow margins are bad for firms that want to borrow debts. The reason may be that firms with either large issues of common and preferred stocks or low cashabilities are more likely to repay the debts (Hennessy and White 2005). Moreover, the COGS/Asset ratio is an appropriate indicator for the cost shifter as it is positively related and significant at a reasonable interval. However, the estimates of EPS, Tobin's Q, and SAG/Asset ratio are not different from zero – and even imprecise. These variables do not seem to be suitable indicators for fitting the data in the empirical example. More interestingly, there are only a few correlations between the errors of capacity expansion and debt equations, which is 0.0052, even though they should be closely related with each other when allowing for the determination of simultaneous capacity and debt levels based on the assumption. This may be due to the influence of those inappropriate indicators in both profit and cost shifters. In addition, variances of errors are small, which ensures the small variations in both capacity expansion and debt equations.

Table 6 Empirical results for extended model

Parameter	Variable	Mean
$\bar{\boldsymbol{\alpha}}$	Constant	-5.3386 (0.4582)
	Firm Size	1.3078 (0.1272)
	Strategic Holdings	-1.4655 (0.3756)
	Asset Efficiency	-0.6221 (0.2801)
	ROA	1.3718

		(0.3590)
	Inventory Turnover	-0.0604
		(0.0324)
	Stock Return	-0.2286
		(0.0830)
	Capacity Expansion	-0.1772
		(0.0725)
	Leverage Ratio	-0.3237
		(0.2773)
$\mathbf{\Sigma}_{\alpha}$	Constant	0.0104
		(0.0156)
	Firm Size	0.0070
		(0.0100)
	Strategic Holdings	0.0095
		(0.0138)
	Asset Efficiency	0.0114
		(0.0165)
	ROA	0.0102
		(0.0141)
	Inventory Turnover	0.0032
		(0.0044)
	Stock Return	0.0099
		(0.0129)
	Capacity Expansion	0.0128
		(0.0177)
	Leverage	0.0108
		(0.0155)
$\boldsymbol{\varphi}$	Index Share	0.0755
		(0.0189)

	Gross Margin	-0.0995 (0.0268)
	Accounts Payable to Inventory	-0.0457 (0.0289)
	Sales Growth	0.3416 (0.0196)
	Inventory Performance	0.1250 (0.0179)
	Last-Period Asset	0.1429 (0.0118)
	Operating Profit Margin	0.2126 (0.0072)
	ROE	-0.0574 (0.0233)
$\boldsymbol{\varphi}'$	Financial Activities	0.3416 (0.2212)
	EPS	-0.0080 (0.0210)
	Cash Flow Margin	-0.4446 (0.1395)
	Tobin's Q	0.0105 (0.0165)
	SAG/Asset Ratio	0.0622 (0.2710)
	COGS/Asset Ratio	0.2423 (0.1616)
σ_d^2	Error in Index Share Equation	0.6259 (0.0625)
$\boldsymbol{\Sigma}_s$	Error in Capacity Expansion Equation	0.9299

	(0.2689)
Covariance of Errors	0.0052 (0.0314)
Covariance of Errors	0.0052 (0.0314)
Error in Debt Equation	0.1065 (0.0298)

2.5.4 Discussion

To observe the critical role of index share in determining capacity expansion and debt, the real data regarding firms' capacity expansion and debt levels in the semiconductor manufacturing sector are classified by the median values of index share. The observed results are displayed in Figure 10. It is found that debt is negative related to the capacity expansion when the firm's index share is above the median, while the below-median index share results in the positive relationship between debt and capacity expansion. These findings specify the importance of index share in the interaction of capacity expansion and financial decision. Therefore, debt is hypothesized to have a negative effect on the capacity expansion for the firms that own above-median index shares, but when the index share is below the median, it is negatively influenced by the capacity expansion.

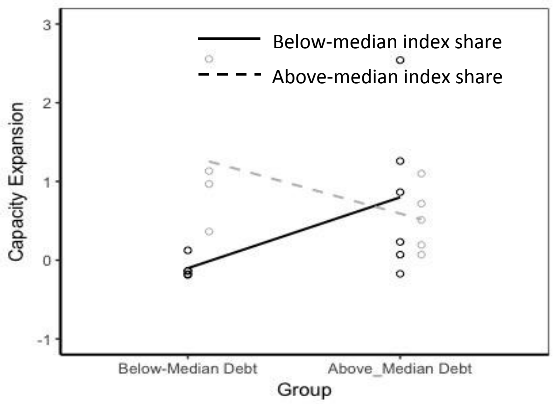


Figure 10 The relationship between capacity expansion and debt of real data

The counterfactual analysis is conducted using the model extension and estimated parameters to investigate the relationship of capacity expansion and debt. The simulation size is the same as that for the basic model, which is $I = 50$ investors, $J = 20$ firms, and $T = 15$ periods. The values of debts are changed from 0 to 1 to evaluate their effects on firms' capacity expansion levels, because the proxy use for the debt level is the leverage ratio, which has a range of (0, 1). The specific algorithm for computing counterfactual equilibrium is provided in Appendix H.

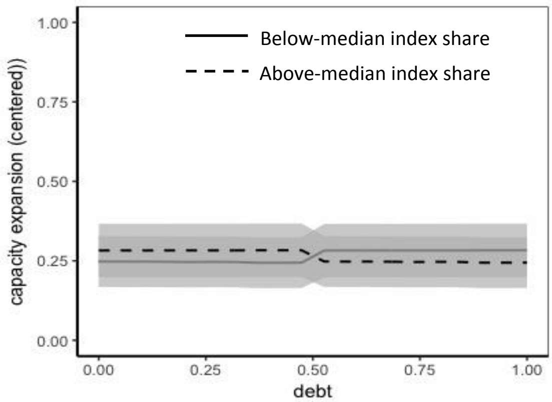


Figure 11 The effect of debt on capacity expansion of counterfactual

The simulated result of the relationship between capacity expansion and debt when categorising the values of index share with its median level is illustrated in Figure 11. This presents that firms with above-median index shares have less capacity expansions with the increasing amounts of debt, while debt has a positive effect on the capacity expansion if firms own index shares that are below the median level, which is consistent with the findings from real data. This is reasonable due to the fact that firms with small index shares intend to use as many debts as possible to expand their capacities compared to those firms with large index shares, since firms that already hold large index shares are likely to be more concerned about spending funds raised from debt financing to other activities instead of capacity expansion (DeAngelo et al. 2011). This drives me to think about the management practice of the firm's capacity expansion and financing strategies when considering the influence of index share. That is,

Managerial Implication 1. *If the debtholders expect the indebted firms to focus on growing their capacities, they should invest in those firms with small index shares.*

2.6 Concluding Remarks

In this chapter, the identification of demand allocation using index share is discussed to determine the capacity expansion and an empirical case of the semiconductor manufacturing sector is employed to evaluate models. The results of the basic model without allowing for the financial boundary show that the firm's index share, as a positive market signal for the prospective demand, has a significant effect on its capacity expansion decision, while capacity expansion negatively affects investors' preference of stock purchasing for each firm in a given sector, and further influences index share that is aggregated from all investors' stock choices. Counterfactual analyses also illustrate the interactive relationship between capacity expansion and index share. That is, with an increase of index share, capacity expansion continuously grows; however, firms that have increased capacity expansions would hurt their index shares in the sector. This interaction will ultimately attain the equilibrium values of capacity expansion and index share, which realises the match of demand and supply in the empirical capacity expansion. When the financial budget with debt is considered, the amounts of capacity expansion and debt are simultaneously decided under the adjustment of index share. It is found that there is a positive impact of debt on capacity expansion if the firm's index share is below the median level of the whole sector, but this relationship is the opposite for firms with above-median index shares.

The managerial implications of modelling demand allocation for capacity expansion via index share are appealing. The balance between gains from expanded capacities and losses of reduced index share should be of concern to firms if they are to achieve their competitive advantages in a given sector. Moreover, debtholders may prefer to invest in firms with small index share in order to facilitate their capacity expansion through fully utilising financial funding. The study in this chapter also contributes to the operations-finance interface in many ways. The strategic capacity expansion is further discussed by applying index share in the demand allocation, which realises the empirical evaluation of operational decision. Besides, a link of the macro-level behaviour – such as index share used to identify the demand allocation – with the micro-level operational policies and financial implications is built, complementing the previous studies that primarily focus on the firm-specific decisions (see Birge 2014). Furthermore, the supply-side model of capacity expansion is able to be extended into more general forms. One possible example is provided in section 2.5, in which the relationships between capacity expansion and debt under the effect of index share are specified with the consideration of budget constraints. This advances the analysis regarding the impact of debt on capacity expansion without allowing for demand allocation as proposed by Xu and Birge (2008). In sum, the operations literature of both capacity expansion and its interaction with financial decisions is deeply investigated and extended in this study.

There are some limitations on this study. To evaluate index share, investors are only allowed to choose one firm's stock each time in a given sector, which is an ideal case in reality. Indeed, they typically purchase multiple stocks to obtain the optimal utilities. This issue is a multi-variety choice problem and can be solved by considering both corner and interior solutions of utility for each investor provided by Kim et al. (2002) and Satomura et al. (2011). However, the estimation of aggregated index share becomes much more complicated without observing the individual choices of stock purchasing, which is a research direction worth investigating in greater depth in the future.

Chapter 3 Measuring Firm Performance of Capacity Expansion

3.1 Introduction

The performance impacts of capacity expansion in both operating and financial aspects have been regarded as critical outcome evaluations in the operations management. Firms commonly expand their capacities for the purpose of better profitability and stock market reaction (e.g., Birge and Xu 2011, Wu et al. 2005). This is consistent with the Efficient Market Hypothesis proposed by Tobin (1969), asserting that stock price is able to rapidly and accurately respond to the adjustment of capacity decision that reflects new information in the market. An empirical evidence of the positive implications of capacity expansion on a firm's performance is provided by Hendricks et al. (1995), suggesting that there is an increased abnormal return after the capacity expansion announcement. However, firms often compete imperfectly in the market due to the existence of unobserved information that is not available to the investors (Yang and Allenby 2014). This may lead to the temporary mismatch of capacity expansion and performance outcomes. This dilemma is more serious in the capital-intensive sectors (e.g., semiconductor manufacturing). In the case of a US-listed semiconductor firm, Micron Technology Inc., it is observed from the World Fab Watch reports that as the increases of capacity expansion from 2006 to 2008, the corresponding profit and stock return reduced dramatically, although its index share continued to rise. This finding reflects the negative performance impacts of capacity expansion, and is contrary to the Efficient Market Hypothesis. Therefore, a key theme in this chapter is to identify suitable measures of performance in an imperfect competition context in order to explore the effect of capacity expansion on performance outcomes.

To estimate the performance impacts of capacity expansion, researchers typically apply the accounting-based measures, such as abnormal values of stock return (e.g., Hendricks et al. 1995, Hendricks and Singhal 2009), ROA (e.g., Hendricks and Singhal 2008), and return on sales (ROS, e.g., Tsikriktsis 2007), but few have investigated the impact of capacity expansion on the value of firm, which is a real evaluation of a firm's market value. One difficulty of using firm value on behalf of the performance outcome is in specifying the profit and stock return that are key components of firms' value when expanding their capacities. It is because capacity expansion, profit, and stock return of firms are related to each other. Firm's capacity expansion strategy is determined through maximising its profit under the demand allocation that is influenced by stock return; conversely, capacity expansion would also affect the index share in a given sector, thereby resulting in the volatility of stock return. If the endogenous relationships of capacity expansion with profit and stock return are not identified clearly, estimation bias will occur (Olivares et al. 2008). Therefore, the joint capacity expansion decision and performance outcomes need to be simultaneously modelled in the research, so as to evaluate capacity expansion and firm value.

In this chapter, the impacts of capacity expansion on both the operating and financial performance are investigated. An essential task prior to estimating the performance effects lies in identifying the demand allocation using index share as this effectively connects uncertain demand with the capacity expansion and performance outcomes in a given sector. This study proposes a discrete choice model-to-model of demand allocation, a supply-side model of capacity expansion with financial constraints on the basis of profit maximisation, and a capital asset pricing model of stock return. Firm profit is calibrated by specifying the unit profit margin and cost that account for the joint decisions of capacity expansion and debt. The model also analyses the impact of capacity expansion on the stock return through adjusting index share, and vice versa. The firm value is then derived by the use of estimated profit and stock return, thus facilitating the analysis of how capacity expansion affects firm value. Besides, the data in the semiconductor manufacturing sector are used to empirically evaluate the model.

The counterfactual results indicate that capacity expansion is negatively related with the stock return if index share is categorised into the below-median and above-median groups. With the increase of capacity expansion, the profit and the value of firm firstly rise and then reduce after peaking. Contrary to much received wisdom, it is found that firms with large index shares do not need to expand too many capacities as those expansions may hurt their firms' values. On the other hand, firms that have small index shares are able to capture better performance including stock return, profit, and firm value when they expand their capacities within a small range, compared with the large-index-share firms. This research contributes to literature on the operations-finance interface in three ways. Firstly, a systematic framework that simultaneously discusses capacity expansion and performance impacts is built. It extends a simple analysis which assumes that capacity expansion has a direct impact on stock return (Hendricks et al. 1995). Secondly, studies linking operational decision and its performance are advanced by using firm value to precisely measure the performance outcomes, which is rarely explored in the extant studies. Thirdly, the results reflect an appealing and practical managerial implication; that is, firms with small index shares may achieve more advantages in capacity expansions than those with large index shares would if they restrict the amount of expansion within a reasonable range. In sum, this study deeply explores the operating and financial performance impacts of capacity expansion and provides some useful insights into the management practice about the capacity expansion decisions.

3.2 Model Development

This section builds the systematic framework for the impacts of capacity expansion on both operating and financial performance outcomes. Before firms decide to expand their capacities, the demand allocation takes place which is evaluated using index share with the consideration of capacity planning, debt, and stock return. As a critical input for operational decisions, demand allocation of the optimal strategies of capacity expansion and debt, is accordingly taken into account so as to achieve profit maximisation. Meanwhile, the stock return is obtained through estimating the portfolio of sector index. Therefore, capacity expansion, debt, and stock return are all simultaneously determined in an interactive context, which is displayed in Figure 12.

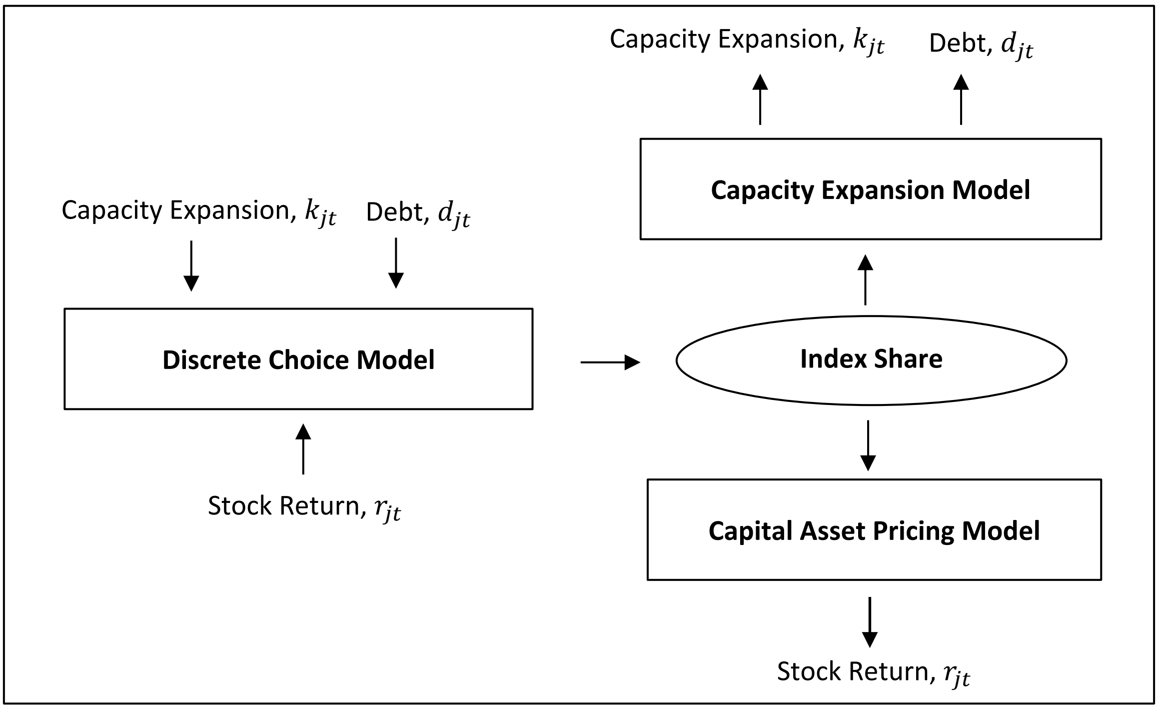


Figure 12 The relationship of capacity expansion with performance impacts

To model the relationship, a discrete choice model is employed to identify the mechanism of demand allocation prior to capacity expansion. The utilities of each investor's stock purchases for firms in a sector are maximised to realise the heterogeneity in the allocation of demand via index share, which is the same as the specification of demand allocation in section 2.2.1, and will not be discussed again in this chapter. Moreover, a capacity expansion model with financial constraints is developed to solve the firm-level operating and financial decisions under an impact of index share. By maximising the operating performance – profits – firms pick the optimal capacity expansion and debt levels. Besides, a capital asset pricing model is used to evaluate the financial performance impact of capacity expansion on stock return, in which the weight of portfolio is index share obtained in the demand allocation.

3.2.1 Operating Performance: Firm Profit

The capacity and debt quantities for each firm can be simultaneously evaluated by maximising its profit with financial constraints under the demand allocation. Due to the heterogeneity of demand allocation, the demand w_{jt} is assumed to be lognormal distributed $w_{jt} \sim LN(\mu_{jt}, \tau)$, with p.d.f. ϕ_{jt} and c.d.f. $\boldsymbol{\Phi}_{\text{jt}}$, where μ_{jt} is the firm-specific average demand that is related to the index share p_{jt} and sales predictors $\mathbf{q}_{jt}$, and τ is the standard deviation of lognormal distribution. Here, forms used to specify the mean demand μ_{jt} vary, and a linear function is chosen for the model simplification, which is $\mu_{jt} = \mu_1 p_{jt} + \mathbf{q}_{jt}\boldsymbol{\mu}_2$, where μ_1 and $\boldsymbol{\mu}_2$ are parameters in the mean demand. Thus, firm j's profit at period t is formulated as,

$$\pi_{jt} = u_{jt}\mathrm{E}[\min(w_{jt}, k_{jt})] - c_{jt}k_{jt}. \tag{60}$$

Here, the production level is supposed to equal the amount of capacity, k_{jt}. This means that a firm can fully utilise its capacity for production, which is reasonable in the semiconductor manufacturing sector. The parameters u_{jt} and c_{jt} are price and unit production cost of firm j at period t, respectively. Since demand is stochastic, the profit can be rewritten as,

$$\pi_{jt} = \int_0^{k_{jt}} (u_{jt}w_{jt})\, d\boldsymbol{\Phi}_{jt}(w_{jt}) + \int_{k_{jt}}^{\infty} (u_{jt}k_{jt})\, d\boldsymbol{\Phi}_{jt}(w_{jt}) - c_{jt}k_{jt}. \tag{61}$$

With the same settings of financial boundaries that involve both the financial constraint and risk-neutral equivalence as those specified in section 2.5.1, the optimal capacity and debt decisions can thus be obtained by solving the following optimisation problem:

$$\max \quad u_{jt}\mathrm{E}[\min(w_{jt}, k_{jt})] - c_{jt}k_{jt}, \tag{62}$$

$$\text{s.t.} \quad 0 \le c_{jt}k_{jt} \le d_{jt} + \mathbf{z}_{jt}\mathbf{g}, \tag{63}$$

$$d_{jt} = \int_0^{w_{jt}^b} u_{jt}w_{jt}d\boldsymbol{\Phi}_{jt}(w_{jt}) + \int_{w_{jt}^b}^{\infty} d_{jt}(1 + i_{jt})d\boldsymbol{\Phi}_{jt}(w_{jt}). \tag{64}$$

By calculating the Lagrangian and Karush-Kuhn-Tucker first-order conditions with respect to capacity and debt, the optimal policies are given by,

$$k_{jt}^{*} = (\mu_1 p_{jt} + \mathbf{q}_{jt}\boldsymbol{\mu}_2) \times \exp\left(\tau \mathbf{Z}^{-1}\left(\frac{u_{jt} - c_{jt}}{u_{jt}}\right)\right), \tag{65}$$

$$c_{jt}k_{jt}^{*} = d_{jt}^{*} + \mathbf{z}_{jt}\mathbf{g}. \tag{66}$$

The detailed calculations of deciding the joint capacity and debt level for the above model with constraints are specified in Appendix I.

To simplify the model without loss of generality, the unit profit margin of firm j at period t is assumed to be the function of a set of observed profit shifters $\mathbf{w}_{jt}$, which is defined by $(u_{jt} - c_{jt})/u_{jt} = \exp(\mathbf{w}_{jt}\boldsymbol{\gamma})/(1 + \exp(\mathbf{w}_{jt}\boldsymbol{\gamma}))$, where $\boldsymbol{\gamma}$ is a parameter vector of profit shifters. The reason for using the specific form $\exp(\cdot)/(\mathbf{1} + \exp(\cdot))$ is due to the property of $\mathbf{Z}^{-1}(\cdot)$ that inputs of distribution are restricted to be in a unit interval (0, 1]. Besides, the research assumes that the unit production cost of each firm c_{jt} is an exponential linear function with its observed cost shifters $\mathbf{s}_{jt}$, in order to ensure a positive value of cost, which is $\exp(\mathbf{s}_{jt}\boldsymbol{\rho})$, where $\boldsymbol{\rho}$ is a vector of parameters for cost shifters.

The capacity expansion and debt levels are typically assumed to be observed with errors. This means that the true value of capacity expansion, Δk_{jt}, can be composed by an estimated capacity expansion level $k_{jt}^{*} - k_{j,t-1}$ and an unobserved component η_{jt}. The term $k_{jt}^{*} - k_{j,t-1}$ is the difference between the optimal amount of capacity and the capacity value in the last period, where $k_{jt-1}$is supposed to be ι per cent of last-period asset $a_{j,t-1}$. Moreover, the observed debt value d_{jt} is a function of estimated amount of debt d_{jt}^{*} and an error term ζ_{jt}. The capacity expansion and debt equations are thus obtained by,

$$\Delta k_{jt} = k_{jt}^{*} - \iota a_{j,t-1} + \eta_{jt,} \tag{67}$$

$$d_{jt} = d_{jt}^{*} + \zeta_{jt.} \tag{68}$$

By combining the equations (65) and (66) with (67) and (68), values of capacity expansion and debt can be written in terms of index share and observed covariates, which are,

$$\Delta k_{jt} = (\mu_1 p_{jt} + \mathbf{q}_{jt}\boldsymbol{\mu}_2) \times \exp\left(\tau \mathbf{Z}^{-1}\left(\frac{\exp(\mathbf{w}_{jt}\boldsymbol{\gamma})}{1 + \exp(\mathbf{w}_{jt}\boldsymbol{\gamma})}\right)\right) - \iota a_{j,t-1} + \eta_{jt} \tag{69}$$

$$d_{jt} = \exp(\mathbf{s}_{jt}\boldsymbol{\rho}) \times (\mu_1 p_{jt} + \mathbf{q}_{jt}\boldsymbol{\mu}_2) \times \exp\left(\tau \mathbf{Z}^{-1}\left(\frac{\exp(\mathbf{w}_{jt}\boldsymbol{\gamma})}{1 + \exp(\mathbf{w}_{jt}\boldsymbol{\gamma})}\right)\right) - \mathbf{z}_{jt}\mathbf{g} + \zeta_{jt.} \tag{70}$$

3.2.2 Financial Performance: Stock Return

The individual firm's expected stock return in a given sector is typically associated with the return on capitalisation-weighted sector index and other sector-based factors on the basis of APT. That is, the rate of return of firm j at period t is derived by formulating the multi-factor model, which is,

$$r_{jt} = r_t^0 + \beta_j^m (r_t^m - r_t^0) + \sum_{p=1}^{P} \beta_j^p r_t^p + \omega_{jt} = \mathbf{r}_t \boldsymbol{\beta}_j^r + \omega_{jt}, \tag{71}$$

where r_t^0 is the risk-free rate at period t, r_t^m is the rate of return on the sector index, and r_t^p is other factors that influence firm j's return, such as the premium of market capitalisation, price-to-book ratio, probability, and investment based on the five-factor asset pricing model proposed by Fama and French (2015). When there is no summation term in equation (71), the rate of return is simplified as a single factor model. ω_{jt} is the demand error. Transforming the function into a matrix form, which is described in the last term of equation (71), the parameter vector $\boldsymbol{\beta}_j^r = \left(1, \beta_j^m, \beta_j^1, \dots, \beta_j^P\right)'$ contains constant value of 1 and weights of factors, the term $\mathbf{r}_t$ is a vector including the risk-free rate and $P + 1$ $(< T - 1)$ influencing factors that are only related to period t, $(r_t^0, r_t^m - r_t^0, r_t^1, \dots r_t^P)$.

However, the endogenous bias of the expected stock return r_{jt} indeed exists due to its interaction with the index share in the concrete world. The index share is commonly used for the weight of each firm's stock return so as to obtain the average stock return in the index market. Conversely, the expected stock return of each firm influences investors' utilities of purchasing stock in a given sector, which would further affect the index share of the firm. The simultaneity of the individual stock return and index share for the simplest case of a single factor model, the capital asset pricing model (CAPM), is given by,

$$r_{jt} = r_t^0 + \beta_j \left(\sum_{j=1}^{J_t} \left(p_{jt} \times r_{jt}\right) - r_t^0 \right) + \omega_{jt}, \tag{72}$$

where the random coefficient β_j can be decomposed into a mean value and a deviation from mean by assuming it to be drawn from the normal distribution, $N(\bar{\beta}, \sigma_\beta^2)$, with the identity of $\beta_j = \bar{\beta} + v_j$, where $v_j \sim N\left(0, \sigma_\beta^2\right), j = 1, \dots, J_t$.

3.3 Statistical Specification

In this section, the likelihood and priors are provided to calculate the posterior of all estimators, and the corresponding MCMC algorithm is developed for the Bayesian evaluation. Moreover, a Monde Carlo test with simulated data is used to verify the model validities.

3.3.1 Likelihood

To calculate the likelihood, the assumptions of errors ξ_{jt}, η_{jt}, and ζ_{jt} in the utility, capacity expansion, and debt functions are set to be consistent with those in Chapter 2. That is, the shock of firm j at period t in the utility function is normally distributed, while the correlated errors of $(\eta_{jt}, \zeta_{jt})'$ follow a multivariate normal distribution with a covariance matrix. Besides, the error in the stock return function (72) is assumed to be independently distributed with different variance for each firm. Thus, the distributions of errors are given by,

$$\xi_{jt} \sim N(0, \sigma_d^2), \tag{73}$$

$$\begin{pmatrix} \eta_{jt} \\ \zeta_{jt} \end{pmatrix} \sim N\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \mathbf{\Sigma}_s = \begin{pmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{21} & \sigma_{22} \end{pmatrix} \right), \tag{74}$$

$$\omega_{jt} \sim N(0, \sigma_j^2), \tag{75}$$

where σ_d^2 is the variance of ξ_{jt}, $\mathbf{\Sigma}_s$ is the covariance matrix of $(\eta_{jt}, \zeta_{jt})'$, and σ_j^2 is the variance of ω_{jt} that differs among firms.

Since the model of demand allocation is the same as the one specified in section 2.2.1, the joint density of index shares at period t will be identical to that of equation (13),

$$\pi_1(\mathbf{P}_t | \mathbf{X}_t, \bar{\boldsymbol{\alpha}}, \mathbf{\Sigma}_\alpha, \sigma_d^2) = \left(J_{(\mathbf{P}_t \to \boldsymbol{\xi}_t)}\right)^{-1} \times \left(\prod_{j=1}^{J_t} \phi_d\left(\left(p_{jt}^{-1}(P_{jt}, \mathbf{X}_{jt}; \mathbf{\Sigma}_\alpha) - \mathbf{X}_{jt}\bar{\boldsymbol{\alpha}}\right) \middle| \sigma_d^2 \right) \right), \tag{76}$$

where $\mathbf{P}_t = (P_{1t}, \dots, P_{J_t t})'$ and $\mathbf{X}_t = \left(\mathbf{X}'_{1t}, \dots, \mathbf{X}'_{J_t t}\right)'$ are vectors of observed index shares and firm-specific characteristics at period t, respectively. $\bar{\boldsymbol{\alpha}}$ and $\mathbf{\Sigma}_\alpha$ are the mean and covariance matrix of random coefficient $\boldsymbol{\alpha}_i$, and $\boldsymbol{\xi}_t = (\xi_{1t}, \dots \xi_{J_t t})'$, as the aggregate shock among firms in the utility function at period t has the normal density of ϕ_d. $p_{jt}^{-1}(P_{jt}, \mathbf{X}_{jt}; \mathbf{\Sigma}_\alpha)$ captures the mean utility δ_{jt} that can be computed through the use of the BLP Contraction Mapping, which has been discussed in sub-section 2.3.1.1. $\left(J_{(\mathbf{P}_t \to \boldsymbol{\xi}_t)}\right)^{-1}$ is the inversed determinant of Jacobian matrix used to transform from $\mathbf{P}_t$ to $\boldsymbol{\xi}_t$.

The joint density of both capacity expansion and debt levels at period t can also be obtained based on the Change-of-Variable Theorem, where the functions of errors are driven from the differences between true values and estimations for both capacity expansion and debt, which is given by,

$$\pi_2(\Delta\mathbf{k}_t, \mathbf{d}_t\,|\mathbf{X}_t, \mathbf{q}_t, \mathbf{w}_t, \mathbf{z}_t, \mathbf{s}_t, \boldsymbol{\varphi}, \boldsymbol{\Sigma}_s, \boldsymbol{\Sigma}_\alpha) = J_{(\boldsymbol{\eta}_t, \boldsymbol{\zeta}_t \to \Delta\mathbf{k}_t, \mathbf{d}_t)} \tag{77}$$

$$\times \left(\prod_{j=1}^{J_t} \phi_s \left(\left[\begin{matrix} \Delta k_{jt} - \left(\mu_1 p_{jt}\left(\delta_{jt}, \mathbf{X}_{jt}; \boldsymbol{\Sigma}_\alpha\right) + \mathbf{q}_{jt}\boldsymbol{\mu}_2\right) \times \exp\left(\tau \mathbf{Z}^{-1}\left(\frac{\exp(\mathbf{w}_{jt}\boldsymbol{\gamma})}{1+\exp(\mathbf{w}_{jt}\boldsymbol{\gamma})}\right)\right) + \iota a_{j,t-1} \\ d_{jt} - \exp(\boldsymbol{s}_{jt}\boldsymbol{\rho}) \times \left(\mu_1 p_{jt}\left(\delta_{jt}, \mathbf{X}_{jt}; \boldsymbol{\Sigma}_\alpha\right) + \mathbf{q}_{jt}\boldsymbol{\mu}_2\right) \times \exp\left(\tau \mathbf{Z}^{-1}\left(\frac{\exp(\mathbf{w}_{jt}\boldsymbol{\gamma})}{1+\exp(\mathbf{w}_{jt}\boldsymbol{\gamma})}\right)\right) + \mathbf{z}_{jt}\mathbf{g} \end{matrix} \right] \middle\| \boldsymbol{\Sigma}_s \right) \right),$$

where $\mathbf{d}_t = \left(d_{1t}, \dots, d_{J_t t}\right)'$, $\mathbf{q}_t = \left(\mathbf{q}'_{1t}, \dots, \mathbf{q}'_{J_t t}\right)'$, $\mathbf{w}_t = \left(\mathbf{w}'_{1t}, \dots, \mathbf{w}'_{J_t t}\right)'$, $\mathbf{z}_t = \left(\mathbf{z}'_{1t}, \dots, \mathbf{z}'_{J_t t}\right)'$, and $\mathbf{s}_t = \left(\mathbf{s}'_{1t}, \dots, \mathbf{s}'_{J_t t}\right)'$ are vectors of observed debt levels, sales forecasts, profit shifters, financial characteristics, and cost shifters at period t, respectively. ϕ_s is the multivariate normal density of $\left(\eta_{jt}, \zeta_{jt}\right)'$. $\boldsymbol{\varphi}$ is the vector of parameters that needs to be estimated in both capacity expansion and debt equations $(\mu_1, \boldsymbol{\mu}_2, \iota, \boldsymbol{\gamma}, \mathbf{g}, \boldsymbol{\rho})'$, where μ_1 and $\boldsymbol{\mu}_2$ are parameters in the mean demand, ι is the per cent of last-period asset, $\boldsymbol{\gamma}$ is the parameter vector for profit shifters, $\mathbf{g}$ is the parameter vector in the financial constraint, and $\boldsymbol{\rho}$ is a vector of parameters for cost shifters. $J_{(\boldsymbol{\eta}_t, \boldsymbol{\zeta}_t \to \Delta\mathbf{k}_t, \mathbf{d}_t)}$ is the determinant of Jacobian matrix used to transform from $\boldsymbol{\eta}_t, \boldsymbol{\zeta}_t$ to $\Delta\mathbf{k}_t, \mathbf{d}_t$, $\boldsymbol{\eta}_t = (\eta_{1t,} \dots, \eta_{J_t t})'$ and $\boldsymbol{\zeta}_t = (\zeta_{1t,} \dots, \zeta_{J_t t})'$.

When considering the sector-based stock pricing-strategy in the model, the expected stock return is simultaneously determined by index share. For the simplest case of CAPM, the joint density of stock returns for firm j is provided by using the Change-of-Variable Theorem,

$$\pi_3\left(\mathbf{r}_j \middle| \mathbf{X}_j, \beta_j, \sigma_j^2, \boldsymbol{\Sigma}_\alpha\right) = J_{(\boldsymbol{\omega}_j \to \mathbf{r}_j)} \tag{78}$$

$$\times \left(\prod_{t=1}^{T} \phi_r \left(r_{jt} - r_t^0 - \beta_j \left(\sum_{j=1}^{J_t} \left(p_{jt}\left(\delta_{jt}, \mathbf{X}_{jt}; \boldsymbol{\Sigma}_\alpha\right) \times r_{jt}\right) - r_t^0 \right) \middle| \sigma_j^2 \right) \right),$$

where $\mathbf{r}_j = \left(r_{j1}, \dots, r_{jT}\right)'$ is the vector of observed stock return for firm j. ϕ_r is the normal density of ω_{jt}. $J_{(\boldsymbol{\omega}_j \to \mathbf{r}_j)}$ is the determinant of Jacobian matrix used to transform from $\boldsymbol{\omega}_j$ to $\mathbf{r}_j$, where $\boldsymbol{\omega}_j = (\omega_{j1,} \dots, \omega_{jT})'$.

The calculations for the determinants of Jacobian matrices, $J_{(\mathbf{P}_t \to \boldsymbol{\xi}_t)}$, $J_{(\boldsymbol{\eta}_t, \boldsymbol{\zeta}_t \to \Delta\mathbf{k}_t, \mathbf{d}_t)}$, and $J_{(\boldsymbol{\omega}_j \to \mathbf{r}_j)}$, are illustrated in Appendix J.

Therefore, the likelihood for all parameters is given by,

$$L(\overline{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_{\alpha}, \sigma_d^2, \boldsymbol{\varphi}, \boldsymbol{\Sigma}_s, \beta_j, \sigma_j^2) \tag{79}$$

$$= \prod_{t=1}^{T} \Big(\pi_1(\mathbf{P}_t | \mathbf{X}_t, \overline{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_{\alpha}, \sigma_d^2) \times \pi_2(\Delta \mathbf{k}_t, \mathbf{d}_t \, | \mathbf{X}_t, \mathbf{q}_t, \mathbf{w}_t, \mathbf{z}_t, \mathbf{s}_t, \boldsymbol{\varphi}, \boldsymbol{\Sigma}_s, \boldsymbol{\Sigma}_{\alpha}) \Big)$$

$$\times \prod_{j=1}^{J_t} \Big(\pi_3(\mathbf{r}_j | \mathbf{X}_j, \beta_j, \sigma_j^2, \boldsymbol{\Sigma}_{\alpha}) \Big).$$

3.3.2 Estimation

A Bayesian approach is used to estimate models and the independent priors of $\overline{\boldsymbol{\alpha}}$, σ_d^2, $\boldsymbol{\varphi}$, $\boldsymbol{\Sigma}_s$, β_j, and σ_j^2 are,

$$\overline{\boldsymbol{\alpha}} \sim N(\overline{\overline{\boldsymbol{\alpha}}}, \mathbf{V}_{\overline{\alpha}}^{-1}), \tag{80}$$

$$\sigma_d^2 \sim v_{d0} s_{d0}^2 / \chi^2_{v_{d0}}, \tag{81}$$

$$\boldsymbol{\varphi} \sim N(\overline{\boldsymbol{\varphi}}, \mathbf{V}_{\varphi}^{-1}), \tag{82}$$

$$\boldsymbol{\Sigma}_s \sim \mathbf{IW}(\mathbf{V}_{s0}, \mathbf{S}_{s0}), \tag{83}$$

$$\beta_j \sim N(\bar{\beta}, \sigma_\beta^2), \tag{84}$$

$$\bar{\beta} \sim N\left(\bar{\bar{\beta}}, \sigma_{\bar{\beta}}^2\right), \tag{85}$$

$$\sigma_\beta^2 \sim v_{\beta 0} s_{\beta 0}^2 / \chi^2_{v_{\beta 0}}, \tag{86}$$

$$\sigma_j^2 \sim v_{r0} s_{r0}^2 / \chi^2_{v_{r0}}. \tag{87}$$

For the covariance matrix of investors' preference, all elements in the Cholesky root of $\boldsymbol{\Sigma}_{\alpha}$ are estimated, where diagonal elements are reparameterised as exponential terms to ensure the positivity of variances. The prior of $\boldsymbol{\Sigma}_{\alpha}$, consistent with that in Chapter 2, is given by,

$$\boldsymbol{\Sigma}_{\alpha} = U'U \text{ for } U = \begin{bmatrix} e^{\theta_{11}} & \dots & \theta_{1R} \\ \vdots & \ddots & \vdots \\ 0 & \dots & e^{\theta_{RR}} \end{bmatrix}, \tag{88}$$

$$\theta_{jl} \sim N\left(0, \sigma_{\theta_{jl}}^2\right) \text{ for } j, l = 1, \dots, R, j < l. \tag{89}$$

Thus, the joint posterior based on the above likelihood and priors are,

$$\pi\left(\bar{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha, \sigma_d^2, \boldsymbol{\varphi}, \boldsymbol{\Sigma}_s, \beta_j, \sigma_j^2 \middle| \{\Delta\mathbf{k}_t, \mathbf{P}_t,\}_{t=1}^T, \{\mathbf{r}_j\}_{j=1}^{J_t}\right) \tag{90}$$

$$\propto L\left(\bar{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha, \sigma_d^2, \boldsymbol{\varphi}, \boldsymbol{\Sigma}_s, \beta_j, \sigma_j^2\right) \times \pi\left(\bar{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha, \sigma_d^2, \boldsymbol{\varphi}, \boldsymbol{\Sigma}_s\right) \times \prod_{j=1}^{J_t}\left(\pi\left(\beta_j, \sigma_j^2\right)\right),$$

where $\pi\left(\bar{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha, \sigma_d^2, \boldsymbol{\varphi}, \boldsymbol{\Sigma}_s\right)$ is the product of individual priors, $\pi(\bar{\boldsymbol{\alpha}})$, $\pi(\boldsymbol{\theta})$, $\pi\left(\sigma_d^2\right)$, $\pi(\boldsymbol{\varphi})$, and $\pi(\boldsymbol{\Sigma}_s)$. $\boldsymbol{\theta} = (\theta_{11}, \dots, \theta_{jl}, \dots, \theta_{RR})'$ is the vector of elements in Cholesky root for $\boldsymbol{\Sigma}_\alpha$. $\pi\left(\beta_j, \sigma_j^2\right)$ is the product of individual priors, $\pi\left(\beta_j\right)$ and $\pi(\sigma_j^2)$.

The conditionals of parameters used to implement the MCMC algorithm are,

$\bar{\boldsymbol{\alpha}} \vert \boldsymbol{\theta}, \sigma_d^2$	mean of heterogeneity in index share eqation,	(91)
$\boldsymbol{\theta} \vert \boldsymbol{\varphi}, \beta_j, \bar{\boldsymbol{\alpha}}, \sigma_d^2$	covariance of heterogeneity in index share eqation,	(92)
$\sigma_d^2 \vert \bar{\boldsymbol{\alpha}}, \boldsymbol{\theta}$	variance of error in index share eqation,	(93)
$\boldsymbol{\varphi} \vert \boldsymbol{\Sigma}_s, \boldsymbol{\theta}$	parameters in capacity expansion and debt eqations,	(94)
$\boldsymbol{\Sigma}_s \vert \boldsymbol{\varphi}$	covariance of errors in capacity expansion and debt eqations,	(95)
$\beta_j \vert \bar{\beta}, \sigma_\beta^2, \sigma_j^2, \boldsymbol{\theta}$	heterogeneity in stock return eqation,	(96)
$\bar{\beta} \vert \sigma_\beta^2, \beta_j, \sigma_j^2$	mean of heterogeneity in stock return eqation,	(97)
$\sigma_\beta^2 \vert \bar{\beta}, \beta_j, \sigma_j^2$	variance of heterogeneity in stock return equation,	(98)
$\sigma_j^2 \vert \beta_j$	variance of error in stock return equation.	(99)

The draws for $\boldsymbol{\theta}, \bar{\boldsymbol{\alpha}}$, and σ_d^2 are the same as provided in section 2.3.2. That is, the draw for $\boldsymbol{\theta}$ is conducted by applying the RW Metropolis algorithm, and a pure Gibbs sampler with standard natural conjugate Bayes analysis is used to draw $\bar{\boldsymbol{\alpha}}$ and σ_d^2. Moreover, the draw for $\boldsymbol{\varphi}$ is also accomplished with the use of the RW Metropolis algorithm as the parameter vector $\boldsymbol{\varphi}$ is included in the Jacobian term. Besides, parameter $\boldsymbol{\Sigma}_s$ is drawn from the inverted Wishart distribution. In addition, parameters and hyper-parameters in the stock return equation, β_j, σ_j^2, $\bar{\beta}$, and σ_β^2 can be obtained by using the hierarchical Bayes modelling method; they are the draws from a hierarchical linear model. The detailed draws of parameters are provided in Appendix K.

The DAG for the model is,

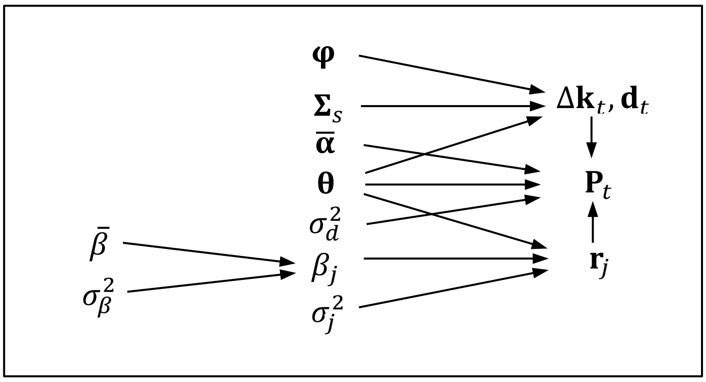


Figure 13 The DAG for the model

3.3.3 Simulation Study

To simulate the models of capacity expansion and performance outcomes, a Monte Carlo test is carried out with simulation settings similar to those described in Chapter 2. The simulated data involve $I = 50$ investors, $J = 15$ firms, and $T = 3$ periods in a sector with $nA = 3$ firm attributes $\mathbf{x}_{jt}$, $nQ = 3$ sales predictors $\mathbf{q}_{jt}$, $nW = 3$ profit shifters $\mathbf{w}_{jt}$, $nZ = 3$ financial characteristics $\mathbf{z}_{jt}$, and $nS = 3$ cost shifters $\mathbf{s}_{jt}$. These variables are simulated based on the covariance matrices specified in the equations of (31), (34), (35), (56) and (57).

Regarding the parameters in the models, the settings of mean $\overline{\boldsymbol{\alpha}}$ and covariance matrix $\boldsymbol{\Sigma}_\alpha$ for random coefficients $\boldsymbol{\alpha}_i$ are provided in equations (32) and (33). The variance of error in the index share equation σ_d^2 is set to 0.01, which is a very small value, while the covariance matrix of errors in the capacity expansion and debt equations $\boldsymbol{\Sigma}_s$ is specified with the same variances of 0.04 and correlations of -0.01. Moreover, the parameter vector in both capacity expansion and debt equations $\boldsymbol{\varphi}$ is,

$$\boldsymbol{\varphi} = (0.1, 0.2, 0.1, 0.1, 0.2, 0.1, 0.1, 0.3, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1). \tag{100}$$

As for parameters in the stock return equation, the random coefficient of return on the sector index is assumed to be normally distributed with mean $\bar{\beta} = 0.7$ and variance $\sigma_\beta^2 = 0.1$ for the simplest model of CAPM. Besides, the variance of error for each firm in the equation is set to be the same value of 0.01.

When covariates and parameters are given, values of endogenous capacity expansion, debt, stock return, and index share are then able to be computed based on models. In addition, the standard deviation of demand distribution τ is restricted to a fixed value of 1 for addressing the identification in the capacity expansion equation. Besides, a method of SQUAREM is applied to implement the

BLP Contraction Mapping with the convergence tolerance of 10^{-10} for calculating the mean demand in the index share equation.

A total of 80,000 posterior draws are taken for the simulation study, and the Markov chain rapidly burns in after 4,000 iterations. Convergence is evaluated by inspecting a sequence plot of posterior outputs, which is suggested by Rossi et al. (2012). The log-likelihood is shown in Figure 14, which remains stable after convergence.

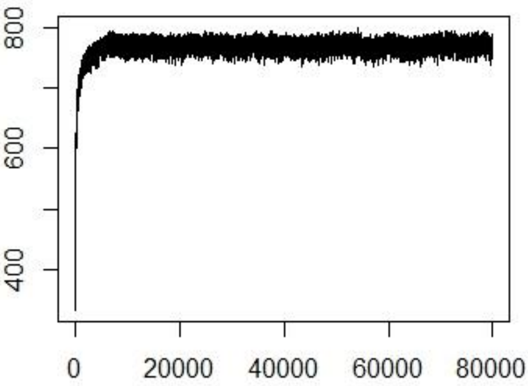


Figure 14 Values of the posterior log-likelihood

After burning in, posterior draws are used to estimate means and standard errors of model parameters, and RMSE and bias are calculated for each element of coefficient vectors shown in Table 7. It is noticed that all Bayes estimators are extremely close to true values given in the simulation settings, with low standard errors, RMSEs, and biases. This verifies the high accuracy and significant efficiency of models achieved by using the Bayesian approach. However, the standard deviation of posterior distribution for return on the sector index is not estimated precisely. This may be due to the limitation of simulated data, and it is found that the standard deviation on sector index return gets closer to the true value of 0.1 when sample size increases.

Table 7 Posterior means, standards errors, RMSEs, and biases of parameters

Parameter	Variable	True	Mean	RMSE	Bias
$\bar{\alpha}$	Firm Attributes	-2	-2.0915 (0.0576)	0.1081	-0.0915
		-3	-3.0744 (0.0563)	0.0933	-0.0744
		-4	-3.8991 (0.0534)	0.1142	0.1009

	Stock Return	-5	-5.2068 (0.0828)	0.2228	-0.2068
	Capacity Expansion	-6	-6.0312 (0.0584)	0.0662	-0.0312
	Leverage Ratio	-7	-7.0033 (0.0382)	0.0383	-0.0033
$\boldsymbol{\Sigma}_{\alpha}$	Firm Attributes	3	3.0460 (0.0693)	0.0832	0.0460
		4	4.0721 (0.1142)	0.1351	0.0721
		4	3.9313 (0.0949)	0.1172	-0.0687
	Stock Return	3	2.7401 (0.4016)	0.4784	-0.2599
	Capacity Expansion	2	2.0374 (0.1261)	0.1315	0.0374
	Leverage Ratio	5	5.0195 (0.1183)	0.1199	0.0195
$\boldsymbol{\varphi}$	Index Share	0.1	0.1452 (0.0314)	0.0550	0.0452
	Sales Forecasts	0.2	0.2021 (0.0119)	0.0121	0.0021
		0.1	0.1018 (0.0057)	0.0060	0.0018
		0.1	0.1007 (0.0065)	0.0065	0.0007
	Profit Shifters	0.2	0.2120 (0.0089)	0.0149	0.0120
		0.1	0.0969	0.0085	-0.0031

			(0.0079)		
		0.1	0.0918 (0.0229)	0.0243	-0.0082
	Last-Period Asset	0.3	0.2445 (0.0328)	0.0645	-0.0555
	Financial Characteristics	0.1	0.1091 (0.0085)	0.0125	0.0091
		0.1	0.1186 (0.0100)	0.0211	0.0186
		0.1	0.1040 (0.0103)	0.0110	0.0040
	Cost Shifters	0.1	0.0953 (0.0107)	0.0117	-0.0047
		0.1	0.0896 (0.0079)	0.0131	-0.0104
		0.1	0.1198 (0.0110)	0.0227	0.0198
$\bar{\beta}$	Return on Sector Index	0.7	0.6929 (0.1395)	0.1397	-0.0071
σ_β^2	Return on Sector Index	0.1	0.2899 (0.1068)	0.2179	0.1899
σ_d^2	Error in Index Share Equation	0.01	0.0092 (0.0022)	0.0023	-0.0008
$\mathbf{\Sigma}_s$	Error in Capacity Expansion Equation	0.04	0.0393 (0.0088)	0.0088	-0.0007
	Covariance of Errors	-0.01	-0.0044 (0.0055)	0.0078	0.0056
	Covariance of Errors	-0.01	-0.0044 (0.0055)	0.0078	0.0056

Error in Debt Equation	0.04	0.0260 (0.0066)	0.0155	-0.0140

3.4 Empirical Application

This section examines models using an empirical case of the semiconductor manufacturing sector, and evaluation results along with counterfactual analyses are explored in depth.

3.4.1 Data

To investigate how capacity expansion impacts the operating and financial performance, firms that design, manufacture, pack and sell semiconductors in the SOX are used to empirically analyse models from a sector-specific view. The data sample includes 64 US-listed semiconductor firms during the periods of 2006 to 2010 with a total of 207 observations, including Intel, Texas Instruments, Micron Technology and On Semiconductor. Variables cover amounts of capacity expansions, index shares, stock returns, debt levels, firm-specific attributes, sales forecasts, profit shifters, financial characteristics, and cost shifters.

Specifically, firm attributes are estimated by firm size, strategic holdings, asset efficiency, ROA, and inventory turnover. Gross margin, accounts payable to inventory, slack resources, sales per share, financial activities, and inventory performance are used to forecast sales at the firm level. Moreover, financial characteristics are measured by EPS, cash flow margin, and Tobin's Q. In addition, ROS and operating profitability are regarded as proxies of profit shifters, while SGA/asset ratio and COGS/asset ratio are used to evaluate cost shifters. The detailed descriptions of data sources and variable definitions are specified in Appendix L.

The descriptive statistics and correlation matrices of variables are presented in Table 8. This shows that variables in each category are comparatively independent with low correlations, and can be regarded as proper proxies.

Table 8 Summary statistics

Panel A: Descriptive Statistics

Variable	Mean	Median	Std.Dev.	Maximum	Minimum
Capacity Expansion	7626.8496	0.0000	33992.5788	274500.00	0.0000
Stock Return	0.1322	-0.0248	0.7245	4.2114	-0.8634

Leverage Ratio	0.1365	0.0336	0.2225	1.4202	0.0000
Firm Size	3.5676	3.5563	0.5367	4.9736	2.3404
Strategic Holdings	0.2308	0.2000	0.1574	0.8100	0.0000
Asset Efficiency	0.6991	0.6950	0.2196	1.3201	0.2070
ROA	0.0936	0.0999	0.1703	0.8285	-0.8571
Inventory Turnover	3.9874	3.6815	1.8335	13.3309	0.8089
Gross Margin	0.5449	0.5331	0.1136	0.8270	0.2397
Accounts Payable to Inventory	0.6057	0.4882	0.3905	2.4113	0.0834
Slack Resources	5.9223	5.8645	0.4773	7.3994	4.8415
Sales Per Share	8.1410	6.3680	8.9092	119.8570	0.3490
Financial Activities	0.0386	0.0235	0.0598	0.5630	0.0000
Inventory Performance	0.1336	0.1197	0.0678	0.6016	0.0328
EPS	0.7545	0.6100	0.8163	6.5500	0.0000
Cash Flow Margin	0.2152	0.2086	0.1191	0.5801	-0.3704
Tobin's Q	1.8905	1.5902	1.1755	7.5723	0.1464
ROS	0.1311	0.1494	0.2886	1.4661	-1.3380
Operating Profitability	0.3703	0.1707	1.7519	21.0189	-1.5442
SGA/Asset Ratio	0.2318	0.2234	0.0863	0.4732	0.0551
COGS/Asset Ratio	0.3230	0.3092	0.1433	0.7930	0.0795

Panel B: Correlation Matrices

	FS	SH	AE	ROA	IT
Firm Size	1.0000	-0.1367	0.2665	-0.0343	0.1295
Strategic Holdings		1.0000	-0.0693	0.0653	0.1395
Asset Efficiency			1.0000	0.2185	0.2467
ROA				1.0000	-0.0422
Inventory Turnover					1.0000

	GM	API	SR	SPS	FA	IP
Gross Margin	1.0000	-0.2528	0.0682	-0.2427	0.0929	-0.3652
Accounts Payable to Inventory		1.0000	0.1225	0.1327	0.0455	-0.4329
Slack Resources			1.0000	0.2425	-0.0624	-0.1479
Sales Per Share				1.0000	0.0702	0.0692
Financial Activities					1.0000	-0.0554
Inventory Performance						1.0000

	EPS	CFM	TQ
EPS	1.0000	0.1431	0.2873
Cash Flow Margin		1.0000	0.4260
Tobin's Q			1.0000

	ROS	OP
ROS	1.0000	0,1060
Operating Profitability		1.0000

	SA	CA
SGA/Asset Ratio	1.0000	0.3287
COGS/Asset Ratio		1.0000

3.4.2 Estimates

A total of 80,000 iterations are run for the evaluation. Means and standard errors of model parameters are calculated using draws after convergence, and results are given in Table 9.

It is found that mean utility levels on capacity expansion, stock return, and leverage ratio are all negative and sufficiently precise at the significance levels. This is in accordance with the real case of firms in the semiconductor manufacturing sector (Uzsoy et al. 2018, Wu et al. 2005). The negative coefficients on capacity expansion and debt reflect the trend that firms with large expansions on capacities and amounts of debts raised suffer from high risks, which would influence investors' purchases of their stocks. In addition, the means associated with the firm size and ROA are positively related and significantly different from zero, while the estimates of constant, strategic holdings, asset efficiency, and inventory turnover have negative effects on the mean utility of individual investors. On the other side, standard deviations of the marginal utility distribution for all variables in the index share equation are estimated to be insignificantly close to 0.01, a tiny number. The failure of precise evaluations on standard deviations may due to the fact that the data are not rich and substantial enough for empirical analysis. In addition, the variance value of shock in the index share equation is small and significant with little standard error.

When capacity and debt levels are simultaneously determined, the parameter of index share in the capacity expansion equation is estimated with a negative value. This reflects that when the firm's share in the index increases, less mean demand is required and the firm may expand to lesser capacity so as to realise the optimal capacity decision. The index share thus acts as a negative market signal for the prospective demand. Regarding the evaluations of sales forecasts, it is reasonable that gross margin, accounts payable to inventory, slack resources, sales per share, and financial activities have positive effects on mean demand, while inventory performance is negatively related due to the fierce competition in the semiconductor manufacturing sector. When firms' new wafers after expansion are put into the market with high profit, low inventory, mass sales, and multiple financial activities, other competitors typically tend to respond quickly with increased capacities and force the firm-specific demand to increase significantly (Lieberman 1987, Yang and Anderson 2014). Moreover, 39.21% of last-period asset is used to estimate capacity level in the last period. Besides, the proxy of profit shifter – ROS – is significantly positively correlated with the optimal capacity level, while another one – operating profitability – has a slight positive impact on the capacity decision with the parameter value close to zero. It seems from this that ROS is much more representative in evaluating profit shifters than operating profitability.

Considering the coefficients in the debt equation, they are evaluated given the value of the optimal capacity level. It is noticed that firms with high EPSs, cash flow margins, and Tobin's Q contribute to debt financing, although the estimate of Tobin's Q is not different from zero – and may even be imprecise. Moreover, COGS/Asset ratio is an appropriate indicator for the cost shifter as it is positively related and significant at a reasonably significant interval, while the estimate of SAG/Asset ratio is a small negative value. More interestingly, there is only a small correlation between the two errors in capacity expansion and debt equations, which is 0.0022, even though they should be closely related to each other when allowing for the joint determination of capacity and debt levels based on the assumption. The reason for the weak correlations may be the influence of those inappropriate indicators in both profit and cost shifters. In addition, the variances of errors are small, which reinforces the small variations in both capacity expansion and debt equations.

Finally, parameters estimated in the stock return equation are discussed. The empirical results show that mean and standard deviation of the distribution for return on sector index are precise with very small standard errors. The mean value of the coefficient on sector index return is 1.0705, verifying that the average risk of all firms' stocks in the given sector is in accordance with the risk of index portfolio, which is SOX (Bodie et al. 2011). Moreover, the estimate of standard deviation associated with the return on sector index has the value of 0.2913. This reflects that each stock's beta value would fluctuate over a range from 0.78 to 1.36. As the beta value of the firm's stock continues to mount, its performance would have a much closer correlation with the market volatility and it may also shift out of defensive sectors into cyclicals.

Table 9 Empirical results

Parameter	Variable	Mean
$\bar{\boldsymbol{\alpha}}$	Constant	-5.3602 (0.4630)
	Firm Size	1.3147 (0.1301)
	Strategic Holdings	-1.4235 (0.3755)
	Asset Efficiency	-0.6384 (0.2824)
	ROA	1.3698 (0.3559)
	Inventory Turnover	-0.0607 (0.0321)
	Stock Return	-0.2298 (0.0832)
	Capacity Expansion	-0.1724 (0.0721)
	Leverage Ratio	-0.3406 (0.2778)
$\boldsymbol{\Sigma}_{\boldsymbol{\alpha}}$	Constant	0.0091

		(0.0133)
	Firm Size	0.0071 (0.0099)
	Strategic Holdings	0.0114 (0.0155)
	Asset Efficiency	0.0114 (0.0169)
	ROA	0.0126 (0.0181)
	Inventory Turnover	0.0030 (0.0039)
	Stock Return	0.0104 (0.0138)
	Capacity Expansion	0.0116 (0.0166)
	Leverage	0.0101 (0.0136)
φ	Index Share	-0.0454 (0.0253)
	Gross Margin	0.1337 (0.0247)
	Accounts Payable to Inventory	0.0043 (0.0231)
	Slack Resources	0.0152 (0.0065)
	Sales per Share	0.0002 (0.0016)
	Financial Activities	0.5397 (0.0192)

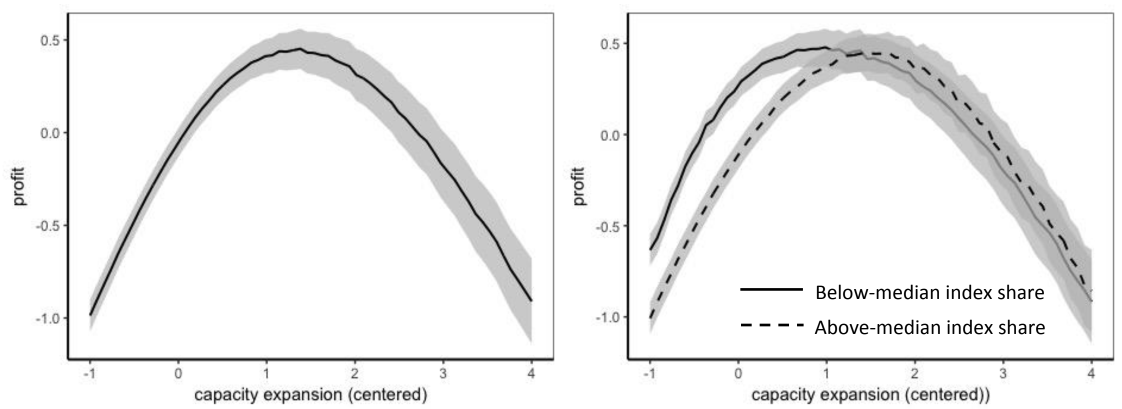
	Inventory Performance	-0.0652 (0.0176)
	Last-Period Asset	0.3921 (0.0190)
	ROS	0.1193 (0.0182)
	Operating Profitability	0.0294 (0.0133)
	EPS	0.0133 (0.0093)
	Cash Flow Margin	0.2086 (0.0257)
	Tobin's Q	0.0062 (0.0138)
	SGA/Asset Ratio	-0.0357 (0.0221)
	COGS/Asset Ratio	0.2515 (0.0216)
$\bar{\beta}$	Return on Sector Index	1.0705 (0.0676)
σ_{β}^{2}	Return on Sector Index	0.2913 (0.0546)
σ_{d}^{2}	Error in Index Share Equation	0.6256 (0.0622)
$\mathbf{\Sigma}_{s}$	Error in Capacity Expansion Equation	1.0182 (0.1010)
	Covariance of Errors	0.0022 (0.0161)
	Covariance of Errors	0.0022

	(0.0161)
Error in Debt Equation	0.0493 (0.0050)

3.4.3 Discussion

Counterfactual analyses are conducted by using models and estimated parameters to simulate the impact of capacity expansion on profit, stock return, and firm value, respectively. The simulation study consists of $I = 50$ investors and $J = 64$ firms available at periods of $T = 10$, and is illustrated on the basis of a single index market. To do the counterfactuals, the value of capacity expansion is changed, and other covariates, including firm attributes, sales forecasts, financial characteristics, as well as profit and cost shifters, are set to fixed values, which are identified as their means. The specific algorithm for computing counterfactual equilibria is given in Appendix M.

The effect of capacity expansion on the firm profit is firstly discussed. Most studies in the operations field mainly focus on the maximisation of profit to obtain optimal operational decisions rather than investigating the value of profit associated with the capacity expansion (e.g., Angelus and Porteus 2002). However, Xu and Birge (2008) conduct a sensitivity analysis for the impact of optimal production level on firm profit, and show that the firm profit estimated by the normalised net income is a concave function of the operational decision. In the light of this finding, capacity expansion is thus hypothesised to facilitate the profit before reaching the optimal value, but conversely, it has a negative effect on the profit.



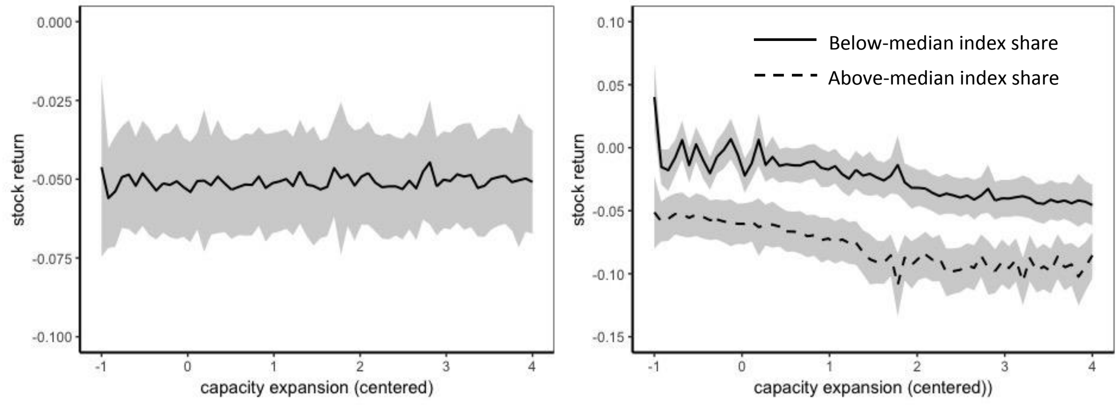
(a) No classification (b) Classification

Figure 15 The effect of capacity expansion on profit

To test this hypothesis, the counterfactuals are conducted by alternating values of capacity expansion level, and results are specified in Figure 15. Curves and shadows in plots show the mean values and confidence intervals of simulations. It is noticed that the profit is a concave function and displays an inverse U-shape in the capacity expansion, consistent with findings of Xu and Birge (2008). That is, a rise in the capacity expansion causes profit to firstly increase and then decrease after arriving at its peak value. One intuitive explanation behind this finding is that, before the firm reaches its maximised profit, the increased profit brings more financial support for the capacity expansion, thereby resulting in the fact that the firm continues to expand capacity for higher profit. However, when the firm profit exceeds the optimal level, operating cost, risk of future cash flow, along with cost of debt may be enhanced by expanded capacity, which in turn decreases firm profit. It is because that the excessive capacity impacts both operating process and financial implications (Xu and Birge 2008, Yang and Anderson 2014). To further exploit the effect of capacity expansion on firm profit, the mediator of index share needs to be considered. This is because index share, as a critical input of demand allocation, affects the optimal capacity expansion level and the corresponding profit. Interestingly, when the value of index share is categorised with its median level, obvious differences occur between two types of firm in terms of the effect of capacity expansion on profit before it reaches the maximised value, which is shown in Figure 15 (b). To be specific, firms with below-median index shares capture remarkably higher profits than those with above-median index shares when firms own the same amounts of capacity expansion before they have the optimal profit; conversely, there is an insignificant difference after the profit reaches its peak value. This suggests that capacity expansion will lead to different profit increments under the effect of index share before attaining the optimal profit, thus a proposition is proposed:

Proposition 3. *As a small-index-share firm's capacity expansion increases in a suitable range, its profit will increase with better performance than that with large index share.*

The impact of capacity expansion on stock return under the influence of index share is another main concern in this study. Typically, capacity expansion alters the firm's index share through influencing investors' preferences of stock purchases; meanwhile, its stock return can rapidly respond to the variability of index share when allowing for the stock-pricing strategy. There are few studies investigating this impact, expect for the empirical research of Hendricks, et al. (1995), which finds a significantly positive effect of capacity expansion on stock return at the first day of the announcement by using an event study approach. This counterfactual study thus intends to test whether stock return has a positive reaction to capacity expansion through the adjustment of index share by applying estimated model parameters.



(a) No classification (b) Classification

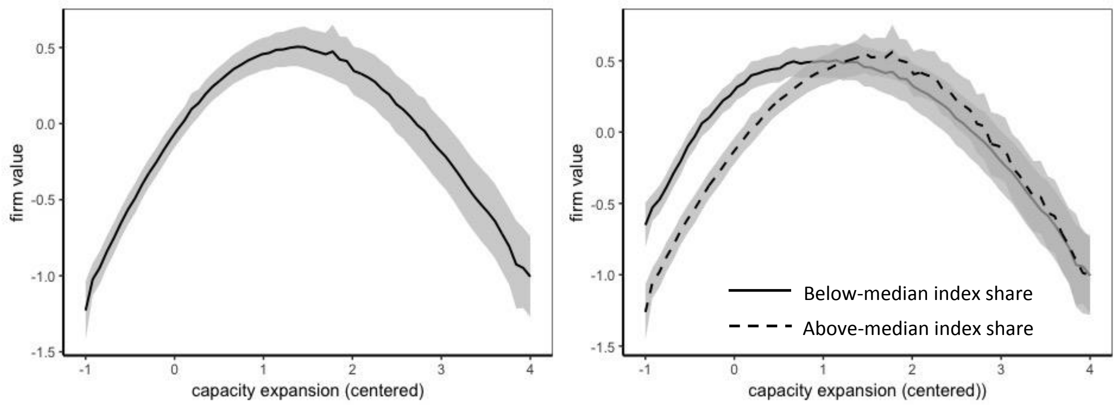
Figure 16 The effect of capacity expansion on stock return

Figure 16 shows the simulated results regarding the impact of capacity expansion on stock return. As illustrated in Figure 16 (a), the relationship is ambiguous, which diverges from the conclusion of Hendricks et al. (1995). One of the possible explanations for this relationship from the perspective of modelling analysis is that when substituting the index share equation that includes the value of capacity expansion into the stock return equation, there exists a square term in solving for the equilibrium stock return. It is thus possible to find more than one value of the stock return for the same amount of capacity expansion, and cause the different relationships between capacity expansion and stock return. Since index share plays an important role in determining the effect of capacity expansion on stock return, it can be classified by the median value to deeply investigate the relationship between capacity expansion and stock return. Figure 16 (b) shows the result of how capacity expansion impacts stock return with the categorisation of index share. Surprisingly, the relationship becomes significantly negative for firms in both groups of index share; but firms that own below-median index shares have greater reactions on the stock returns compared with those firms with above-median index shares when the same amounts of capacity are expanded. This finding indicates that capacity expansion will reduce the stock return with different effects resulting from the index share classification, therefore, a proposition is given by,

Proposition 4. *As a small-index-share firm's capacity expansion increases, its stock return will decrease but have better performance than that with large index share.*

Since the values of both profit and stock return have already been simulated after altering capacity expansion quantities, the performance impact of firm value is also available to be evaluated on the basis of an identity proposed by Chod and Lyandres (2011), $r_{jt} = \frac{\pi_{jt} - V_{jt}}{V_{jt}}$, where V_{jt} is the value of the firm. Solving the above equation for V_{jt}, the firm value is obtained by,

$$V_{jt} = \frac{\pi_{jt}}{1 + r_{jt}}. \tag{101}$$



(a) No classification (b) Classification

Figure 17 The effect of capacity expansion on firm value

The relationship of capacity expansion with firm value is displayed in Figure 17. It is found that with the increase of capacity expansion, the firm value firstly rises and then begins to drop off after reaching its peak, which is similar with the effect on profit. When categorising the firm value with the median of index share, it is noticed that if the same capacities are expanded for both types of firm before they reach the optimal capacity expansion levels, firms with above-median index shares have significantly lower firm values than those with below-median index shares. Conversely, the difference of firm value is less obvious after firms have higher amounts of capacity expansions than their optimal values. It is also consistent with the result in terms of the relationship between capacity expansion and profit under the classification of index share. This reflects a proposition in regard to the firm value of capacity expansion, which is,

Proposition 5. *A firm's profit is more important in determining the value of firm for its capacity expansion compared with the stock return.*

The managerial implication behind these findings is quite appealing, which provides a useful insight for small-index-share firm about the capacity expansion and financial decisions. That is,

Managerial Implication 2. *A firm with small index share can expand capacity within a reasonable range so as to achieve improved performance of profit, stock return, and firm value.*

3.5 Concluding Remarks

This study has investigated firm performance impacts of capacity expansion from both operating and financial perspectives. The simultaneous structure that involves joint decisions of capacity expansion, debt, and stock return is constructed by using a discrete choice model of demand allocation, a supply-side model of capacity expansion with financial constraints, and a capital asset pricing model of stock return. Three main performance outcomes after firm's capacity expansion are measured, which are firm profit, stock return, and firm value, and an empirical case of the semiconductor manufacturing sector is used to empirically evaluate the model. The counterfactual results indicate that the effects of capacity expansion on profit and firm value have similar patterns with an inverse U-shape, which means it increases until it peaks and then decrease with the increasing of the amount of capacity expansion. When using the median of index shares in the sector to classify the performance outcomes of capacity expansion into two groups, it is found that firms with below-median index shares gain significantly higher profits and firm values than those with index shares that are above the median level before their expansions in capacity attain the optimal values. However, the difference in profits and firm values for firms in two groups is less obvious when the amounts of capacity expansions exceed the peak. Contrary to the much received wisdom, capacity expansion has a negative impact on stock return, implying that the increase in capacity expansion may hurt the stock performance in the financial market. However, firms that own below-median index share have remarkably higher stock return than those in the group of above-median index share, which reflects the better financial performance of small-index-share firms.

The findings in this study also provide great managerial implications for operations management; which is, firms that own small index shares is advised to expand more capacities within a suitable range, since the expanded capacities improve the firms' performance by bringing them higher profit, stock return, and firm value, compared with those firms with large index shares. Thus, investing in small-index-share firms is a wise choice for potential entrants in the market. Apart from the appealing managerial implications behind these findings, this study also contributes to the operations-finance interface in several aspects. Firstly, it builds a systematic structure of interactive operational and financial decisions, extending the simple analysis that examines the direct impact of capacity expansion on performance outcomes using reduced regressions, such as the study of Hendricks et al. (1995). Secondly, literature that links operational decision and its performance is advanced by considering firm value to precisely measure the impact, which has been discussed by a few extant studies. To conclude, the research explores in great depth the effects of capacity expansion on both operating and financial performance and provides useful insights into the management practice about the capacity expansion strategy.

However, this study does have some limitations in terms of the relationship between capacity expansion and firm performance, and prospects for further study in this field should also be considered. For example, the fixed cost as a critical expenditure in the process of capacity expansion may affect the decision on expansion level and its performance of the future market. Failure to consider the influence of fixed cost is likely to result in the estimation biases of real operational and financial activities, which is the research concern that requires further investigation. This is discussed in depth in the next chapter.

Chapter 4 The Impacts of Fixed Cost on Capacity Expansion and Supply Chain Coordination

4.1 Introduction

Firms in capital-intensive sectors typically incur large fixed costs associated with the capacity expansions, such as semiconductor, petrochemical, and automobile manufacturers (see Asano 2002, Wu et al. 2005, Yang and Anderson 2014). The great expenditures for new facilities and equipment are required to ramp up firms' capacity levels, reflecting a critical role of fixed cost on determining operational decisions, but few studies have empirically investigated how the fixed cost impacts capacity expansion. However, there indeed exists a close relationship between the fixed cost and capacity expansion decision from the theoretical perspective. For instance, firms with significant fixed costs for expanding their capacities are often forced to fully utilise capacities in productions to realise the clearance strategy (Anderson and Yang 2015, Goyal and Netessine 2007). As a result, the corresponding prices may be reduced below the variable and fixed costs to maintain productions at capacity levels, which adjust supply chain coordination by bringing down firm profits. Moreover, fixed costs may also be considered to deter new entrants due to the high pay-outs for the excess capacities (Rhim et al. 2003). Therefore, applying fixed cost in the empirical capacity expansion is extremely necessary and important in the operations management field.

Although the analytical models regarding fixed cost and capacity expansion are widely considered in much of the operations and supply chain literature (see Chen and Simchi-Levi 2004, Van Mieghem 2003, Yang and Anderson 2014), an empirical challenge in measuring the effect of fixed cost on capacity expansion still exists, which is the discontinuity of fixed cost when capacity expansion occurs. Similar to the fixed ordering cost in inventory theory, the fixed cost associated with capacity expansion may introduce frictions that lead to an increase in the inaction of a firm's optimal policy (e.g., Abel and Eberly 1998), the temporary change of capacity decision (e.g., Dixit 1995, Van Mieghem and Rudi 2002), and the non-differentiable boundary constraint (e.g., Howell and Allenby, 2015). One possible solution to address this issue is to raise the (s, S) policy under the assumption of convex cost and concave profit, but it is still not practically applicable because of the complexity and difficulty in dealing with the additional nonlinearities. Hence, another ingenious method inspired by the literature of Howell and Allenby (2015) is applied to figure out the discontinuity of fixed cost in this chapter. The rationale is to firstly divide the optimisation problem into different sub-problems depending upon whether firms expand capacities or not, and then the optimal solution for each sub-problem is easily solved based on the Lagrangian analysis, which thus achieves the overall optimal decision by finding the best one in sub-problems. This study empirically addresses discontinuous fixed cost by using the second method from an economic view.

To study the impact of fixed cost on capacity expansion and supply chain process, the detailed information of the prospective demand allocation, the price and variable costs on capacity production as well as the historical fixed expenditures on capacity expansion, are required (Ghemawat 1984, Ye and Duenyas 2007). However, in many cases, the complete data set is unlikely to be directly observed and available for the researchers (Gaur et al. 2007). This can particularly occur in the semiconductor manufacturing sector when firms either have different product lines or their new capacities take a long lead time to build (Gaimon and Burgess 2003). Therefore, key proxies, such as sector-based index share and individual-level characteristics (i.e. profit shifters and cost shifters) are used to depict the underlying allocation mechanism of demand and unit profit, while missing data of fixed cost are imputed by using both traditional statistical and machine learning techniques. Applying the advanced statistical approaches to transform unobservable information into indicators that are typically available to the researcher can facilitate and complement the empirical study of fixed cost. Besides, this research only considers the portion of fixed cost related to capacity expansion for each firm in a deterministic setting; this is because expanding capacity is expensive and firms need to spend more than one period in constructing new facilities and equipment (Anderson and Yang 2015, Wu et al. 2005,). In sum, the empirical research of how fixed cost affects capacity expansion is implemented by incorporating index share, firm attributes, portion of fixed cost, and existing capacity expansion quantities.

In this chapter, the importance of fixed cost in determining the capacity expansion and supply chain coordination is discussed. A supply-side model of capacity expansion with the discontinuous fixed cost and a discrete choice model for demand allocation are proposed to investigate this issue in depth. The financial constraint in the model is calibrated using cash outflows including fixed and variable costs as well as debt repayment, and cash inflows that account for the contribution from both capacity expansion and financial market. Besides, the Bayesian approach along with semiconductor data are used to empirically estimate the model coefficients; and models with and without considering fixed costs are compared. In order to impute the missing data of fixed cost, I compare eight different methods and pick the one with the lowest RMSE. The counterfactual analyses are conducted by altering the value of fixed cost. It is found that a firm's optimal capacity expansion level is nearly invariable at first and then increases rapidly with a rise of fixed cost, while there are two inflection points for the negative relationship between fixed cost and firm profit, where the first one is due to the change of capacity expansion and the second one occurs when demand is equal to the capacity level. This reflects the significant impact of fixed cost on both capacity expansion and firm profit. The counterfactual results also show that if suppliers of facilities and equipment decrease (increase) their profits by reducing (raising) fixed costs of downstream firms that expand capacities, those firms with large expansion planning would obtain higher (lower) profit, which can be used to negotiate with their upstream suppliers. This is a kind of supply chain coordination.

This study contributes to the operations theory and practice in three ways. First, the capacity expansion model is extended using a financial link between cash inflows and cash outflows to construct the boundary constraint that accounts for firm's fixed cost, which solves the discontinuity in fixed cost based on an economic framework. It advances the theoretical literature of fixed cost and capacity expansion by considering both operational decisions and financial matters. Second, the Bayesian method is used to empirically examine the model for firms in the semiconductor manufacturing sector, which have better model fit compared with the model without allowing for fixed cost. The results confirm the important role of fixed cost on the capacity expansion from a practical viewpoint. Third, the counterfactual analyses reflect the important managerial implication, which is that firms with large capacity expansions are able to negotiate with their upstream suppliers by adjusting fixed costs, so as to achieve win-win for supply chain partners. To conclude, models and empirical plural in this chapter deeply discuss the impact of fixed cost on capacity expansion and supply chain coordination, and complement the literature on operational research by considering discontinuous fixed costs in empirical capacity expansion studies.

4.2 Model Development

A systematic framework that considers the impact of fixed cost on capacity expansion is built with both supply-side model of capacity expansion and heterogeneous demand allocation specification in this section. The discontinuous fixed cost influences firm profit and financial constraint in the capacity expansion model from the operational and financial perspectives, where the relationship between cash inflows and outflows provides an insight into the construction of financial constraint. That is, the firm is supposed to acquire more cash flows from different sources – such as the contribution realised by capacity production and other financial income – than the payment for variable and fixed costs as well as debt. In addition, the identification of demand allocation has already been discussed in section 2.2.1 and will not be specified again in this chapter.

When allowing for fixed cost in the capacity expansion decision, the amount of capacity for each firm can be evaluated through its profit maximisation with a discontinuous financial constraint under the demand uncertainty. Consider a financial constraint that is constituted by a firm's cash outflows and inflows. That is, cash outflows of a firm composed of fixed cost, production expenditure along with the debt repayment should be less than its cash inflows, which are made up of the contribution from capacity expansion and other incomes. Suppose that firm j ($\in \{1,..,J_t\} \equiv L(J_t)$) in a sector decides its own optimal capacity plan at period t ($\in \{1,..,T\} \equiv L(\mathrm{T})$), where $L(\cdot)$ is an integer set from 1 to any positive integer $(\cdot)$. The firm j's profit at period t with a financial constraint is then formulated by,

$$\max \quad u_{jt}\mathrm{E}\big[\min\big(w_{jt}, k_{jt}\big)\big] - c_{jt}k_{jt} - \delta A_{jt}\mathrm{I}\big(\Delta k_{jt} > 0\big), \tag{102}$$

$$\text{s.t.} \quad \delta A_{jt}\mathrm{I}\big(\Delta k_{jt} > 0\big) + c_{jt}k_{jt} + d_{jt} \le h_{jt}k_{jt} + o_{jt}, \tag{103}$$

where k_{jt} is the capacity level and w_{jt} is the firm-specific demand. The production level is assumed to equal the amount of capacity, reflecting that the firm can fully utilise its capacity for production, which is reasonable, especially in the semiconductor manufacturing sector. The parameter u_{jt} and c_{jt} are price and unit production cost of firm j at period t, respectively. A_{jt} is the fixed cost if firms expand their capacities, and δ is the percentage of fixed cost paid by firm j at period t, where $0 < \delta \le 1$. Let Δk_{jt} stand for the capacity expansion amount, and $\mathrm{I}(\cdot)$ denote an indicator function that is equal to 1 when $\Delta k_{jt} > 0$, and 0 otherwise. This induces a discontinuity with a gap between no expansion and capacity expansion. d_{jt} is the debt level that should be repaid by firm j at period t. h_{jt} reflects the unit cash inflow obtained from capacity decision, and o_{jt} refers to other incomes in the cash inflows, which is specified by a linear function of index share and financial characteristics, $o_{jt} = g_1 p_{jt} + \mathbf{z}_{jt}\mathbf{g}_2$, where g_1 and $\mathbf{g}_2$ are parameters in other incomes. Taking index share into consideration is due to the fact that other incomes can also be obtained from financial activities, which is under the influence of index share.

Remark 1: The unit cash inflow of capacity h_{jt} has its maximised value of price u_{jt} when demand is good enough to exceed capacity planning, $w_{jt} > k_{jt}$, while h_{jt} cannot be lower than the unit production cost c_{jt} to ensure the benefit of capacity level. Thus, $c_{jt} < h_{jt} \le u_{jt}$.

To solve the profit maximisation problem with the discontinuity in fixed cost, two sub-problems are defined by dividing the constraint into patterns with different fixed cost values, which are A_{jt} when $\Delta k_{jt} > 0$ and 0 when $\Delta k_{jt} = 0$. They are specified as,

$$\begin{aligned} &\max \quad u_{jt}\mathrm{E}\big[\min\big(w_{jt}, k_{jt}\big)\big] - c_{jt}k_{jt} - \delta A_{jt}, \\ &\text{s.t.} \quad \delta A_{jt} + c_{jt}k_{jt} + d_{jt} \le h_{jt}k_{jt} + o_{jt}, \qquad \text{when } \Delta k_{jt} > 0 \\ &\max \quad u_{jt}\mathrm{E}\big[\min\big(w_{jt}, k_{jt}\big)\big] - c_{jt}k_{jt}, \\ &\text{s.t.} \quad c_{jt}k_{jt} + d_{jt} \le h_{jt}k_{jt} + o_{jt}. \qquad \text{when } \Delta k_{jt} = 0 \end{aligned}$$

This shows that the optimal capacity policy in each sub-problem is now determined by the continuous and concave profit function along with financial constraint. To solve for the optimal solution of each sub-problem, the firm-level demand w_{jt} is assumed to follow the lognormal distribution with p.d.f. ϕ_{jt} and c.d.f. $\mathbf{\Phi}_{\mathrm{jt}}$, $w_{jt} \sim LN(\mu_{jt}, \tau)$, where μ_{jt} is the firm-specific mean demand that is related to the index share p_{jt} and sales predictors $\mathbf{q}_{jt}$, and τ is the standard deviation of lognormal distribution. Here, the form used to specify the mean demand μ_{jt} varies, and a linear function is chosen for the reason of model simplification, which is $\mu_{jt} = \mu_1 p_{jt} + \mathbf{q}_{jt}\boldsymbol{\mu}_2$, where μ_1 and $\boldsymbol{\mu}_2$ are parameters in the mean demand. By using the Lagrangian and Karush-Kuhn-Tucker first-order conditions, the optimal capacity decisions for both sub-problems are,

$$k_{jt}^1 = \max\left(\mathbf{\Phi}_{jt}^{-1}\left(\frac{u_{jt} - c_{jt}}{u_{jt}}\right), \frac{\delta A_{jt} + d_{jt} - (g_1 p_{jt} + \mathbf{z}_{jt}\mathbf{g}_2)}{h_{jt} - c_{jt}}\right), \quad \text{when } \Delta k_{jt} > 0 \quad (104)$$

$$k_{jt}^2 = \max\left(\mathbf{\Phi}_{jt}^{-1}\left(\frac{u_{jt} - c_{jt}}{u_{jt}}\right), \frac{d_{jt} - (g_1 p_{jt} + \mathbf{z}_{jt}\mathbf{g}_2)}{h_{jt} - c_{jt}}\right), \quad \text{when } \Delta k_{jt} = 0 \quad (105)$$

where, $\mathbf{\Phi}_{jt}^{-1}\left(\frac{u_{jt} - c_{jt}}{u_{jt}}\right) = (\mu_1 p_{jt} + \mathbf{q}_{jt}\boldsymbol{\mu}_2) \times \exp\left(\tau \mathbf{Z}^{-1}\left(\frac{u_{jt} - c_{jt}}{u_{jt}}\right)\right)$.

The optimal capacity level for the overall profit maximisation problem is, therefore,

$$k_{jt}^* = \{k_{jt}^1, k_{jt}^2\}. \quad (106)$$

To simplify the model without loss of generality, the unit profit margin of firm j at period t is assumed to be the function of a set of observed profit shifters, $\mathbf{w}_{jt}$, which is defined as $(u_{jt} - c_{jt})/u_{jt} = \exp(\mathbf{w}_{jt}\boldsymbol{\gamma})/(1 + \exp(\mathbf{w}_{jt}\boldsymbol{\gamma}))$, where $\boldsymbol{\gamma}$ is a parameter vector of profit shifters. The reason for using a specific form $\exp(\cdot)/(\mathbf{1} + \exp(\cdot))$ is due to the property of $\mathbf{Z}^{-1}(\cdot)$ that inputs of distribution are restricted to be in the unit interval (0, 1]. Besides, assuming that the unit contribution from capacity after deducting the unit production cost $h_{jt} - c_{jt}$ is an exponential linear function with the observed features in terms of unit profits $\mathbf{s}_{jt}$ in order to ensure a positive value, which is $\exp(\mathbf{s}_{jt}\boldsymbol{\rho})$, where $\boldsymbol{\rho}$ is a vector of parameters for unit profits.

The capacity expansion level is typically observed with an error. In the light of this, the true value of capacity expansion Δk_{jt} is set to be composed by an estimated capacity expansion level $k_{jt}^* - k_{j,t-1}$ and an unobserved component η_{jt}. The term $k_{jt}^* - k_{j,t-1}$ is the difference between the optimal amount of capacity and the capacity value in the last period, where $k_{j,t-1}$is supposed to be ι per cent of the observable last-period asset, $a_{j,t-1}$. Thus, the capacity expansion equation is,

$$\Delta k_{jt} = k_{jt}^{*} - \iota a_{j,t-1} + \eta_{jt}. \tag{107}$$

4.3 Statistical Specification

It is noticed that η_{jt} is a function of debt repayment d_{jt}, sales forecasts $\mathbf{q}_{jt}$, profit shifters $\mathbf{w}_{jt}$, financial characteristics $\mathbf{z}_{jt}$, unit profits $\mathbf{s}_{jt}$, last-period asset A_{jt}, parameter vector in the capacity expansion equation, $\boldsymbol{\varphi} = (\mu_1, \boldsymbol{\mu}_2, \iota, \boldsymbol{\gamma}, g_1, \mathbf{g}_2, \delta, \boldsymbol{\rho})'$, along with covariates and coefficients in the index share function, $(\delta_{jt}, \mathbf{X}_{jt}, \boldsymbol{\Sigma}_\alpha)$. Specifically, the mean utility δ_{jt} used to capture index share is computed by $p_{jt}^{-1}(P_{jt}, \mathbf{X}_{jt}; \boldsymbol{\Sigma}_\alpha)$ through applying the BLP Contraction Mapping, which is proposed by Berry et al. (1995), where P_{jt} is the observed index share of firm j at period t. When $\mathbf{Y}_{jt}$ is set to be a matrix of $(d_{jt}, \mathbf{q}_{jt}, \mathbf{w}_{jt}, \mathbf{z}_{jt}, \mathbf{s}_{jt}, A_{jt})$, the function of error in the capacity expansion equation can then be written as,

$$\eta_{jt}(\Delta k_{jt} | \mathbf{Y}_{jt}, \boldsymbol{\varphi}, P_{jt}, \mathbf{X}_{jt}, \boldsymbol{\Sigma}_\alpha) = \tag{108}$$

$$\begin{cases} \Delta k_{jt} - \max\left(\boldsymbol{\Phi}_{jt}^{-1}\left(\frac{\exp(\mathbf{w}_{jt}\boldsymbol{\gamma})}{1+\exp(\mathbf{w}_{jt}\boldsymbol{\gamma})}\right), \frac{\delta A_{jt} + d_{jt} - (g_1 p_{jt} + \mathbf{z}_{jt}\mathbf{g}_2)}{\exp(\mathbf{s}_{jt}\boldsymbol{\rho})} \right) + \iota a_{j,t-1} & \text{when } \Delta k_{jt} > 0 \\ \Delta k_{jt} - \max\left(\boldsymbol{\Phi}_{jt}^{-1}\left(\frac{\exp(\mathbf{w}_{jt}\boldsymbol{\gamma})}{1+\exp(\mathbf{w}_{jt}\boldsymbol{\gamma})}\right), \frac{d_{jt} - (g_1 p_{jt} + \mathbf{z}_{jt}\mathbf{g}_2)}{\exp(\mathbf{s}_{jt}\boldsymbol{\rho})} \right) + \iota a_{j,t-1} & \text{when } \Delta k_{jt} = 0 \end{cases},$$

where, $\boldsymbol{\Phi}_{jt}^{-1}\left(\frac{\exp(\mathbf{w}_{jt}\boldsymbol{\gamma})}{1+\exp(\mathbf{w}_{jt}\boldsymbol{\gamma})}\right) = (\mu_1 p_{jt} + \mathbf{q}_{jt}\boldsymbol{\mu}_2) \times \exp\left(\tau Z^{-1}\left(\frac{\exp(\mathbf{w}_{jt}\boldsymbol{\gamma})}{1+\exp(\mathbf{w}_{jt}\boldsymbol{\gamma})}\right)\right)$.

4.3.1 Likelihood

To specify the likelihood, the error η_{jt} in the capacity expansion equation and demand shock ξ_{jt} in the utility function are assumed to be independently drawn from normal distributions with zero means and identical variances, which are specified as,

$$\eta_{jt} \sim N(0, \sigma_s^2), \tag{109}$$

$$\xi_{jt} \sim N(0, \sigma_d^2), \tag{110}$$

where σ_s^2 is the variance of η_{jt} and σ_d^2 is the variance of ξ_{jt}.

The densities of capacity expansion and index share at period t are thus,

$$\pi_1(\Delta\mathbf{k}_t|\mathbf{Y}_t, \boldsymbol{\varphi}, \mathbf{P}_t, \mathbf{X}_t, \boldsymbol{\Sigma}_\alpha, \sigma_s^2) = J_{(\boldsymbol{\eta}_t \to \Delta\mathbf{k}_t)} \prod_{j=1}^{J_t} \phi_s\big(\eta_{jt}\big(\Delta k_{jt}\big|\mathbf{Y}_{jt}, \boldsymbol{\varphi}, P_{jt}, \mathbf{X}_{jt}, \boldsymbol{\Sigma}_\alpha\big)\big|\sigma_s^2\big), \quad (111)$$

$$\pi_2\big(\mathbf{P}_t|\mathbf{X}_t, \overline{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha, \sigma_d^2\big) = \big(J_{(\mathbf{P}_t \to \boldsymbol{\xi}_t)}\big)^{-1} \prod_{j=1}^{J_t} \phi_d\big(\big(p_{jt}^{-1}\big(P_{jt}, \mathbf{X}_{jt}; \boldsymbol{\Sigma}_\alpha\big) - \mathbf{X}_{jt}\overline{\boldsymbol{\alpha}}\big)\big|\sigma_d^2\big), \quad (112)$$

where the density of index share is consistent with that in equation (13) as the models of demand allocation are the same for both research studies, which is specified in section 2.2.1. $\Delta\mathbf{k}_t = \big(\Delta k_{1t}, \dots, \Delta k_{J_t t}\big)'$ and $\mathbf{P}_t = (P_{1t}, \dots, P_{J_t t})'$ are observed capacity expansions and index shares at period t. $\mathbf{Y}_t = \big(\mathbf{Y}_{1t}', \dots, \mathbf{Y}_{J_t t}'\big)'$ and $\mathbf{X}_t = \big(\mathbf{X}_{1t}', \dots, \mathbf{X}_{J_t t}'\big)'$ are a set of covariates that include debt levels, sales forecasts, profit shifters, financial characteristics, unit profits, last-period assets, and firm features, respectively. $\boldsymbol{\varphi}, \sigma_s^2, \overline{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha$, and σ_d^2 are parameter vectors that are required to be estimated in the model. ϕ_s and ϕ_d are normal densities of η_{jt} and ξ_{jt} . $J_{(\boldsymbol{\eta}_t \to \Delta\mathbf{k}_t)}$ and $J_{(\mathbf{P}_t \to \boldsymbol{\xi}_t)}$ are the determinants of Jacobian matrices used to transform from $\boldsymbol{\eta}_t$ to $\Delta\mathbf{k}_t$ and from $\mathbf{P}_t$ to $\boldsymbol{\xi}_t$, where $\boldsymbol{\eta}_t = (\eta_{1t,} \dots, \eta_{J_t t})'$, $\boldsymbol{\xi}_t = (\xi_{1t}, \dots \xi_{J_t t})'$. The detailed calculations of these determinants are illustrated in Appendix N.

Therefore, the likelihood for all parameters is given by,

$$L\big(\boldsymbol{\varphi}, \sigma_s^2, \overline{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha, \sigma_d^2\big) = \prod_{t=1}^{T} \Big(\pi_1(\Delta\mathbf{k}_t|\mathbf{Y}_t, \boldsymbol{\varphi}, \mathbf{P}_t, \mathbf{X}_t, \boldsymbol{\Sigma}_\alpha, \sigma_s^2) \times \pi_2\big(\mathbf{P}_t|\mathbf{X}_t, \overline{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha, \sigma_d^2\big)\Big). \quad (113)$$

4.3.2 Estimation

To conduct the Bayesian estimation, the independent priors of $\boldsymbol{\varphi}, \sigma_s^2, \overline{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha$, and σ_d^2 are,

$$\boldsymbol{\varphi} \sim N\big(\overline{\boldsymbol{\varphi}}, \mathbf{V}_\varphi^{-1}\big), \quad (114)$$

$$\sigma_s^2 \sim v_{s0} s_{s0}^2 / \chi_{v_{s0}}^2, \quad (115)$$

$$\overline{\boldsymbol{\alpha}} \sim N\big(\overline{\overline{\boldsymbol{\alpha}}}, \mathbf{V}_{\overline{\alpha}}^{-1}\big), \quad (116)$$

$$\theta_{jl} \sim N\left(0, \sigma_{\theta_{jl}}^2\right), \quad (117)$$

$$\sigma_d^2 \sim v_{d0} s_{d0}^2 / \chi_{v_{d0}}^2, \quad (118)$$

where $\boldsymbol{\Sigma}_\alpha$ is a Cholesky decomposition of the form with element θ_{jl} for $j, l = 1, \dots, R, j < l$,

$$\boldsymbol{\Sigma}_\alpha = U'U \text{ for } U = \begin{bmatrix} e^{\theta_{11}} & \dots & \theta_{1R} \\ \vdots & \ddots & \vdots \\ 0 & \dots & e^{\theta_{RR}} \end{bmatrix}, \tag{119}$$

which is consistent with the prior setting in Chapter 2.

The joint posterior is thus specified as,

$$\pi\left(\boldsymbol{\varphi}, \sigma_s^2, \overline{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha, \sigma_d^2 \middle| \{\Delta\mathbf{k}_t, \mathbf{P}_t,\}_{t=1}^T\right) \propto L\left(\boldsymbol{\varphi}, \sigma_s^2, \overline{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha, \sigma_d^2\right) \times \pi\left(\boldsymbol{\varphi}, \sigma_s^2, \overline{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha, \sigma_d^2\right), \tag{120}$$

where $\pi\left(\boldsymbol{\varphi}, \sigma_s^2, \overline{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha, \sigma_d^2\right)$ is the product of individual priors, $\pi(\boldsymbol{\varphi})$, $\pi(\sigma_s^2)$, $\pi(\overline{\boldsymbol{\alpha}})$, $\pi(\boldsymbol{\theta})$, and $\pi\left(\sigma_d^2\right)$. $\boldsymbol{\theta} = (\theta_{11}, \dots, \theta_{jl}, \dots, \theta_{RR})'$ is the vector of elements in Cholesky root for $\boldsymbol{\Sigma}_\alpha$.

The conditionals of parameters used to implement the MCMC algorithm are,

$$\boldsymbol{\varphi}|\sigma_s^2, \boldsymbol{\theta} \qquad \text{parameters in capacity expansion eqation,} \tag{121}$$

$$\sigma_s^2|\boldsymbol{\varphi} \qquad \text{variance of errors in capacity expansion eqation,} \tag{122}$$

$$\overline{\boldsymbol{\alpha}}|\boldsymbol{\theta}, \sigma_d^2 \qquad \text{mean of heterogeneity in index share eqation,} \tag{123}$$

$$\boldsymbol{\theta}|\boldsymbol{\varphi}, \overline{\boldsymbol{\alpha}}, \sigma_d^2 \qquad \text{covariance of heterogeneity in index share eqation,} \tag{124}$$

$$\sigma_d^2|\overline{\boldsymbol{\alpha}}, \boldsymbol{\theta} \qquad \text{variance of error in index share eqation,} \tag{125}$$

The draws for $\boldsymbol{\varphi}$ and $\boldsymbol{\theta}$ are accomplished by using the RW Metropolis algorithm, respectively, and the parameter σ_s^2 is drawn from the inverted gamma distribution. Moreover, the conditional draws for $\overline{\boldsymbol{\alpha}}$ and σ_d^2 can be conducted with the use of a pure Gibbs sampler based on the standard natural conjugate Bayes analysis, as they are parameters in an univariate regression when mean utility δ_{jt} is computed by the BLP Contraction Mapping with a given $\boldsymbol{\theta}$. The detailed draws of parameters are provided in Appendix O.

The DAG for the model is displayed by,

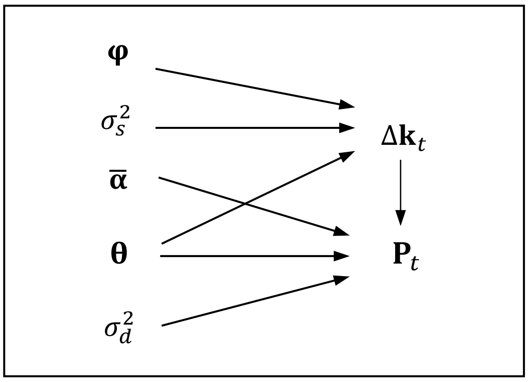


Figure 18 The DAG for the model

4.3.3 Simulation Study

To simulate the models regarding the effect of fixed cost on capacity expansion, a Monte Carlo test is conducted. The process of simulated data generation is similar to what I have employed in Chapters 2 and 3. The sample size is $I = 50$ investors and $J = 15$ firms per period in a sector for a total periods of $T = 3$. Each firm is assumed to have $nA = 3$ firm attributes $\mathbf{x}_{jt}$, $nQ = 3$ sale predictors $\mathbf{q}_{jt}$, $nW = 3$ profit shifters $\mathbf{w}_{jt}$, $nZ = 3$ financial characteristics $\mathbf{z}_{jt}$, and $nS = 3$ unit profits $\mathbf{s}_{jt}$, which are simulated based on the covariance matrices specified in equations (31), (34), (35), (56), and (57). In addition, values of stock return and debt for firm j at period t are simulated by the i.i.d. uniform draws.

The settings of parameters in models are as follow. Mean $\bar{\boldsymbol{\alpha}}$ and covariance matrix $\boldsymbol{\Sigma}_{\alpha}$ for random coefficients $\boldsymbol{\alpha}_i$ (an intercept, $nA = 3$ attributes, stock return, capacity expansion, and debt) is provided in equations (32) and (33). The variance of error in the index share equation is set to be the same as that in the capacity expansion equation, which is a very small value of 0.01. Moreover, the parameter vector in both capacity expansion and debt equations $\boldsymbol{\varphi}$ is given by,

$$\boldsymbol{\varphi} = (0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.1, 0.5, 0.2, 0.1, 0.1, -0.1, 0.6, 0.1, 0.1, -0.1). \quad (126)$$

When covariates and parameters are given, values of endogenous capacity expansion and index share are then able to be computed based on models. It is noticed that the standard deviation of demand distribution τ is restricted to a fixed value of 1 for addressing the identification in the capacity expansion equation. In addition, a method of SQUAREM is applied to implement the BLP Contraction Mapping with the convergence tolerance of 10^{-10} for calculating the mean demand in the index share equation.

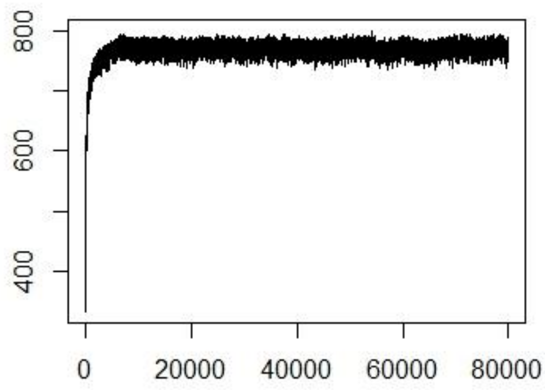


Figure 19 Values of the posterior log-likelihood

In the simulation study, a total of 80,000 posterior draws are taken and the Markov chain rapidly burns in after 4,000 iterations. Convergence is evaluated by inspecting a sequence plot of posterior outputs, which is suggested by Rossi et al. (2012). Values of the posterior log-likelihood are shown in Figure 19, which remains stable after convergence.

Draws upon convergence are used to estimate the means and standard errors of the model parameters, and results of the RMSE and bias for each coefficient are provided in Table 10. It is found that all estimations are extremely close to true values with low standard errors, RMSEs, and biases. These results verify the high accuracy and significant efficiency of the model by using the Bayesian approach.

Table 10 Posterior means, standards errors, RMSEs, and biases of parameters

Parameter	Variable	True	Mean	RMSE	Bias
φ	Fixed Cost	0.6	0.5538 (0.0210)	0.0507	-0.0462
	Index Share	0.1	0.1002 (0.0615)	0.0615	0.0002
	Sales Forecasts	0.1	0.1031 (0.0062)	0.0069	0.0031
		0.1	0.1109 (0.0079)	0.0135	0.0109
		0.1	0.0864 (0.0039)	0.0141	-0.0136
	Profit Margins	0.1	0.0965 (0.0076)	0.0084	-0.0035
		0.1	0.1442 (0.0127)	0.0460	0.0442
		0.1	0.0918 (0.0108)	0.0136	-0.0082
	Index Share	0.2	0.1559 (0.0147)	0.0465	-0.0441
	Financial Characteristics	0.1	0.1114 (0.0141)	0.0181	0.0114

		0.1	0.0970 (0.0126)	0.0130	-0.0030
		-0.1	-0.0817 (0.0073)	0.0197	0.0183
	Unit Profits	0.1	0.1031 (0.0157)	0.0160	0.0031
		0.1	0.0670 (0.0228)	0.0401	-0.0330
		-0.1	-0.1042 (0.0134)	0.0140	-0.0042
	Last-Period Asset	0.5	0.4405 (0.0138)	0.0611	-0.0595
σ_s^2	Error in Capacity Expansion Equation	0.01	0.0086 (0.0014)	0.0020	-0.0014
$\overline{\boldsymbol{\alpha}}$	Firm Attributes	-2	-2.0055 (0.0408)	0.0412	-0.0055
		-3	-3.0104 (0.0428)	0.0440	-0.0104
		-4	-4.0116 (0.0583)	0.0594	-0.0116
	Stock Return	-5	-5.0091 (0.0391)	0.0401	-0.0091
	Capacity Expansion	-6	-6.0112 (0.0362)	0.0379	-0.0112
	Leverage Ratio	-7	-6.9964 (0.0474)	0.0475	0.0036
$\boldsymbol{\Sigma_\alpha}$	Firm Attributes	3	2.9893 (0.0647)	0.0656	-0.0107
		4	4.0456	0.0847	0.0456

			(0.0714)		
		4	4.0245 (0.0887)	0.0920	0.0245
	Stock Return	3	2.8211 (0.1598)	0.2399	-0.1789
	Capacity Expansion	2	2.0275 (0.0963)	0.1001	0.0275
	Leverage Ratio	5	5.0666 (0.1851)	0.1967	0.0666
σ_d^2	Error in Index Share Equation	0.01	0.0105 (0.0017)	0.0018	0.0005

4.4 Empirical Application

In this section, empirical evidence derived from data in the semiconductor manufacturing sector is used to examine the impact of fixed cost on capacity expansion. The estimate results of models with and without considering fixed cost are compared based on different measuring criteria, and counterfactual analyses are conducted to obtain managerial implications of fixed cost in empirical capacity expansion and supply chain coordination.

4.4.1 Data

To empirically investigate how fixed cost affects capacity expansion, data in the semiconductor manufacturing sector are applied to test the model. The sample covers 64 US-listed firms that design, manufacture, pack, and sell semiconductors in the SOX, such as Intel, Texas Instruments, Micron Technology, and On Semiconductor, during the periods of 2006 to 2010. Two main variables, capacity expansion and fixed cost, are obtained from the World Feb Watch reports provided by the Industry Research and Statistics department of Semiconductor Equipment and Materials International. Other data used for the analysis involve index shares, stock returns, debt repayments, firm attributes, sales forecasts, profit shifters, financial characteristics, and unit profits.

Specifically, firm size, strategic holdings, asset efficiency, ROA, and inventory turnover are chosen to estimate firm attributes. Financial activities, book value per share, gross margin, and inventory are used to forecast sales in firm level, and financial characteristics are measured by inventory/asset ratio, B/M ratio, cash flow margin, and slack resources. Moreover, EPS and earnings before interest, taxes, depreciation and amortisation (EBITDA)/sales ratio are regarded as proxies of profit shifters, while COGS/asset ratio and sales per share are used to evaluate cost shifters. The detailed descriptions of variable definitions are specified in Appendix P.

In this empirical case, the amounts of capacity expansions are defined as the maximum planned wafers that firms could produce if fab equipment was fully utilised, and fixed costs are made up of equipment cost and constitution cost. There are three primary features of data with respect to capacity expansion and fixed cost. The first behaviour is the presence of a large proportion of firms without capacity expansions, while firms that require additional capacities usually expand significantly, leading to a huge gap between no expansion and massive expansions. The same situation occurs in the data of fixed cost because capacity expansions are expensive and firms incur fixed costs when expanding their capacities. Table 11 displays the distribution of both capacity expansion and fixed cost. As shown in the table, fewer than 25% firms in the SOX index fund expanded capacities and paid for their fixed costs each year, indicating that the majority of capacity expansion and fixed cost quantities observed in the data are zeros. Besides, mean values and variances of both variables are quite large. This reflects that once firms have capacity expansion plans, they intend to expand a great deal with large amounts of expenditures for fixed costs. To control the variations of capacity expansion and fixed cost, I normalise them with standard normal distributions, and the smoothness of variables then increases.

Table 11 Distributions of capacity expansion and fixed cost

Panel A: Capacity Expansion						
Year	Percentage	Mean	Std.Dev.	Minimum	Median	Maximum
2006	13.726%	35125.607	49724.426	1573.000	25000.000	142000.000
2007	6.818%	71666.667	86875.749	1250.000	45000.000	168750.000
2008	10.526%	93234.375	82670.425	3000.000	72468.750	225000.000
2009	10.638%	24623.127	16310.732	10000.000	20000.000	46115.635
2010	22.222%	124770.833	106226.186	11875.000	117000.000	274500.000
Panel B: Fixed Cost						
Year	Percentage	Mean	Std.Dev.	Minimum	Median	Maximum
2006	11.765%	727.810	878.613	31.429	326.214	1995.000
2007	6.818%	1446.333	1260.278	4.000	2000.000	2335.000
2008	5.263%	4382.500	1282.500	3100.000	4382.500	5665.000

2009	8.511%	307.563	133.596	197.000	266.625	500.000
2010	22.222%	2881.987	2423.191	90.000	3379.090	6475.000

Notes: Percentage is the ratio of firms with capacity expansion to total firms, and the fixed cost is in US$ millions.

The second feature of data is the presence of missing values in fixed cost. It is noticed from Table 11 that the portion of firms with capacity expansion in panel A is not equal to the corresponding ratio of firms incurring fixed costs in panel B, reflecting that there exists the lack of data in fixed cost. To address this issue, a prediction method is used to estimate the missing fixed costs, which is chosen from six conventional methods and two decision tree approaches including mean values (mean), ordinary least squares (ols), partial least squares (pls), standard principal component regression (pcr), lasso regression (lasso), and ridge regression (ridge), as well as recursive partitioning (rpart) and randomForest (rfot). Since firm-level characteristics are commonly used to explain the variation in fixed cost in the empirical setting, the predictor variables that have high correlations with fixed cost are selected to match the observed values of fixed costs, so as to obtain the marginal predictions for the missing fixed costs. The RMSEs of eight prediction methods are calculated using 200 repetitions of fivefold cross-validation, and it is found that the randomForest specification has the best prediction for fixed cost. As specified in Table 12, the randomForest approach has the highest number of times for the lowest RMSE, which is 843 times and occupies 20.7% over all methods. I thus use randomForest to predict the missing values of fixed costs.

Table 12 Frequency of each method having the lowest RMSE

	mean	ols	pls	pcr	lasso	ridge	rpart	rfot
Numbers	236	587	600	522	507	640	265	843
Percentages	5.62%	13.98%	14.29%	12.43%	12.07%	15.24%	6.31%	20.07%

The third characteristics of data set used is the positive correlation between capacity expansion and fixed cost, which is presented in Figure 20. It shows that with the increases of capacity expansions, the amounts of fixed costs also increase. When a smooth line is added into the plot, a significant positive relationship of capacity expansion with fixed cost is shown. This finding is quite common in the semiconductor manufacturing sector as a firm’s ability to pay for a new wafer fab or piece of equipment determines its capacity expansion level. This suggests that fixed cost may serve to boost the value of the corner solution of capacity expansion by influencing boundary constraint so that firm chooses the corner solution rather than interior solution as its optimal capacity expansion level.

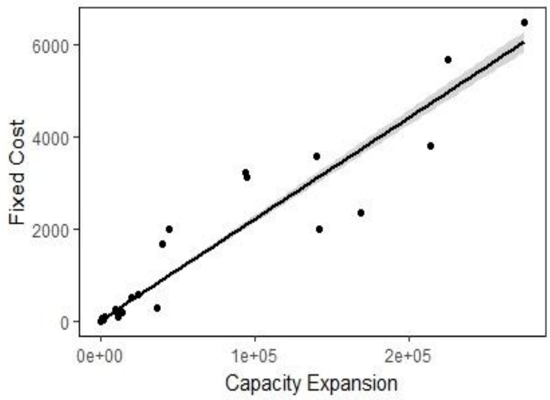


Figure 20 The relationship of capacity expansion with fixed cost of observed data

The descriptive statistics and correlation matrices of other variables are presented in Table 13. It is found that variables in firm attributes, sales forecasts, firm characteristics, profit shifters, and unit profits are comparatively independent with each other.

Table 13 Summary statistics

Panel A: Descriptive Statistics					
Variable	Mean	Median	Std.Dev.	Maximum	Minimum
Stock Return	0.1322	-0.0248	0.7245	4.2114	-0.8634
Leverage Ratio	0.1365	0.0336	0.2225	1.4202	0.0000
Firm Size	3.5676	3.5563	0.5367	4.9736	2.3404
Strategic Holdings	0.2308	0.2000	0.1574	0.8100	0.0000
Asset Efficiency	0.6991	0.6950	0.2196	1.3201	0.2070
ROA	0.0936	0.0999	0.1703	0.8285	-0.8571
Inventory Turnover	3.9874	3.6815	1.8335	13.3309	0.8089
Financial Activities	0.0386	0.0235	0.0598	0.5630	0.0000
Book Value per Share	8.6174	7.5125	7.8986	83.6645	-3.0827
Gross Margin	0.5449	0.5331	0.1136	0.8270	0.2397
Inventory	11.9355	11.8059	1.2569	15.2774	9.5455
Inventory/Asset Ratio	0.0910	0.0795	0.0474	0.2901	0.0164
B/M Ratio	0.5195	0.4136	0.4393	3.9700	-0.1423
Cash Flow Margin	0.2152	0.2086	0.1191	0.5801	-0.3704
Slack Resources	5.9223	5.8645	0.4773	7.3994	4.8415

EPS	0.7545	0.6100	0.8163	6.5500	0.0000
EBITDA/Sales Ratio	0.1734	0.2140	0.2461	0.6094	-1.4171
COGS / Asset Ratio	0.3230	0.3092	0.1433	0.7930	0.0795
Sales per Share	8.1410	6.3680	8.9092	119.8570	0.3490

Panel B: Correlation Matrices

	FS	SH	AE	ROA	IT
Firm Size	1.0000	-0.1367	0.2665	-0.0343	0.1295
Strategic Holdings		1.0000	-0.0693	0.0653	0.1395
Asset Efficiency			1.0000	0.2185	0.2467
ROA				1.0000	-0.0422
Inventory Turnover					1.0000
	FA	BVPS	GM	IN	
Financial Activities	1.0000	0.2906	0.0445	-0.1609	
Book Value per Share		1.0000	-0.1686	0.0009	
Gross Margin			1.0000	-0.2181	
Inventory				1.0000	
	I/A	B/M	CFM	SR	
Inventory/Asset Ratio	1.0000	-0.0198	-0.3187	-0.0952	
B/M Ratio		1.0000	-0.2514	-0.0947	
Cash Flow Margin			1.0000	0.2246	
Slack Resources				1.0000	
	EPS	E/S			
EPS	1.0000	0.2022			
EBITDA/Sales Ratio		1.0000			
	C/A	SPS			
COGS / Asset Ratio	1.0000	0.3043			
Sales per Share		1.0000			

4.4.2 Estimates

This empirical study runs 140,000 iterations and achieves means and standard errors of model parameters by using draws after chains burn in. The results are specified in Table 14.

It is noticed that 69.12% of fixed cost is used to estimate the capacity level, which increases the possibility of choosing the corner solution as the optimal capacity decision due to the influence of fixed cost on the budget constraint. This result reflects the importance of fixed cost in determining the capacity expansion. Moreover, the parameter of index share in the mean demand is estimated with a negative value, meaning that when a firm's share in the index increases, less mean demand is required and the firm may expand less capacity so as to realise the optimal capacity level. The index share thus acts as a negative market signal for the prospective demand. However, although the index share decreases the corner solution of capacity level, it has a positive impact on other incomes. This may be due to the fact that index share indicates one source of a firm's cash inflows in a financial context, which serves to increase earnings (Strebulaev and Whited 2012).

Regarding the evaluation of sales forecasts, it is reasonable that financial activities and book value per share are positively related to mean demand, while gross margin and inventory have negative effects under the fierce competition in the semiconductor manufacturing sector, despite the fact that the coefficient of book value per share is not different from zero – and even imprecise. When a firm's new wafers after expansion are put into the market with low expenditure on financial activities and book value per share, along with high inventory and gross margin, other competitors typically tend to respond faster with the increased capacities and force the firm-level demand to decrease (Lieberman 1987, Yang and Anderson 2014). In addition, as a proxy of profit shifter, EPS is significantly positively correlated with the interior capacity decision, while another proxy, EBITDA/Sales ratio, has an insignificant negative impact with the parameter value close to zero. It reflects that EPS is more representative in evaluating profit shifters than the EBITDA/Sales ratio is.

Consider the coefficients of financial characteristics in determining the corner solution of capacity level, it is found that if a firm has high inventory/asset ratio, B/M ratio, and cash flow margin, along with low slack resources, this facilitates the corner capacity decision. The reason may be that as the firm's financial support from inventory and earnings increases, its capacity is more likely to be determined based on the boundary constraint (Xu and Birge 2004). Moreover, COGS/Asset ratio and sales per share are appropriate indicators for the unit profit as they are extremely stable with low standard errors. Besides, the variance of error in capacity expansion equation is small, which ensures the small variation in capacity expansion decision.

Next, the random coefficients in the index share equation are discussed. Results show that the mean utility on capacity expansion is negatively related at a significance level. This is in accordance with a real-life situation of a firm in the semiconductor manufacturing sector (Uzsoy et al. 2018; Wu et al. 2005); that is, firms with large expansions on capacities suffer from high risk, which serves to limit investors' purchase of their stocks. In addition, the estimates of both stock return and leverage ratios also have negative impacts on the mean utility, presenting passive reaction behaviours of investors' stock purchasing. It is intuitive as the growing stock returns and high debt repayments of firms are unstable and risky, which may reduce the probability for investors to buy their stocks.

Moreover, the means associated with firm size and ROA are positive and significantly different from zeros, while the estimates of constant, strategic holdings, asset efficiency, and inventory turnover have negative effects on the mean utility of individual investors. To be specific, firms with large sizes benefit from the economies of scale (Manne 1961). It may constantly drop down the average cost with the increase in output and, accordingly, investors are more likely to purchase these firms' stocks. Besides, since high earning power may predict better stock performance of the firm from a financial point of view (Hendricks and Singhal 2008), investors thus prefer to buy a firm's stock with high profitability, which can be estimated by a widely used financial indicator, ROA. On the contrary, when there is an increase in the ratio of the firm's non-tradable shares, evaluated by an index of strategic holdings, its stock is less likely to be bought by investors as it would reduce the stock liquidity in the financial market (Bodie et al. 2011). Similarly, the higher the asset efficiency and inventory turnover are, the greater the asset liquidity of a firm is. It enables the firm to be more difficult to control the operational risk (Van Mieghem 2003), and therefore lower the possible purchase of its stock.

Besides, the standard deviations of marginal utility distributions for all variables in the index share equation are estimated to be insignificantly close to 0.01, a tiny number. This might be because of a few small differences among investors' preferences for purchasing stocks. The failure of precise evaluations on standard deviations may be due to the fact that data are not rich and substantial enough for empirical analysis. In addition, the variance value of shock in the index share equation is small and significant with little standard error.

Table 14 Empirical results

Parameter	Variable	Mean
$\boldsymbol{\varphi}$	Fixed Cost	0.6912 (0.0098)
	Index Share	-0.1095

		(0.0411)
	Financial Activities	0.1622 (0.0536)
	Book Value per Share	0.0004 (0.0030)
	Gross Margin	-0.0463 (0.0125)
	Inventory	-0.0198 (0.0162)
	EPS	0.0788 (0.0328)
	EBITDA/Sales Ratio	-0.0767 (0.0718)
	Index Share	0.0831 (0.0387)
	Inventory/Asset Ratio	-0.2161 (0.0253)
	B/M Ratio	-0.0728 (0.0266)
	Cash Flow Margin	-0.0500 (0.0403)
	Slack Resources	0.1317 (0.0244)
	COGS/Asset Ratio	0.1076 (0.0228)
	Sales per Share	-0.0707 (0.0049)
	Last-Period Asset	-0.0199 (0.0307)
σ_s^2	Error in Capacity Expansion Equation	0.1146 (0.0111)

$\bar{\alpha}$	Constant	-5.3643 (0.4594)
	Firm Size	1.3143 (0.1288)
	Strategic Holdings	-1.4362 (0.3782)
	Asset Efficiency	-0.6332 (0.2843)
	ROA	1.3620 (0.3558)
	Inventory Turnover	-0.0604 (0.0325)
	Stock Return	-0.2284 (0.0836)
	Capacity Expansion	-0.1712 (0.0706)
	Leverage Ratio	-0.3323 (0.2754)
Σ_{α}	Constant	0.0091 (0.0126)
	Firm Size	0.0060 (0.0081)
	Strategic Holdings	0.0115 (0.0160)
	Asset Efficiency	0.0105 (0.0138)
	ROA	0.0096 (0.0127)
	Inventory Turnover	0.0030 (0.0041)
	Stock Return	0.0097

		(0.0133)
	Capacity Expansion	0.0110 (0.0148)
	Leverage	0.0082 (0.0121)
σ_d^2	Error in Index Share Equation	0.6254 (0.0617)

4.4.3 Model Comparison

To test the model fitting, the capacity expansion model with fixed cost is compared to a model without considering the fixed cost. The only difference between these two models is that the term $\delta A_{jt}\mathrm{I}(\Delta k_{jt} > 0)$ in the capacity expansion model without fixed cost is equal to zero. Three evaluation methods, AIC, BIC and LMD, are used to conduct the model comparison, and the results are specified in Table 15. As can be seen from the table, the model with fixed costs has much lower values in AIC and BIC, along with higher result of LMD, compared with the model without fixed costs. It reflects a better fit of the fixed cost model.

Table 15 Comparisons of models with and without fixed costs

Model	AIC	BIC	LMD
Capacity Expansion Model w/ Fixed Costs	-1126.5955	-1016.6157	575.9870
Capacity Expansion Model w/o Fixed Costs	-742.0390	-628.7265	385.3912

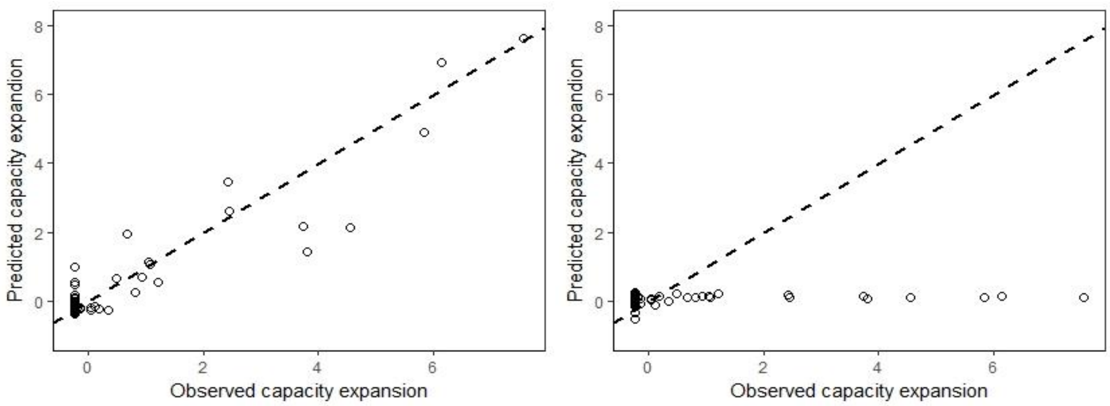
The level of fixed cost improving the estimation of capacity expansion is also discussed by using the estimated parameters to predict capacity expansion when controlling for all of the other predictor variables as original data. RMSEs of capacity expansion are then computed for both models. It is noted that RMSEs of capacity expansion in a sample that does not include zero expansions are also considered since the impact of fixed cost only occurs if firms expand their capacities. The results in Table 16 show that RMSEs of capacity expansion in the model with fixed costs are lower for both situations, and the improvement is much more significant after not accounting for zeros in capacity expansion. The reason may be due to the fact that the fixed cost model accounts for the gap between zero expansion and large capacity expansion, and enhances the value of boundary solution so as to raise the possibility for it to be chosen as the optimal capacity level. The prediction of capacity expansion and data observation is thus well matched in the model with fixed cost.

Table 16 RMSEs of capacity expansion in the models with and without fixed costs

Model	RMSE 1	RMSE 2
Capacity Expansion Model w/ Fixed Costs	0.3352	0.8879
Capacity Expansion Model w/o Fixed Costs	0.9848	2.7275

Notes: RMSE 1 refers to the RMSEs of variables in the whole sample, and RMSE 2 refers to the RMSEs of variables in the sample of firms with only capacity expansion.

Figure 21 displays the predicted capacity expansions against their observations. The average values for the last 10,000 iterations are used to specify the predictions of capacity expansions, and a dashed line is added for each plot to indicate the perfect match. It is easy to see from the plots that the fixed cost model shows a quite significant match of predicted and observed capacity expansions, while the model without fixed cost substantially under-predicts for firms with capacity expansions. It also confirms that fixed cost contributes to the determination of capacity expansion particularly for the firms with large capacity expansions.



(a) Capacity Expansion in Model w/ Fixed Costs (b) Capacity Expansion in Model w/o Fixed Costs

Figure 21 Predicted values against observed values

4.4.4 Discussion

The capacity expansion model with fixed cost allows me to undertake the counterfactual analyses such as the impact of fixed cost on a firm's capacity expansion and its corresponding profit. In this section, models and estimated parameters are used to investigate how the capacity expansion is influenced through the use of fixed cost, and how the profit varies after raising fixed cost. The compensating value of either increasing or decreasing the expenditure for fixed cost is also explored, in which compensating value is defined as the amount necessary to compensate for the change in fixed cost so as to yield the same level of profit. To conduct the counterfactuals, this simulation study considers $I = 50$ investors and $J = 64$ firms available each period for a total periods of $T = 10$. The specific algorithms for computing counterfactual equilibria are given in Appendix Q.

The influences of fixed cost on capacity expansion and firm profit are firstly discussed. Considering the relationship of fixed cost with capacity expansion, it is noticed that firms with high fixed costs usually expand large amounts of capacities based on the observed data of the semiconductor manufacturing sector specified in Figure 20. It reflects a positive correlation between fixed cost and capacity expansion – that is, an increase in fixed cost facilitates capacity expansion. Moreover, in the corporate finance setting, the increased fixed cost loses profit as the firm is typically required to pay for fixed cost as a financial expenditure (Berk et al. 2013). In the light of these findings, fixed cost is thus hypothesised to be positively related to capacity expansion, while having a negative impact on the firm profit.

To test the hypothesis, the counterfactual study is done by the shift in fixed costs, and the results are provided in Figure 22. Curves and shadows in the plots show the mean values and confidence intervals of the simulations. It is shown from Figure 22 (a) that the value of capacity expansion remains unchanged firstly, and then grows rapidly as fixed costs are raised, where the positive relationship in the last place is consistent with the hypothesis. The reason why the capacity expansion is nearly invariable at first is that the interior solution based on the profit maximisation is greater than the corner solution induced by the fixed cost, resulting in firms making capacity expansion decisions without considering the boundary constraint. This is intuitive because firms may not take the financial budgets into account for determining their capacity expansion levels when fixed costs are too small (Ye and Duenyas 2007). It can thus be concluded that,

Proposition 6. *Fixed cost has a significantly positive impact on a firm's capacity expansion when fixed cost is large, even though the capacity expansion may not be influenced by low fixed cost.*

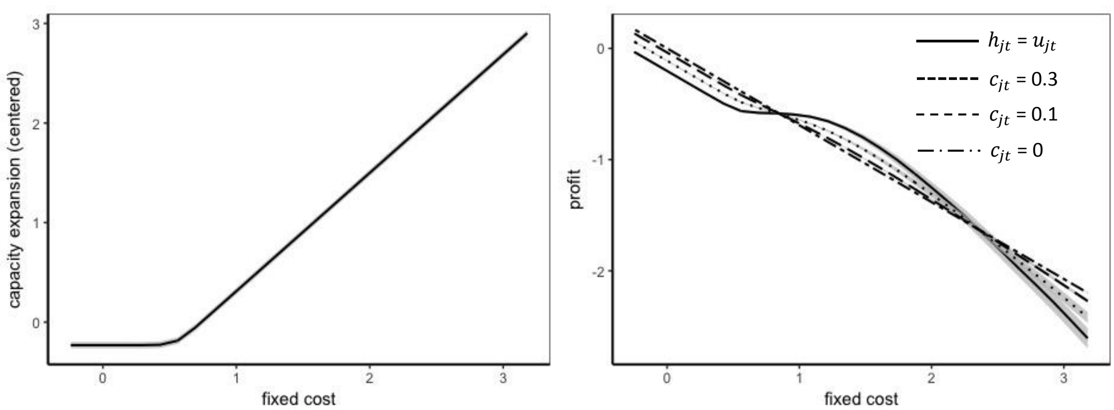


Figure 22 The relationship of fixed cost with capacity expansion and profit

Moreover, to compute firm profit, the unit cash inflow obtained from capacity decision h_{jt} is required to be identified since the model only estimates the unit profit margin $(u_{jt} - c_{jt})/u_{jt}$ and unit contribution from capacity after deducting the unit production cost $h_{jt} - c_{jt}$. As noted in remark 1, the unit cash inflow of capacity is limited in a range of $(c_{jt}, u_{jt}]$. The value of h_{jt} is thus set based on $c_{jt} = 0$, $c_{jt} = 0.1$, $c_{jt} = 0.3$, and the boundary point u_{jt} to evaluate the firm profit. The simulated results for all cases are shown in Figure 22 (b). It is found that firm profit rapidly goes down with the increase of fixed cost, reflecting a negative relationship between fixed cost and firm profit, which is consistent with the study of Berk et al. (2013). However, when the unit cash inflow of capacity level reaches its maximum value that is equal to the unit price u_{jt}, the negative outcome of firm profit has two inflection points. The first one occurs when a firm turns to consider the financial constraint for determining the optimal capacity policy, which is the transformation from the interior solution to the corner solution of capacity decision, and the second one is due to the equal demand and capacity level. Interestingly, there are still inflections with the decrease of unit cost, but they disappear for the special case of $c_{jt} = 0$, where the variable cost does not present. This is a critical state for the relationship of fixed cost with firm profit since the unit profit margin would be one in this case, which is not going to happen for the real case. In sum, these findings suggest that the presence of fixed cost will lead to the firm profit reduction depending on the comparison of either local optima of capacity expansions or the firm-level demand and capacity level. Therefore, it is proposed that

Proposition 7. *As a firm's fixed cost on capacity expansion increases, its profit will decrease with different downtrends.*

The supply chain coordination between supplier and downstream firms can also be considered through computing the compensating value for the variation of fixed cost. The maximised profit function that is associated with the fixed cost are defined as,

$$\pi_{jt}(A_{jt}) = \max \quad p_{jt}\mathrm{E}[\min(w_{jt}, k_{jt})] - c_{jt}k_{jt} - \delta A_{jt}\mathrm{I}(\Delta k_{jt} > 0), \qquad (127)$$

$$\text{s.t.} \quad \delta A_{jt}\mathrm{I}(\Delta k_{jt} > 0) + c_{jt}k_{jt} + d_{jt} \le h_{jt}k_{jt} + o_{jt}, \qquad (128)$$

which is consistent with the plural provided in equations (102) and (103).

To find the compensating value (CV) when increasing or decreasing the expenditure for fixed cost by a%, I solve the following equation, which is,

$$\pi_{jt}(A_{jt}) = \pi_{jt}(\mathrm{a}\% * A_{jt}) + CV. \qquad (129)$$

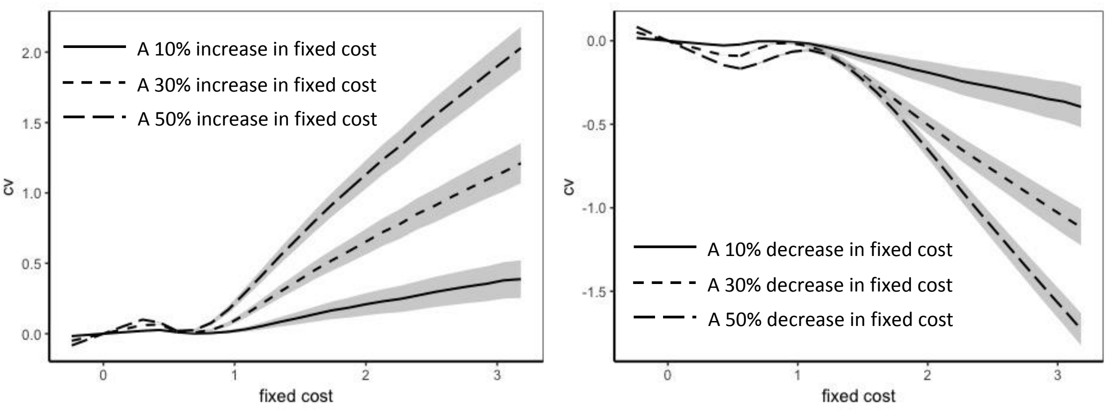


Figure 23 The effects of increases in fixed cost on profit

The purpose of considering CV is to yield the same level of firm profit for the variation of fixed cost provided by the upstream firms, such as facilities and equipment suppliers in the semiconductor manufacturing sector. Figure 23 provides some evidence of the compensating values that occur if there are increases or decreases of fixed costs. The results show that the value to compensate the increased (decreased) fixed cost is significantly positively (negatively) related with fixed cost, even though slight ups and downs exist for small fixed cost levels. It means that if suppliers of facilities and equipment decrease (increase) their profits by reducing (raising) fixed costs of downstream firms that expand capacities, those firms with large expansion planning may obtain higher (lower) profits. These striking findings imply a supply chain coordination in terms of capacity expansion and fixed costs, as similar to the forms specified in Cachon (2003) and Snyder and Shen (2011); that is,

Managerial Implication 3. *A large-capacity-expansion firm is able to negotiate with its upstream supplier by adjusting fixed cost in order to achieve win-win for supply chain partners.*

4.5 Concluding Remarks

In this chapter, the impacts of fixed cost on capacity expansion and supply chain coordination are discussed, particularly for the capital-intensive firms, such as semiconductor manufacturers. The budget constraint in the model is calibrated using cash outflows that involve both fixed cost and product cost along with debt repayment, and cash inflows of contributions from capacity expansion and other incomes. The discontinuity in fixed cost is figured out through an economic consideration, where the optimal solution of capacity expansion is obtained by dividing the optimisation problem into two groups depending on whether the firm's capacity is expended. When comparing capacity expansion model with fixed cost to that without allowing for fixed cost, the evaluation results show a better fit for the model constructed with the consideration of fixed cost, which are specified as lower values of AIC and BIC, as well as higher LDM. Moreover, the presence of fixed cost well improves the matching between predictions and observations of capacity expansion, having lower

RMSE than that obtained from the model without fixed cost. It reflects the necessity and importance of incorporating fixed cost into the study of capacity expansion decision.

The counterfactual analysis is also conducted to investigate how fixed cost affects the capacity expansion as well as corresponding firm profit and supply chain coordination. The findings are significant and meaningful. That is, with the increase of fixed cost, the amount of capacity expansion is almost unchanged at first and then increases rapidly, while firm profit keeps decreasing with the existence of two inflection points. The first one occurs when the interior and corner solutions of capacity expansion are equal, and the second point is reached for the case of the same demand and optimal capacity decision. As for the impact of fixed cost on supply chain coordination, the compensating values of variating fixed costs are evaluated. It is found that when fixed cost of capacity expansion is increased (decreased), firms with large expansion planning require more (less) value to compensate for the losses in order to yield the same level of profits. This implies a kind of supply coordination in operational research, which is when the relationship of fixed cost with compensating value can be used to realise the negotiation between downstream firms and upstream suppliers.

In addition, many contributions can be obtained from the study of how fixed cost impacts a firm's capacity expansion and its supply chain process. First, the literature regarding capacity expansion is extended with the consideration of fixed cost from both operational and financial perspectives. A budget constraint in the capacity expansion model is developed using a financial link of cash inflows and outflows that accounts for a firm's fixed cost, and the optimal decision of capacity expansion is found by comparing the interior and corner solutions for each sub-problem. Second, the importance of fixed cost on capacity expansion and supply chain coordination is evaluated by an empirical case of the semiconductor manufacturing sector, where the characteristics of significant fixed expenditure for the expansion in capacity are widely exhibited in this sector. Third, the managerial implication behind the findings of this study is worth noticing; which is that firms with large capacity expansion are able to negotiate with their upstream suppliers by adjusting the fixed cost in order to achieve win-win for supply chain partners. This builds the link between capacity expansion and supply chain coordination under the influence of fixed cost. In conclusion, this study further complements operational research by incorporating the discontinuous fixed costs in the empirical capacity expansion, and realises the interactive operational decisions and financial matters.

However, some limitations of this research still exist and need to be further considered. For instance, the endogeneity of debt is not taken into account in this study, which is widely discussed by recent research in the financial field. The reason for not considering this factor is that when debt is endogenously determined, the optimal decision of capacity expansion is the interior solution that is not related with the fixed cost, but the debt policy is closely associated with the fixed cost, because it is obtained based on the budget constraint. Therefore, the relationship between capacity expansion and fixed cost is not able to be directly investigated in an endogenous context, while the link of debt and fixed cost is built. The issue of simultaneity of capacity expansion and debt under the influence of fixed cost is another research direction worth exploring in great depth in the future.

Chapter 5 Conclusion

The thesis discussed the capacity expansion decision in the interaction between operational and financial contexts. The demand prior to a firm's capacity expansion planning is identified with the use of index share, providing insight into demand allocation mechanism from a sector-specific view. It realises the match of demand with supply in the empirical capacity expansion. Financial budget is also considered within the supply-side model of capacity expansion when both operational and financial decisions are simultaneously determined under the adjustment of index share, which is a possible extension of the basic framework of interactive demand and supply of capacity expansion. Moreover, the firm performance outcomes of capacity expansion are investigated in both operating and financial aspects. Firm profit and stock return, along with the value of the firm are used to measure the performance impacts, where firm value is calibrated through the estimated values of profit and stock return when a firm's capacity expands. Besides, this thesis also explores the effect of fixed cost on capacity expansion and supply chain process due to the fact that high fixed expenditures are typically incurred when firms expand their capacities, particularly for the capital-intensive sectors, such as semiconductor manufacturing sector. The compensating value of either increasing or decreasing fixed cost is evaluated to achieve the negotiation between upstream firms and suppliers in the supply chain process. To conclude, three streams of research are analysed in depth in this thesis. The first one is the specification of demand allocation mechanism for the capacity expansion decision. Then, the impacts of capacity expansion on both operating and financial performance are empirically evaluated, and finally, the study of how fixed cost affects the capacity expansion and corresponding supply chain coordination is well investigated in this thesis.

5.1 Methodology and Evaluation Approach

The simultaneous framework of matching supply and demand is employed to address the research regarding capacity expansion in this thesis. Strictly speaking, demand allocation is evaluated by a discrete choice model in which all investors' stock purchasing choices are specified and aggregated into the index share in a given sector. Moreover, the supply-side model of capacity expansion is applied to obtain the optimal capacity expansion decision through a firm's profit maximisation. To extend the supply-side model in to an advanced form, the budget constraint is considered to jointly determine the capacity expansion and debt policies. Besides, the capital pricing model is used to measure the stock performance after the capacity expansion, in which the index share used for constructing the expected return on sector index is simultaneously estimated by maximising the investors' utilities of purchasing stock in the sector. In order to investigate the importance of fixed cost in the capacity expansion decision, the discontinuous fixed cost is taken into account of both profit function and financial constraint of the supply-side model of capacity expansion. This optimisation problem is able to be solved based on an economic consideration.

As for the evaluation method applied in this thesis, a Bayesian approach rather than more controversial methods is specified to examine the models for each case. The reasons for using Bayesian estimation are that small-sample events are allowed for the investigation in the Bayesian analysis, meaning that an empirical case of a few semiconductor manufacturers in a given index fund (e.g., SOX) is available for application in the study, and the random coefficient of the Bayesian hierarchical model is much more intuitive and straightforward to be used for estimating the stock return of individual firm compared with the GMM and MLE approaches. Besides, the evaluation process can be more simplified when using MCMC algorithms with specific conditionals on parameters in the Bayesian estimation. In additions, Monte Carlo tests have been conducted to simulate all models and verify their validities.

5.2 Main Results and Propositions

An empirical application of firms that design, manufacture, pack, and sell semiconductors in the SOX index fund is provided to evaluate models from a sector view. Regarding the first study that identifies the demand allocation using index share to determine the capacity expansion, the empirical result of basic model without considering financial budget shows that sector demand before firm makes capacity expansion goes up with the increasing of its index share, implying a positive signal of index share in prospecting the future demand, which has a significant effect on the capacity expansion. The interactions between capacity expansion and index share are further examined by conducting counterfactual analyses. It is found that firms with increased index shares continuously expand their capacities, while index shares are negatively influenced by the expansion in capacities. Ultimately, the capacity expansion and index share will achieve their equilibrium values, realising the matching of demand and supply in the empirical capacity expansion. When incorporating financial budgets with debt into the supply-side model of capacity expansion, the operational and financial decisions are simultaneously made under the influence of index share. The counterfactual outcomes illustrate the relationship of debt with capacity expansion, which is that the increased amount of debt will drive the expansion of capacity for firms with below-median index share; however, the negative impact of debt on capacity expansion occurs when firms own index shares that are above the median level in a given sector. Therefore, propositions regarding the interactive capacity expansion and index share are specified as,

Proposition 1. *The increase of a firm's index share facilitates its capacity expansion, ceteris paribus.*

Proposition 2. *The expansion of a firm's capacity level reduces its index share, ceteris paribus.*

The second research study in regard to the operating and financial performance outcomes of capacity expansion is also empirically evaluated. The counterfactuals that investigate the effects of capacity expansion on firm profit, stock return, and value of firm are constructed by alternating the amount of capacity expanded. The results indicate that with the increasing of capacity expansion, first, both profit and firm value increase and then reduce after reaching the peak, presenting an inverse U-shape pattern. This reflects the existence of optimal capacity expansion with the maximised profit and firm value. When classifying the performance of capacity expansion with the use of index share, it is noticed that firms with below-median index shares have significantly higher profits and firm value compared to those who own index shares that are above the median level, if the same amount of capacity expansion is considered before reaching the optimal values. However, when the expanded capacity exceeds its peak level, the situation reverses with a slight difference of performance outcomes for firms in the two groups. Contrary to the much received wisdom, the financial performance measure – stock return – is negatively influenced by capacity expansion for both groups with different levels of index share, indicating that the expansion in capacity has a negative stock reaction in the financial market. However, firms with below-median index shares present significantly higher stock return than those that own above-median index shares for the same capacity expansion level. This implies that the small-index-share firms may have better financial performance after their capacity expansions. Three propositions for performance impacts of capacity expansion are thus proposed as follows,

Proposition 3. *As a small-index-share firm's capacity expansion increases in a suitable range, its profit will increase with better performance than that with large index share.*

Proposition 4. *As a small-index share firm's capacity expansion increases, its stock return will decrease but have better performance than that with large index share.*

Proposition 5. *A firm's profit is more important in determining the value of the firm for its capacity expansion compared with the stock return.*

For the third research study that incorporates fixed cost into the determination of capacity expansion, the empirical findings specify that the capacity expansion model with fixed cost has a better fit than that where the fixed cost is not considered, supported by lower values of AIC and BIC, along with higher LMD for the fixed cost model. Moreover, the capacity expansion model that allows for fixed cost significantly improves the matching of predicted capacity expansions with data observations, which is specified as a lower RMSE compared to that of the model without fixed cost. All these findings reflect the necessity and importance of taking fixed cost into account for the study of capacity expansion. To discuss how fixed cost affects capacity expansion and corresponding supply chain coordination, the counterfactual results are analysed with the variation of fixed cost. It is worth noticing that the amount of capacity expansion is nearly unchanged at the first stage and then goes up rapidly as fixed cost increases. However, the firm profit is negatively related to the fixed cost with two inflection points that occur when interior and corner solutions of capacity expansion are equal and when demand is the same as the optimal capacity decision. This means that the increase of fixed cost indeed hurts firm profit, although it facilitates the capacity expansion level when it is higher than a certain value. When evaluating the impact of fixed cost on supply chain process, the compensating value that yields the same level of profits for the adjustment of fixed cost is also evaluated. I find that if fixed costs of capacity expansions for downstream firms are increased (decreased) by suppliers, those firms with large expansion levels may require more (less) value to compensate for the change in fixed cost, which can be used to negotiate with their upstream suppliers. This represents a kind of supply chain coordination in operational research. To conclude, the important roles of fixed cost on capacity expansion and firm profit are presented by,

Proposition 6. *Fixed cost has a significantly positive impact on a firm's capacity expansion when fixed cost is large, even though the capacity expansion may not be influenced by low fixed cost.*

Proposition 7. *As a firm's fixed cost on capacity expansion increases, its profit will decrease with different downtrends.*

5.3 Managerial Implications and Recommendations

Drawing on these findings and outcomes, the managerial implications along with corresponding recommendations for practitioners are provided, which are appealing and practical:

Managerial Implication 1. *If the debtholders expect the indebted firms to focus on growing their capacities, they should invest in those firms with small index shares.*

Debtholders concentrating on capacity expansions should be advised to invest in firms with small index share as they facilitate capacity expansion through fully utilising financial funding.

Managerial Implication 2. *A firm with small index share can expand capacity within a reasonable range so as to achieve improved performance of profit, stock return, and firm value.*

Investing in small-index-share firms is a wise choice for potential entrants, because if firms that own small index shares expand their capacities within a suitable range (less than optimal profit levels), they can obtain better performance outcomes from capacity expansion, which have higher profit, stock return, and firm value compared to those firms with large index shares.

Managerial Implication 3. *A large-capacity-expansion firm is able to negotiate with its upstream supplier by adjusting fixed cost in order to achieve win-win for supply chain partners.*

Firms with large capacity expansions can alter their fixed costs to realise the coordination with their upstream suppliers due to that the rise (reduce) in fixed cost for capacity expansion will increase (decrease) the compensating value used to yield the same profit level, which leads to the overall profit increment. It builds the link between capacity expansion and supply chain coordination under the influence of fixed cost.

5.4 Contributions

This thesis contributes to the operations-finance interface in many ways. Overall speaking, the systematic frameworks of simultaneous models are constructed to advance the studies on interactive operational and financial decisions, which extends the simple analyses using reduced forms (e.g., Hendricks et al. 1995). Moreover, a case of semiconductor manufacturing sector is applied to empirically examine the models, realizing the evaluation of empirical capacity expansion with financial implications. Besides, this thesis also provides useful insights into the management practice regarding the operational strategies, such as capacity expansion, along with financial decisions. This involves that debtholders focusing on capacity expansions are suggested to invest in small-index-share firms; compared to firms that own large index shares, much improved operating and financial performance outcomes of capacity expansion are obtained by small-index-share firms; a coordination between supply chain partners (suppliers and downstream firms) can be built by the variance of fixed cost of capacity expansion. The specific contributions of the interactive mechanism between capacity expansion and financial implications for each chapter are presented as follows.

For the study of modelling demand allocation before a firm makes a capacity expansion decision, literature on strategic capacity expansion is further discussed by using index share to specify demand allocation, which realises the empirical evaluation of operational policies. Besides, the association between operational decisions and financial implications is also analysed at a macro level. The structure that incorporates the sector-based index share into the determination of firm-specific capacity expansion is constructed in this study, which advances the previous research that mainly focuses on the firm-level operational and financial decisions, such as capacity expansion and debt specified by Birge (2014). Furthermore, the methodology built in this study can be incorporated into more advanced supply-side models of capacity expansion. One possible extension is to consider financial budget in the model to investigate a relationship between capacity expansion and debt under the effect of index share. This would improve the research strand that discusses the impact of debt on capacity expansion without specific demand allocation mechanism proposed by Xu and Birge (2008). To conclude, in regard to the identification of demand allocation, the study extends the operations literature in empirical capacity expansion and its interaction with financial decision.

The research, which conducts an in-depth investigation of the effect of capacity expansion on the operating and financial performance, also makes great contributions to the operations studies. First, a systematic structure of interactive operational and financial decisions is built, which extends the simple analysis of a direct relationship between capacity expansion and its performance outcomes using reduced regressions (e.g., Hendricks et al., 1995). Second, literature linking the operations-finance interface is advanced by considering firm value to precisely measure a firm's performance impact, which is rarely discussed by the extant studies from both operational and financial viewpoints. Third, this study also reveals an appealing managerial implication, which is, firms with small index shares may obtain more advantage in capacity expansion, such as higher profit, stock return, and firm value within a reasonable range, compared to large-index-share firms. Therefore, the research of how capacity expansion affects a firm's performance provides useful insights into the interaction of operational decisions with financial implications.

In addition, there are many contributions derived from the study exploring the impact of fixed cost on the capacity expansion and supply chain coordination. The first one is that literature on capacity expansion are advanced by incorporating fixed cost into the interactive setting with a consideration of both operational decisions and financial matters. The supply-side model of capacity expansion is developed using a financial link of cash inflows and outflows that accounts for fixed cost, and the optimal capacity expansion policy is obtained by comparing both interior and boundary solutions. Then, the necessity and importance of fixed cost when determining the capacity expansion is examined by comparing capacity expansion models with and without fixed cost using an empirical case of a semiconductor manufacturing sector, since large fixed expenditures should be paid to achieve expansions of capacities in this sector. Besides, the effect of fixed cost on supply chain coordination is also considered in this study, suggesting significant, managerial practice for the firm's operations. In conclusion, the study direction complements the operational research literature by incorporating the discontinuous fixed cost into the empirical expansion, and realises the interactive link of operations and finance.

5.5 Limitations and Future Research

There are, however, still some limitations that need to be taken into account in future research. In the evaluation of index share for demand allocation before capacity expansion in this thesis, it is assumed that investors only consider choosing one firm's stock each time in a given sector, which is an ideal case. In reality, though, they typically purchase multiple stocks so as to realise their optimal decision. This issue is a multi-variety choice problem and can be solved by determining both interior and corner solutions of utility for each investor as proposed by Kim et al. (2002) and Satomura et al. (2011). However, it would become much more complicated and difficult to estimate the aggregated index share if individual choices of stock purchasing are not observable, such as in the semiconductor manufacturing sector, which is worth of further investigation and research.

Moreover, the endogeneity of debt, a widely discussed topic of recent research in the financial field (e.g. DeAngelo et al. 2011, Hennessy and Whited 2005, Strebulaev and Whited 2012), is not taken into account in this study that investigates the effect of fixed cost on capacity expansion. The reason for not considering this issue is that when debt is endogenously determined, the optimal decision of capacity expansion is the interior solution that is not related with the fixed cost; however, the debt policy is closely associated with the fixed cost, because it is obtained based on the budget constraint. Therefore, the relationship between capacity expansion and fixed cost cannot be directly investigated in an endogenous context, while the link of debt and fixed cost is built. The issue of simultaneity of capacity expansion and debt under the influence of fixed cost is another research area that warrants in-depth exploration.

Furthermore, fixed cost as a critical expenditure in the process of capacity expansion may affect the value of the firm through altering firm profit and stock return (Howell and Allenby 2015, Kuo and Yang 2013). Failure to consider the influence of fixed cost in the value of the firm after they make the capacity expansion decisions is likely to result in the estimation biases of real operational and financial activities, which is a possible research concern in the future.

Besides, due to the large expenditure for purchasing database of the semiconductor manufacturing sector that are used to conduct the empirical analysis in the thesis, some parameters are not able to be well estimated precisely with relatively small data set. This issue can be solved when there are enough budget to support the purchase of larger sample size along with longer periods, where the models are ready to be empirically examined again.

In addition, it is noticed that this thesis is also applicable to be empirically evaluated by using cases in other sector, such as the automobile and chemical industries, following the studies of Bihlmaier et al. (2009), You et al. (2011) and Mitra et al. (2014). This is because firms in these sectors have similar characteristics to the semiconductor manufacturers, which have high demand volatility, intensive capital investment, and large fixed expenditure. Therefore, the methodology and evaluation in this thesis have broad application prospects in these fields, which are ready to be examined empirically.

Appendix A A Determinants of Jacobian Matrices for Basic Model in Chapter 2

The determinant of the Jacobian matrix used to transform from $\mathbf{P}_t$ to $\boldsymbol{\xi}_t$ is given by,

$$J_{(\mathbf{P}_t \to \boldsymbol{\xi}_t)} = J_{(\mathbf{p}_t \to \boldsymbol{\xi}_t)} = \left\|\nabla_{\boldsymbol{\xi}_t} \mathbf{p}_t\right\| = \left\| \begin{bmatrix} \frac{\partial p_{1t}}{\partial \xi_{1t}} & \cdots & \frac{\partial p_{1t}}{\partial \xi_{Jt}} \\ \vdots & \ddots & \vdots \\ \frac{\partial p_{Jt}}{\partial \xi_{1t}} & \cdots & \frac{\partial p_{Jt}}{\partial \xi_{Jt}} \end{bmatrix}_{J_t \times J_t} \right\|, \tag{A.1}$$

where the first equation is satisfied due to the fact that index share p_{jt} is assumed to be equal to the share observations P_{jt} based on the BLP model proposed by Berry et al. (1995), and the partial derivatives are specified as,

$$\frac{\partial p_{jt}}{\partial \xi_{lt}} = \begin{cases} \frac{1}{N_p} \sum_{i=1}^{N_p} p_{ijt}\left(1 - p_{ijt}\right) & \text{if } l = j \\ -\frac{1}{N_p} \sum_{i=1}^{N_p} p_{ijt} p_{ilt} & \text{if } l \neq j \end{cases}, \tag{A.2}$$

$$p_{ijt} = \frac{\exp\left(\delta_{jt} + \mathbf{X}_{jt} \mathbf{v}_i\right)}{1 + \sum_{j=1}^{J_t} \exp\left(\delta_{jt} + \mathbf{X}_{jt} \mathbf{v}_i\right)}. \tag{A.3}$$

It is found that the Jacobian is only a function of $\boldsymbol{\Sigma}_\alpha$ when P_{jt} and $\mathbf{X}_{jt}$ are given, as δ_{jt} is obtained by using the BLP Contraction Mapping conditional on the parameter $\boldsymbol{\Sigma}_\alpha$.

The determinant of the Jacobian matrix used to transform from $\boldsymbol{\eta}_t$ to $\Delta \mathbf{k}_t$ is given by,

$$J_{(\boldsymbol{\eta}_t \to \Delta \mathbf{k}_t)} = \left\|\nabla_{\Delta \mathbf{k}_t} \boldsymbol{\eta}_t\right\| = \left\| \begin{bmatrix} \frac{\partial \eta_{1t}}{\partial \Delta k_{1t}} & \cdots & \frac{\partial \eta_{1t}}{\partial \Delta k_{Jt}} \\ \vdots & \ddots & \vdots \\ \frac{\partial \eta_{Jt}}{\partial \Delta k_{1t}} & \cdots & \frac{\partial \eta_{Jt}}{\partial \Delta k_{Jt}} \end{bmatrix}_{J_t \times J_t} \right\|, \tag{A.4}$$

where the partial derivatives are given by,

$$\frac{\partial \eta_{jt}}{\partial \Delta k_{lt}} = \begin{cases} h_{jt} \times \dfrac{1}{\tau}\left(\dfrac{1}{\Delta k_{jt} + k_{jt-1}} - \dfrac{\mu_1}{N_p}\sum_{i=1}^{N_p} \alpha_i^k p_{ijt}\left(1 - p_{ijt}\right)\right) & \text{if } l = j \\ h_{jt} \times \dfrac{1}{\tau}\left(-\dfrac{\mu_1}{N_p}\sum_{i=1}^{N_p} \alpha_i^k p_{ijt} p_{ilt}\right) & \text{if } l \neq j \end{cases}, \tag{A.5}$$

$$h_{jt} = z\left(\frac{1}{\tau}\left(\ln\left(\Delta k_{jt} + k_{j,t-1}\right) - \mu_1 p_{jt}\left(\delta_{jt}, \mathbf{X}_{jt}; \mathbf{\Sigma}_\alpha\right) - \mathbf{q}_{jt}\boldsymbol{\mu}_2\right)\right). \tag{A.6}$$

α_i^k is the parameter of capacity expansion quantities, Δk_{jt}. z is the probability density of the standard normal distribution.

Appendix B MCMC Algorithm for Basic Model in Chapter 2

1. Generate $\boldsymbol{\theta}$

A RW Metropolis chain is used to generate draws of $\boldsymbol{\theta}$, and the equation is,

$$\boldsymbol{\theta}^{\text{new}} = \boldsymbol{\theta}^{\text{old}} + \text{MVN}(0, s_1^2 \boldsymbol{\Sigma}_1), \tag{B.1}$$

where s_1^2 is a scaling constant and $\boldsymbol{\Sigma}_1$ is the candidate covariance matrix.

The posterior used for drawing $\boldsymbol{\theta}$ is specified as,

$$\pi\left(\boldsymbol{\theta} | \boldsymbol{\varphi}, \overline{\boldsymbol{\alpha}}, \sigma_d^2\right) \propto L\left(\overline{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha, \boldsymbol{\varphi}, \sigma_d^2, \sigma_s^2\right) \times \pi(\boldsymbol{\theta}). \tag{B.2}$$

2. Generate $\boldsymbol{\varphi}$

A RW Metropolis chain is used to generate draws of $\boldsymbol{\varphi}$, and the equation is,

$$\boldsymbol{\varphi}^{\text{new}} = \boldsymbol{\varphi}^{\text{old}} + \text{MVN}(0, s_2^2 \boldsymbol{\Sigma}_2), \tag{B.3}$$

where s_2^2 is a scaling constant and $\boldsymbol{\Sigma}_2$ is the candidate covariance matrix.

The posterior used for drawing $\boldsymbol{\varphi}$ is specified as,

$$\pi(\boldsymbol{\varphi} | \sigma_s^2, \boldsymbol{\theta}) \propto L\left(\overline{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha, \boldsymbol{\varphi}, \sigma_d^2, \sigma_s^2\right) \times \pi(\boldsymbol{\varphi}). \tag{B.4}$$

3. Generate σ_s^2

The variance of error in capacity expansion equation is drawn from the inverted gamma distribution, and the corresponding posterior is,

$$\sigma_s^2 | \boldsymbol{\varphi} \sim \frac{v_{s1} s_{s1}^2}{\chi_{v_{s1}}^2} \text{with } v_{s1} = v_{s0} + n, s_{s1}^2 = \frac{v_{s0} s_{s0}^2 + n s_s^2}{v_{s0} + n}. \tag{B.5}$$

where $n s_s^2 = \boldsymbol{\eta}' \boldsymbol{\eta}$, with $\boldsymbol{\eta} = (\eta_{11}, \dots, \eta_{J_1 1}, \dots, \eta_{J_T T})'$, and n is the number of observations.

4. Generate $\overline{\boldsymbol{\alpha}}, \sigma_d^2$

A Gibbs sampler is employed to implement draws of $\overline{\boldsymbol{\alpha}}$ and σ_d^2 based on the univariate regression, which is given by,

Appendix B

$$\delta_{jt} = \mathbf{X}_{jt}\overline{\boldsymbol{\alpha}} + \xi_{jt} \text{ where } \xi_{jt} \sim N\left(0, \sigma_d^2\right). \tag{B.6}$$

The posteriors used for drawing $\overline{\boldsymbol{\alpha}}$ and σ_d^2 are specified as,

$$\overline{\boldsymbol{\alpha}}|\boldsymbol{\theta}, \sigma_d^2 \sim N\left(\widetilde{\boldsymbol{\alpha}}, \sigma_d^2(\mathbf{X}'\mathbf{X} + \mathbf{V}_{\overline{\alpha}})^{-1}\right) \text{ with } \widetilde{\boldsymbol{\alpha}} = (\mathbf{X}'\mathbf{X} + \mathbf{V}_{\overline{\alpha}})^{-1}\,(\mathbf{X}'\,\mathbf{X}\widehat{\boldsymbol{\alpha}} + \mathbf{V}_{\overline{\alpha}}\overline{\overline{\boldsymbol{\alpha}}}), \tag{B.7}$$

$$\sigma_d^2|\overline{\boldsymbol{\alpha}}, \boldsymbol{\theta} \sim \frac{v_{d1}s_{d1}^2}{\chi_{v_{d1}}^2} \qquad \text{with } v_{d1} = v_{d0} + n_d, s_{d1}^2 = \frac{v_{d0}s_{d0}^2 + ns_d^2}{v_{d0} + n}, \tag{B.8}$$

where $\mathbf{X} = \left(\mathbf{X}'_{11}, \ldots., \mathbf{X}'_{J_1 1}, \ldots, \mathbf{X}'_{J_T T}\right)'$, $ns_d^2 = \boldsymbol{\xi}'\boldsymbol{\xi}$, with $\boldsymbol{\xi} = (\xi_{11}, \ldots, \xi_{J_1 1}, \ldots, \xi_{J_T T})'$, and n is the number of observations.

Appendix C Data Sources and Variable Definitions in Chapter 2

Data on capacity expansions are obtained from the World Fab Watch reports provided by the Semiconductor Equipment and Materials International's (SEMI) Industry Research and Statistics department, while index shares are taken from iShares sponsored by the Black Rock Institutional Trust Company, which are weightings of stock in SOX based on the adjusted market value. Other financial data are collected from either annual reports of listed firms, or Datastream, a database providing firms' public information.

To be specific, stock return is defined by the percentage of change in price to last period's price of the stock, which is consistent with literature in the financial field. A leverage ratio is typically referred to as the financial measurement of debt variable. It is scaled by firm asset to ensure the better smoothness. Besides, firm size, strategic holdings, asset efficiency, ROA, and inventory turnover are chosen to estimate firm attributes. Based on the study of Kesavan et al. (2010), gross margin, accounts payable to inventory, sales growth and inventory performance are used to forecast sales at the firm level. When allowing for financial constraints to determine the optimal capacity expansion and debt policies, financial characteristics are measured by financial activities, EPS, cash flow margin, and Tobin's Q. Moreover, operating profit margin and ROE are regarded as proxies of profit shifters, while SGA/asset ratio and COGS/asset ratio are used to evaluate cost shifters. The detailed definitions of individual variables are specified in Table C.1.

Table C.1: Variable definitions and measurement

Category	Variable	Symbol	Definition/Measurement
	Capacity Expansion	CE	$\mathrm{Z}(\mathrm{Capacity\ Expansion}_t)$
	Stock Return	SR	$(\mathrm{Price}_t - \mathrm{Price}_{t-1})/\mathrm{Price}_t$
	Leverage Ratio	LR	$\mathrm{Debt}_t/\mathrm{Asset}_t$
Firm Attributes	Firm Size	FS	$\log(\mathrm{Employee\ Number}_t)$
	Strategic Holdings	SH	NOSHST
	Asset Efficiency	AE	$\mathrm{Sales}_t/\mathrm{Asset}_t$
	ROA	ROA	$\mathrm{EBIT}_t/\mathrm{Asset}_{t-1}$
	Inventory Turnover	IT	$\mathrm{COGS}_t/\mathrm{Inventory}_{t-1}$

Appendix C

Sales Forecasts	Gross Margin	GM	$(\text{Sales}_t - \text{COGS}_t)/\text{Sales}_t$
	Accounts Payable to Inventory	API	$\text{Accounts Payable}_t/\text{Inventory}_t$
	Sales Growth	SG	$(\text{Sales}_t - \text{Sales}_{t-1})/\text{Sales}_{t-1}$
	Inventory Performance	IP	$\text{Inventory}_t/\text{Sales}_t$
Financial Characteristics	Financial Activities	FA	$\text{Net Proceeds from Sale}_t/\text{Asset}_t$
	EPS	EPS	$\text{Net Income}_t/\text{Shares Outstanding}$
	Cash Flow Margin	GFM	$\text{Cash Flow}_t/\text{Sales}_t$
	Tobin's Q	TQ	$\text{Market Value}_t/\text{Asset}_t$
Profit Shifters	Operating Profit Margin	OPM	$\text{Operating Profit}_t/\text{Equity}_t$
	ROE	ROE	$\text{EBIT}_t/\text{Equity}_{t-1}$
Cost Shifters	SGA/Asset Ratio	SGA/A	$\text{SGA}_t/\text{Asset}_t$
	COGS/Asset Ratio	COGS/A	$\text{COGS}_t/\text{Asset}_t$

Notes: $\text{Z}(\cdot)$ is the normalisation of values. NOSHST refers to the percentage of total shares in issue held strategically and not available to ordinary shareholders.

Appendix D Algorithm of Computing Counterfactual Equilibria for Basic Model in Chapter 2

In the counterfactual analysis for the effect of index share on capacity expansion, the following procedures are used to evaluate the counterfactual equilibria of capacity expansions with the change of index share values, which are,

1. Given the estimated parameters for iteration n, calculate firm j's capacity expansion decision at period t, k_{jt}, with the change of index share p_{jt} in a range of 0 and 1, for $\forall j \in L(J_t), t \in L(T)$. The formula used to estimate the optimal capacity expansion level is based on the capacity expansion model, provided by equation (8).
2. Repeat the above steps to obtain the equilibria of capacity expansions for all iterations.

To undertake the counterfactual analysis regarding the effect of capacity expansion on index share, the counterfactual equilibria of index shares are calculated when the values of capacity expansions are given. The procedures are provided by,

1. Given the estimated parameters for iteration n, calculate firm j's index share at period t, p_{jt}, with the change of capacity expansion levels k_{jt} in a range of -1 and 1, for $\forall j \in L(J_t), t \in L(T)$. The formula used to estimate the index share is based on the demand allocation model, provided by equation (4).
2. Repeat the above steps to obtain the equilibria of index share for all iterations.

Appendix E Calculations of Optimal Decisions for Extension Model in Chapter 2

The firm's profit maximisation problem concerning both the financial constraint and the risk-neutral equivalence is specified as,

$$\max \quad u_{jt}\mathrm{E}\left[\min(w_{jt}, k_{jt})\right] - h_{jt}\mathrm{E}\left[(k_{jt} - w_{jt})^{+}\right] - l_{jt}\mathrm{E}\left[(w_{jt} - k_{jt})^{+}\right] - c_{jt}k_{jt}, \quad (\mathrm{E}.1)$$

$$\mathrm{s.t.} \quad 0 \le c_{jt}k_{jt} \le d_{jt} + \mathbf{z}_{jt}\mathbf{g}, \quad (\mathrm{E}.2)$$

$$d_{jt} = \int_0^{w_{jt}^b} u_{jt}w_{jt}d\mathbf{\Phi}_{jt}(w_{jt}) + \int_{w_{jt}^b}^{\infty} d_{jt}(1 + i_{jt})d\mathbf{\Phi}_{jt}(w_{jt}). \quad (\mathrm{E}.3)$$

The Lagrangian is,

$$L(k_{jt}, D_{jt}) = V(k_{jt}) + \lambda_1\left(c_{jt}k_{jt} - \frac{D_{jt}}{1 + i_{jt}} - \mathbf{z}_{jt}\mathbf{g}\right)$$

$$+\lambda_2\left(\frac{D_{jt}}{1 + i_{jt}} - \int_0^{w_{jt}^b} u_{jt}w_{jt}d\mathbf{\Phi}_{jt}(w_{jt}) - \int_{w_{jt}^b}^{\infty} D_{jt}\, d\mathbf{\Phi}_{jt}(w_{jt})\right), \quad (\mathrm{E}.4)$$

where λ_1 and λ_2 are Lagrangian multipliers, and $D_{jt} = d_{jt}(1 + i_{jt})$ is the face value of debt.

Differentiating the Lagrangian gives the standard Karush-Kuhn-Tucker first-order conditions,

$$\frac{\partial L(k_{jt}, D_{jt})}{\partial k_{jt}} = (u_{jt} + l_{jt} - c_{jt}) - (u_{jt} + l_{jt} + h_j)\mathbf{\Phi}_{jt}(k_{jt}) + \lambda_1 c_{jt}$$

$$-\lambda_1\left(\frac{1}{1 + i_{jt}}\frac{\partial D_{jt}}{\partial k_{jt}}\right) + \lambda_2\frac{\partial D_{jt}}{\partial k_{jt}}\left(\frac{1}{1 + i_{jt}} - \int_{w_{jt}^b}^{\infty} d\mathbf{\Phi}_j(w_{jt})\right) = 0 \quad \text{for } k_{jt} \ge 0, \quad (\mathrm{E}.5)$$

$$\frac{\partial L(k_{jt}, D_{jt})}{\partial D_{jt}} = \frac{\partial k_{jt}}{\partial D_{jt}}\left((u_{jt} + l_{jt} - c_{jt}) - (u_{jt} + l_{jt} + h_{jt})\mathbf{\Phi}_{jt}(k_{jt})\right) + \frac{\partial k_{jt}}{\partial D_{jt}}\lambda_1 c_{jt}$$

$$-\lambda_1\frac{1}{1 + i_{jt}} + \lambda_2\left(\frac{1}{1 + i_{jt}} - \int_{w_{jt}^b}^{\infty} d\mathbf{\Phi}_{jt}(w_{jt})\right) = 0 \quad \text{for } D_{jt} \ge 0, \quad (\mathrm{E}.6)$$

$$c_{jt}k_{jt} - \frac{D_{jt}}{1 + i_{jt}} - \mathbf{z}_{jt}\mathbf{g} \le 0 \quad \text{for } \lambda_1 \ge 0, \quad (\mathrm{E}.7)$$

$$\lambda_1\left(c_{jt}k_{jt}-\frac{D_{jt}}{1+i_{jt}}-\mathbf{z}_{jt}\mathbf{g}\right)=0, \tag{E.8}$$

$$\frac{D_{jt}}{1+i_{jt}}-\int_0^{w_{jt}^b}u_{jt}w_{jt}d\mathbf{\Phi}_{jt}(w_{jt})-\int_{w_{jt}^b}^{\infty}D_{jt}\,d\mathbf{\Phi}_{jt}(w_{jt})=0. \tag{E.9}$$

Case 1: If $\lambda_1=0$, then $\lambda_2=0$, the financial constraint is not binding. This means that the financial constraint is redundant and has no influence on the firm's capacity decision. We have an interior solution of capacity, k_{jt}^I; that is,

$$k_{jt}^I=\mathbf{\Phi}_{jt}^{-1}\left(\frac{u_{jt}+l_{jt}-c_{jt}}{u_{jt}+l_{jt}+h_{jt}}\right)=\mu\left(p_{jt}(k_{jt}^I,d_{jt}),\mathbf{q}_{jt}\right)\times\exp\left(\tau\mathbf{Z}^{-1}\left(\frac{u_{jt}+l_{jt}-c_{jt}}{u_{jt}+l_{jt}+h_{jt}}\right)\right). \tag{E.10}$$

In order for the interior capacity level to be the optimal one, the amount of debt raised should be sufficient to support the firm's capacity decision. The optimal debt thus satisfies,

$$c_{jt}k_{jt}^I=d_{jt}+\mathbf{z}_{jt}\mathbf{g}. \tag{E.11}$$

Case 2: If $\lambda_1>0$, then $\lambda_2>0$ and the financial constraint is binding. The optimisation problem with two equality constraints is solved. By rearranging terms in equation (E.9) and taking the derivative of the face value of debt with respect to capacity, we have,

$$\frac{\partial D_{jt}}{\partial k_{jt}}\left(\frac{1}{1+i_{jt}}-\int_{w_{jt}^b}^{\infty}d\mathbf{\Phi}_{jt}(w_{jt})\right)=0. \tag{E.12}$$

Due to the fact that the debt of firm raised from the financial market is influenced by its capacity investment level, the term $\frac{\partial D_{jt}}{\partial k_{jt}}$ is not equal to zero, an equation of interest rate determined by D_{jt} can be obtained, which is $\frac{1}{1+i_{jt}}=\int_{w_{jt}^b}^{\infty}d\mathbf{\Phi}_j(w_{jt})$. By substituting them into both equations $(\mathrm{E}.5)$ and $(\mathrm{E}.6)$, we calculate the first-order conditions in terms of k_{jt} and D_{jt} in a reduced form, which is,

$$(u_{jt}+l_{jt}-c_{jt})-(u_{jt}+l_{jt}+h_j)\mathbf{\Phi}_{jt}(k_{jt})+\lambda_1\left(c_{jt}-\frac{1}{1+i_{jt}}\frac{\partial D_{jt}}{\partial k_{jt}}\right)=0. \tag{E.13}$$

Differentiating the equality financial constraint with capacity and substituting it into equation $(\mathrm{E}.13)$, the same solutions of capacity and debt as the case in terms of unbinding constraint are given. This reflects that the firm's capital structure is dependent of its capacity decision.

Therefore, the optimal levels of capacity and debt for the financially constrained firm j at period t, k_{jt}^* and d_{jt}^*, occur at the solution of the following equations,

$$k_{jt}^* = \mu\left(p_{jt}\left(k_{jt}^*, d_{jt}^*\right), \mathbf{q}_{jt}\right) \times \exp\left(\tau \mathbf{Z}^{-1}\left(\frac{u_{jt} + l_{jt} - c_{jt}}{u_{jt} + l_{jt} + h_{jt}}\right)\right), \tag{E.14}$$

$$c_{jt} k_{jt}^* = d_{jt}^* + \mathbf{z}_{jt}\mathbf{g}. \tag{E.15}$$

Appendix F Determinants of Jacobian Matrices for Extension Model in Chapter 2

The determinant of the Jacobian matrix used to transform from $\boldsymbol{\eta}_t, \boldsymbol{\zeta}_t$ to $\Delta\mathbf{k}_t, \mathbf{d}_t$ is given by,

$$J_{(\boldsymbol{\eta}_t,\boldsymbol{\zeta}_t\rightarrow\Delta\mathbf{k}_t,\mathbf{d}_t)} = \begin{Vmatrix} \nabla_{\Delta\mathbf{k}_t}\boldsymbol{\eta}_t & \nabla_{\mathbf{d}_t}\boldsymbol{\eta}_t \\ \nabla_{\Delta\mathbf{k}_t}\boldsymbol{\zeta}_t & \nabla_{\mathbf{d}_t}\boldsymbol{\zeta}_t \end{Vmatrix} = \begin{Vmatrix} \begin{bmatrix} \frac{\partial\eta_{1t}}{\partial\Delta k_{1t}} & \cdots & \frac{\partial\eta_{1t}}{\partial\Delta k_{Jt}} & \frac{\partial\eta_{1t}}{\partial d_{1t}} & \cdots & \frac{\partial\eta_{1t}}{\partial d_{Jt}} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{\partial\eta_{Jt}}{\partial\Delta k_{1t}} & \cdots & \frac{\partial\eta_{Jt}}{\partial\Delta k_{Jt}} & \frac{\partial\eta_{Jt}}{\partial d_{1t}} & \cdots & \frac{\partial\eta_{Jt}}{\partial d_{Jt}} \\ \frac{\partial\zeta_{1t}}{\partial\Delta k_{1t}} & \cdots & \frac{\partial\zeta_{1t}}{\partial\Delta k_{Jt}} & \frac{\partial\zeta_{1t}}{\partial d_{1t}} & \cdots & \frac{\partial\zeta_{1t}}{\partial d_{Jt}} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{\partial\zeta_{Jt}}{\partial\Delta k_{1t}} & \cdots & \frac{\partial\zeta_{Jt}}{\partial\Delta k_{Jt}} & \frac{\partial\zeta_{Jt}}{\partial d_{1t}} & \cdots & \frac{\partial\zeta_{Jt}}{\partial d_{Jt}} \end{bmatrix}_{(2J_t)\times(2J_t)} \end{Vmatrix}, \tag{F.1}$$

where $\frac{\partial\eta_{jt}}{\partial\Delta k_{lt}}$ is the same as that shown in equation (A.5), and the rest of partial derivatives are,

$$\frac{\partial\eta_{jt}}{\partial d_{lt}} = \begin{cases} h_{jt} \times \frac{1}{\tau}\left(-\frac{\mu_1}{N_p}\sum_{i=1}^{N_p}\alpha_i^d p_{ijt}(1-p_{ijt})\right) & \text{if } l = j \\ h_{jt} \times \frac{1}{\tau}\left(-\frac{\mu_1}{N_p}\sum_{i=1}^{N_p}\alpha_i^d p_{ijt}p_{ilt}\right) & \text{if } l \neq j \end{cases}, \tag{F.2}$$

$$\frac{\partial\zeta_{jt}}{\partial\Delta k_{lt}} = \begin{cases} -\left(d_{jt} + \mathbf{z}_{jt}\mathbf{g}\right)/\left(\Delta k_{jt} + k_{j,t-1}\right)^2 & \text{if } l = j \\ 0 & \text{if } l \neq j \end{cases}, \tag{F.3}$$

$$\frac{\partial\zeta_{jt}}{\partial d_{lt}} = \begin{cases} 1/\left(\Delta k_{jt} + k_{j,t-1}\right) & \text{if } l = j \\ 0 & \text{if } l \neq j \end{cases}. \tag{F.4}$$

α_i^d is the parameter of debt levels, d_{jt}.

Appendix G MCMC Algorithm for Extension Model in Chapter 2

The MCMC algorithms of $\boldsymbol{\theta}, \boldsymbol{\varphi}, \overline{\boldsymbol{\alpha}}$, and σ_d^2 are the same as that for the basic model, except that σ_s^2 used in the draw of $\boldsymbol{\varphi}$ should be replaced by $\boldsymbol{\Sigma}_s$. In addition, we are required to generate the draws of $\boldsymbol{\varphi}'$ and $\boldsymbol{\Sigma}_s$, respectively.

1. Generate $\boldsymbol{\varphi}'$

The parameter vector of $\boldsymbol{\varphi}'$, which is $(\mathbf{g}, \boldsymbol{\rho})'$, is drawn from the posterior for a linear instrumental model by using the Gibbs sampler when $\boldsymbol{\varphi}$ is given. The debt equation is,

$$d_{jt}/\Delta k_{jt} + k_{jt-1} = (-\mathbf{z}_{jt}/\Delta k_{jt} + k_{jt-1} \quad \mathbf{s}_{jt}) \begin{pmatrix} \mathbf{g} \\ \boldsymbol{\rho} \end{pmatrix} + \zeta_{jt} \text{ where } \begin{pmatrix} \eta_{jt} \\ \zeta_{jt} \end{pmatrix} \sim N\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \boldsymbol{\Sigma}_s \right). \qquad (\text{G}.1)$$

2. Generate $\boldsymbol{\Sigma}_s$

The covariance matrix of errors in both capacity expansion and debt equations is drawn from the inverted Wishart distribution, and the corresponding posterior is given by,

$$\boldsymbol{\Sigma}_s | \boldsymbol{\varphi}, \boldsymbol{\varphi}' \sim IW(\mathbf{V}_{s0} + n, \mathbf{S}_{s0} + \mathbf{S}) \text{ with } \mathbf{S} = \sum_{t=1}^{T} \sum_{j=1}^{J_t} \left(\begin{pmatrix} \eta_{jt} \\ \zeta_{jt} \end{pmatrix} (\eta_{jt} \quad \zeta_{jt}) \right). \qquad (\text{G}.2)$$

Appendix H Algorithm of Computing Counterfactual Equilibria for Extension Model in Chapter 2

In the counterfactual analysis for the effect of debt on capacity expansion when considering the critical role of index share, the following procedures are used to evaluate the counterfactual equilibria of capacity expansion with the change of debt value, which are,

1. For each iteration n, start with an initial guess of each firm j's capacity expansion decision at period t, k_{jt}^{0}. When the value of debt d_{jt} is changed uniformly in a range of 0 and 1, for $\forall j \in L(J_t), t \in L(T)$, compute the corresponding index share p_{jt} by solving equation (4).
2. Given the estimated parameters for each iteration n and index share p_{jt}, re-calculate the capacity expansion decision k_{jt}^{1} based on the optimal capacity expansion rule derived by equation (42).
3. Update k_{jt}^{0} with k_{jt}^{1} in each iteration n, and repeat the above two steps until convergence, which is, $\sum_{t=1}^{T}\sum_{j=1}^{J_t}\left|k_{jt}^{1}-k_{jt}^{0}\right| \leq \mathrm{tol}=10^{-10}$.
4. Repeat the above steps to obtain the equilibria of capacity expansions for all iterations.

Appendix I Calculations of Optimal Decisions for Model in Chapter 3

The firm's profit maximisation problem concerning both the financial constraint and the risk-neutral equivalence is specified as,

$$\max \quad u_{jt}\mathrm{E}\big[\min\big(w_{jt}, k_{jt}\big)\big] - c_{jt}k_{jt}, \tag{I.1}$$

$$\text{s.t.} \quad 0 \le c_{jt}k_{jt} \le d_{jt} + \mathbf{z}_{jt}\mathbf{g}, \tag{I.2}$$

$$d_{jt} = \int_0^{w_{jt}^b} u_{jt}w_{jt}d\mathbf{\Phi}_{jt}\big(w_{jt}\big) + \int_{w_{jt}^b}^{\infty} d_{jt}\big(1+i_{jt}\big)d\mathbf{\Phi}_{jt}\big(w_{jt}\big). \tag{I.3}$$

The Lagrangian is,

$$L\big(k_{jt}, D_{jt}\big) = \pi_{jt} + \lambda_1\left(c_{jt}k_{jt} - \frac{D_{jt}}{1+i_{jt}} - \mathbf{z}_{jt}\mathbf{g}\right)$$

$$+\lambda_2\left(\frac{D_{jt}}{1+i_{jt}} - \int_0^{w_{jt}^b} u_{jt}w_{jt}d\mathbf{\Phi}_{jt}\big(w_{jt}\big) - \int_{w_{jt}^b}^{\infty} D_{jt}\, d\mathbf{\Phi}_{jt}\big(w_{jt}\big)\right), \tag{I.4}$$

where π_{jt} is the firm profit, $\pi_{jt} = \int_0^{k_{jt}}\big(u_{jt}w_{jt}\big)\, d\mathbf{\Phi}_{jt}\big(w_{jt}\big) + \int_{k_{jt}}^{\infty}\big(u_{jt}k_{jt}\big)\, d\mathbf{\Phi}_{jt}\big(w_{jt}\big) - c_{jt}k_{jt}$, λ_1 and λ_2 are Lagrangian multipliers, and $D_{jt} = d_{jt}\big(1+i_{jt}\big)$ is the face value of debt.

Differentiating the Lagrangian gives the standard Karush-Kuhn-Tucker first-order conditions,

$$\frac{\partial L\big(k_{jt}, D_{jt}\big)}{\partial k_{jt}} = \big(u_{jt} - c_{jt}\big) - u_{jt}\mathbf{\Phi}_{jt}\big(k_{jt}\big) + \lambda_1 c_{jt}$$

$$-\lambda_1\left(\frac{1}{1+i_{jt}}\frac{\partial D_{jt}}{\partial k_{jt}}\right) + \lambda_2\frac{\partial D_{jt}}{\partial k_{jt}}\left(\frac{1}{1+i_{jt}} - \int_{w_{jt}^b}^{\infty} d\mathbf{\Phi}_j\big(w_{jt}\big)\right) = 0 \quad \text{for } k_{jt} \ge 0, \tag{I.5}$$

$$\frac{\partial L\big(k_{jt}, D_{jt}\big)}{\partial D_{jt}} = \frac{\partial k_{jt}}{\partial D_{jt}}\Big(\big(u_{jt} - c_{jt}\big) - u_{jt}\mathbf{\Phi}_{jt}\big(k_{jt}\big)\Big) + \frac{\partial k_{jt}}{\partial D_{jt}}\lambda_1 c_{jt}$$

$$-\lambda_1\frac{1}{1+i_{jt}} + \lambda_2\left(\frac{1}{1+i_{jt}} - \int_{w_{jt}^b}^{\infty} d\mathbf{\Phi}_{jt}\big(w_{jt}\big)\right) = 0 \quad \text{for } D_{jt} \ge 0, \tag{I.6}$$

$$c_{jt}k_{jt} - \frac{D_{jt}}{1+i_{jt}} - \mathbf{z}_{jt}\mathbf{g} \le 0 \quad \text{for } \lambda_1 \ge 0, \tag{I.7}$$

$$\lambda_1\left(c_{jt}k_{jt}-\frac{D_{jt}}{1+i_{jt}}-\mathbf{z}_{jt}\mathbf{g}\right)=0, \tag{I.8}$$

$$\frac{D_{jt}}{1+i_{jt}}-\int_0^{w_{jt}^b}u_{jt}w_{jt}d\mathbf{\Phi}_{jt}(w_{jt})-\int_{w_{jt}^b}^{\infty}D_{jt}\,d\mathbf{\Phi}_{jt}(w_{jt})=0. \tag{I.9}$$

Case 1: If $\lambda_1=0$, then $\lambda_2=0$, and the financial constraint is not binding. This means that the financial constraint is redundant and has no influence on the firm's capacity decision. We have an interior solution of capacity, k_{jt}^I, that is,

$$k_{jt}^I=\mathbf{\Phi}_{jt}^{-1}\left(\frac{u_{jt}-c_{jt}}{u_{jt}}\right)=(\mu_1 p_{jt}+\boldsymbol{\mu}_2\mathbf{q}_{jt})\times\exp\left(\tau\mathbf{Z}^{-1}\left(\frac{u_{jt}-c_{jt}}{u_{jt}}\right)\right). \tag{I.10}$$

In order for the interior capacity level to be the optimal one, the amount of debt raised should be sufficient to support the firm's capacity decision. The optimal debt thus satisfies,

$$c_{jt}k_{jt}^I=d_{jt}+\mathbf{z}_{jt}\mathbf{g}. \tag{I.11}$$

Case 2: If $\lambda_1>0$, then $\lambda_2>0$ and the financial constraint is binding. The optimisation problem with two equality constraints is solved. By rearranging terms in equation (I.9) and taking the derivative of the face value of debt with respect to capacity, we have,

$$\frac{\partial D_{jt}}{\partial k_{jt}}\left(\frac{1}{1+i_{jt}}-\int_{w_{jt}^b}^{\infty}d\mathbf{\Phi}_{jt}(w_{jt})\right)=0. \tag{I.12}$$

Due to the fact that the debt of firm raised from the financial market is influenced by its capacity investment level, the term $\frac{\partial D_{jt}}{\partial k_{jt}}$ is not equal to zero, so an equation of interest rate determined by D_{jt} can be obtained, which is $\frac{1}{1+i_{jt}}=\int_{w_{jt}^b}^{\infty}d\mathbf{\Phi}_j(w_{jt})$. By substituting them into both equations $(\mathrm{I.5})$ and $(\mathrm{I.6})$, we calculate the first-order conditions in terms of k_{jt} and D_{jt} in a reduced form,

$$(u_{jt}-c_{jt})-u_{jt}\mathbf{\Phi}_{jt}(k_{jt})+\lambda_1\left(c_{jt}-\frac{1}{1+i_{jt}}\frac{\partial D_{jt}}{\partial k_{jt}}\right)=0. \tag{I.13}$$

Differentiating the equality financial constraint with capacity and substituting it into equation $(\mathrm{I.13})$, the same solutions of capacity and debt as the case in terms of unbinding constraint are given. This reflects that a firm's capital structure is dependent of its capacity decision.

Therefore, the optimal levels of capacity and debt for the financially constrained firm j at period t, k_{jt}^* and d_{jt}^*, occur at the solution of the following equations,

$$k_{jt}^{*} = \left(\mu_1 p_{jt} + \boldsymbol{\mu}_2 \mathbf{q}_{jt}\right) \times \exp\left(\tau \mathbf{Z}^{-1}\left(\frac{u_{jt} - c_{jt}}{u_{jt}}\right)\right), \tag{I.14}$$

$$c_{jt} k_{jt}^{*} = d_{jt}^{*} + \mathbf{z}_{jt}\mathbf{g}. \tag{I.15}$$

Appendix J Determinants of Jacobian Matrices for Models in Chapter 3

The determinant of the Jacobian matrix used to transform from $\mathbf{P}_t$ to $\boldsymbol{\xi}_t$ is,

$$J_{(\mathbf{P}_t \to \boldsymbol{\xi}_t)} = J_{(\mathbf{p}_t \to \boldsymbol{\xi}_t)} = \left\| \nabla_{\boldsymbol{\xi}_t} \mathbf{p}_t \right\| = \left\| \begin{bmatrix} \frac{\partial p_{1t}}{\partial \xi_{1t}} & \cdots & \frac{\partial p_{1t}}{\partial \xi_{Jt}} \\ \vdots & \ddots & \vdots \\ \frac{\partial p_{Jt}}{\partial \xi_{1t}} & \cdots & \frac{\partial p_{Jt}}{\partial \xi_{Jt}} \end{bmatrix}_{J_t \times J_t} \right\|, \tag{J.1}$$

where the first equation is satisfied due to the fact that the index share p_{jt} is assumed to be equal to the share observations P_{jt} based on the BLP model proposed by Berry et al. (1995), and the partial derivatives are specified as,

$$\frac{\partial p_{jt}}{\partial \xi_{lt}} = \begin{cases} \frac{1}{N_p} \sum_{i=1}^{N_p} p_{ijt}\left(1 - p_{ijt}\right) & \text{if } l = j \\ -\frac{1}{N_p} \sum_{i=1}^{N_p} p_{ijt} p_{ilt} & \text{if } l \neq j \end{cases}, \tag{J.2}$$

$$p_{ijt} = \frac{\exp\left(\delta_{jt} + \mathbf{X}_{jt}\mathbf{v}_i\right)}{1 + \sum_{j=1}^{J_t} \exp\left(\delta_{jt} + \mathbf{X}_{jt}\mathbf{v}_i\right)}. \tag{J.3}$$

It is found that the Jacobian matrix is only a function of $\boldsymbol{\Sigma}_\alpha$ when P_{jt} and $\mathbf{X}_{jt}$ are given, as δ_{jt} is obtained by using the BLP Contraction Mapping conditional on the parameter $\boldsymbol{\Sigma}_\alpha$.

The determinant of the Jacobian matrix used to transform from $\boldsymbol{\eta}_t, \boldsymbol{\zeta}_t$ to $\Delta\mathbf{k}_t, \mathbf{d}_t$ is,

$$J_{(\boldsymbol{\eta}_t, \boldsymbol{\zeta}_t \to \Delta\mathbf{k}_t, \mathbf{d}_t)} = \left\| \begin{matrix} \nabla_{\Delta\mathbf{k}_t} \boldsymbol{\eta}_t & \nabla_{\mathbf{d}_t} \boldsymbol{\eta}_t \\ \nabla_{\Delta\mathbf{k}_t} \boldsymbol{\zeta}_t & \nabla_{\mathbf{d}_t} \boldsymbol{\zeta}_t \end{matrix} \right\| = \left\| \begin{bmatrix} \frac{\partial \eta_{1t}}{\partial \Delta k_{1t}} & \cdots & \frac{\partial \eta_{1t}}{\partial \Delta k_{Jt}} & \frac{\partial \eta_{1t}}{\partial d_{1t}} & \cdots & \frac{\partial \eta_{1t}}{\partial d_{Jt}} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{\partial \eta_{Jt}}{\partial \Delta k_{1t}} & \cdots & \frac{\partial \eta_{Jt}}{\partial \Delta k_{Jt}} & \frac{\partial \eta_{Jt}}{\partial d_{1t}} & \cdots & \frac{\partial \eta_{Jt}}{\partial d_{Jt}} \\ \frac{\partial \zeta_{1t}}{\partial \Delta k_{1t}} & \cdots & \frac{\partial \zeta_{1t}}{\partial \Delta k_{Jt}} & \frac{\partial \zeta_{1t}}{\partial d_{1t}} & \cdots & \frac{\partial \zeta_{1t}}{\partial d_{Jt}} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{\partial \zeta_{Jt}}{\partial \Delta k_{1t}} & \cdots & \frac{\partial \zeta_{Jt}}{\partial \Delta k_{Jt}} & \frac{\partial \zeta_{Jt}}{\partial d_{1t}} & \cdots & \frac{\partial \zeta_{Jt}}{\partial d_{Jt}} \end{bmatrix}_{(2J_t) \times (2J_t)} \right\|, \tag{J.4}$$

where the partial derivatives are given by,

$$\frac{\partial \eta_{jt}}{\partial \Delta k_{lt}} = \begin{cases} 1 - \frac{\mu_1}{N_p}\sum_{i=1}^{N_p} \alpha_i^k p_{ijt}\left(1 - p_{ijt}\right) \times \exp\left(\tau \mathbf{Z}^{-1}\left(\frac{\exp\left(\mathbf{w}_{jt}\boldsymbol{\gamma}\right)}{1 + \exp\left(\mathbf{w}_{jt}\boldsymbol{\gamma}\right)}\right)\right) & \text{if } l = j \\ -\frac{\mu_1}{N_p}\sum_{i=1}^{N_p} \alpha_i^k p_{ijt} p_{ilt} \times \exp\left(\tau \mathbf{Z}^{-1}\left(\frac{\exp\left(\mathbf{w}_{jt}\boldsymbol{\gamma}\right)}{1 + \exp\left(\mathbf{w}_{jt}\boldsymbol{\gamma}\right)}\right)\right) & \text{if } l \neq j \end{cases}, \tag{J.5}$$

$$\frac{\partial \eta_{jt}}{\partial d_{lt}} = \begin{cases} -\frac{\mu_1}{N_p}\sum_{i=1}^{N_p} \alpha_i^d p_{ijt}\left(1 - p_{ijt}\right) \times \exp\left(\tau \mathbf{Z}^{-1}\left(\frac{\exp\left(\mathbf{w}_{jt}\boldsymbol{\gamma}\right)}{1 + \exp\left(\mathbf{w}_{jt}\boldsymbol{\gamma}\right)}\right)\right) & \text{if } l = j \\ -\frac{\mu_1}{N_p}\sum_{i=1}^{N_p} \alpha_i^d p_{ijt} p_{ilt} \times \exp\left(\tau \mathbf{Z}^{-1}\left(\frac{\exp\left(\mathbf{w}_{jt}\boldsymbol{\gamma}\right)}{1 + \exp\left(\mathbf{w}_{jt}\boldsymbol{\gamma}\right)}\right)\right) & \text{if } l \neq j \end{cases}, \tag{J.6}$$

$$\frac{\partial \zeta_{jt}}{\partial \Delta k_{lt}} = \begin{cases} -c_{jt} \times \frac{\mu_1}{N_p}\sum_{i=1}^{N_p} \alpha_i^k p_{ijt}\left(1 - p_{ijt}\right) \times \exp\left(\tau \mathbf{Z}^{-1}\left(\frac{\exp\left(\mathbf{w}_{jt}\boldsymbol{\gamma}\right)}{1 + \exp\left(\mathbf{w}_{jt}\boldsymbol{\gamma}\right)}\right)\right) & \text{if } l = j \\ -c_{jt} \times \frac{\mu_1}{N_p}\sum_{i=1}^{N_p} \alpha_i^k p_{ijt} p_{ilt} \times \exp\left(\tau \mathbf{Z}^{-1}\left(\frac{\exp\left(\mathbf{w}_{jt}\boldsymbol{\gamma}\right)}{1 + \exp\left(\mathbf{w}_{jt}\boldsymbol{\gamma}\right)}\right)\right) & \text{if } l \neq j \end{cases}, \tag{J.7}$$

$$\frac{\partial \zeta_{jt}}{\partial d_{lt}} = \begin{cases} 1 - c_{jt} \times \frac{\mu_1}{N_p}\sum_{i=1}^{N_p} \alpha_i^d p_{ijt}\left(1 - p_{ijt}\right) \times \exp\left(\tau \mathbf{Z}^{-1}\left(\frac{\exp\left(\mathbf{w}_{jt}\boldsymbol{\gamma}\right)}{1 + \exp\left(\mathbf{w}_{jt}\boldsymbol{\gamma}\right)}\right)\right) & \text{if } l = j \\ -c_{jt} \times \frac{\mu_1}{N_p}\sum_{i=1}^{N_p} \alpha_i^d p_{ijt} p_{ilt} \times \exp\left(\tau \mathbf{Z}^{-1}\left(\frac{\exp\left(\mathbf{w}_{jt}\boldsymbol{\gamma}\right)}{1 + \exp\left(\mathbf{w}_{jt}\boldsymbol{\gamma}\right)}\right)\right) & \text{if } l \neq j \end{cases}. \tag{J.8}$$

α_i^k is the parameter of the capacity expansion, Δk_{jt}, α_i^d is the parameter of the debt, d_{jt}.

The determinant of the Jacobian matrix used to transform from $\boldsymbol{\omega}_j$ to $\mathbf{r}_j$ is,

$$J_{(\boldsymbol{\omega}_j \to \mathbf{r}_j)} = \left\| \nabla_{\mathbf{r}_j} \boldsymbol{\omega}_j \right\| = \left\| \begin{bmatrix} \frac{\partial \omega_{j1}}{\partial r_{j1}} & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \frac{\partial \omega_{jT}}{\partial r_{jT}} \end{bmatrix}_{T \times T} \right\|, \tag{J.9}$$

where the partial derivatives are specified as,

$$\frac{\partial \omega_{jt}}{\partial r_{lt}} = 1 - \beta_j \left(\sum_{j'=1}^{J_t} \left(\frac{\partial p_{j't}}{\partial r_{lt}} \times r_{j't} \right) + p_{lt} \right) \tag{J.10}$$

$$\frac{\partial p_{jt}}{\partial r_{lt}} = \begin{cases} \frac{1}{N_p}\sum_{i=1}^{N_p} \alpha_i^r p_{ijt}\left(1 - p_{ijt}\right) & \text{if } l = j \\ -\frac{1}{N_p}\sum_{i=1}^{N_p} \alpha_i^r p_{ijt} p_{ilt} & \text{if } l \neq j \end{cases}. \tag{J.11}$$

α_i^r is the parameter of the stock return, r_{jt}.

Appendix K MCMC Algorithm for Models in Chapter 3

1. Generate $\boldsymbol{\theta}$

A RW Metropolis chain is used to generate draws of $\boldsymbol{\theta}$, and the equation is,

$$\boldsymbol{\theta}^{\text{new}} = \boldsymbol{\theta}^{\text{old}} + \text{MVN}(0, s_1^2 \boldsymbol{\Sigma}_1), \tag{K.1}$$

where s_1^2 is a scaling constant and $\boldsymbol{\Sigma}_1$ is the candidate covariance matrix.

The posterior used for drawing $\boldsymbol{\theta}$ is specified as,

$$\pi\left(\boldsymbol{\theta} | \boldsymbol{\varphi}, \beta_j \overline{\boldsymbol{\alpha}}, \sigma_d^2\right) \propto L\left(\overline{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha, \sigma_d^2, \boldsymbol{\varphi}, \boldsymbol{\Sigma}_s, \beta_j, \sigma_j^2\right) \times \pi(\boldsymbol{\theta}). \tag{K.2}$$

2. Generate $\boldsymbol{\varphi}$

A RW Metropolis chain is used to generate draws of $\boldsymbol{\varphi}$, and the equation is,

$$\boldsymbol{\varphi}^{\text{new}} = \boldsymbol{\varphi}^{\text{old}} + \text{MVN}(0, s_2^2 \boldsymbol{\Sigma}_2), \tag{K.3}$$

where s_2^2 is a scaling constant and $\boldsymbol{\Sigma}_2$ is the candidate covariance matrix.

The posteriors used for drawing $\boldsymbol{\varphi}$ for both cases are specified as,

$$\pi(\boldsymbol{\varphi} | \boldsymbol{\Sigma}_s, \boldsymbol{\theta}) \propto L\left(\overline{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha, \sigma_d^2, \boldsymbol{\varphi}, \boldsymbol{\Sigma}_s, \beta_j, \sigma_j^2\right) \times \pi(\boldsymbol{\varphi}). \tag{K.4}$$

3. Generate $\overline{\boldsymbol{\alpha}}, \sigma_d^2$

A Gibbs sampler is employed to implement draws of $\overline{\boldsymbol{\alpha}}$ and σ_d^2 based on the univariate regression, which is given by,

$$\delta_{jt} = \mathbf{X}_{jt} \overline{\boldsymbol{\alpha}} + \xi_{jt} \text{ where } \xi_{jt} \sim N\left(0, \sigma_d^2\right). \tag{K.5}$$

The posteriors used for drawing $\overline{\boldsymbol{\alpha}}$ and σ_d^2 are specified as,

$$\overline{\boldsymbol{\alpha}} | \boldsymbol{\theta}, \sigma_d^2 \sim N\left(\widetilde{\boldsymbol{\alpha}}, \sigma_d^2 (\mathbf{X}'\mathbf{X} + \mathbf{V}_{\overline{\alpha}})^{-1}\right) \text{ with } \widetilde{\boldsymbol{\alpha}} = (\mathbf{X}'\mathbf{X} + \mathbf{V}_{\overline{\alpha}})^{-1} (\mathbf{X}'\mathbf{X}\widehat{\boldsymbol{\alpha}} + \mathbf{V}_{\overline{\alpha}} \overline{\overline{\boldsymbol{\alpha}}}), \tag{K.6}$$

$$\sigma_d^2 \left| \overline{\boldsymbol{\alpha}}, \boldsymbol{\theta} \sim \frac{v_{d1} s_{d1}^2}{\chi^2_{v_{d1}}} \right. \qquad \text{with } v_{d1} = v_{d0} + n_d, s_{d1}^2 = \frac{v_{d0} s_{d0}^2 + n s_d^2}{v_{d0} + n}, \tag{K.7}$$

where $\mathbf{X} = \left(\mathbf{X}'_{11}, \dots., \mathbf{X}'_{J_1 1}, \dots, \mathbf{X}'_{J_T T}\right)'$, $n s_d^2 = \boldsymbol{\xi}'\boldsymbol{\xi}$, with $\boldsymbol{\xi} = (\xi_{11}, \dots, \xi_{J_1 1}, \dots, \xi_{J_T T})'$, and n is the number of observations.

4. Generate $\mathbf{\Sigma}_s$

The covariance matrix of error in both capacity expansion and debt equations is drawn from the inverted Wishart distribution, and the corresponding posteriors are,

$$\mathbf{\Sigma}_s|\boldsymbol{\varphi} \sim IW(\mathbf{V}_{s0} + n, \mathbf{S}_{s0} + \mathbf{S}) \text{ with } \mathbf{S} = \sum_{t=1}^{T}\sum_{j=1}^{J_t}\left(\begin{pmatrix}\eta_{jt}\\ \zeta_{jt}\end{pmatrix}(\eta_{jt} \quad \zeta_{jt})\right). \tag{K.8}$$

5. Generate β_j, σ_j^2

For each firm j, the random coefficient β_j and the error σ_j^2 in the stock return equation can be drawn from the univariate linear regression by using the Gibbs sampler. The equation is specified as,

$$r_{jt} = r_t^0 + \beta_j\left(\sum_{j=1}^{J_t}(p_{jt} \times r_{jt}) - r_t^0\right) + \omega_{jt} \text{ where } \omega_{jt} \sim N\left(0, \sigma_j^2\right), \tag{K.9}$$

and the posteriors are,

$$\beta_j|\bar{\beta}, \sigma_\beta^2, \sigma_j^2, \boldsymbol{\theta} \sim N\left(\tilde{\beta}, \sigma_j^2\left(\mathbf{R}'\mathbf{R} + \frac{1}{\sigma_\beta^2}\right)^{-1}\right) \text{with } \tilde{\beta} = \left(\mathbf{R}'\mathbf{R} + \frac{1}{\sigma_\beta^2}\right)^{-1}\left(\mathbf{R}'\mathbf{R}\hat{\beta}_j + \frac{1}{\sigma_\beta^2}\bar{\beta}\right), \tag{K.10}$$

$$\sigma_j^2|\beta_j \sim \frac{v_{r1}s_{r1}^2}{\chi_{v_{r1}}^2} \qquad \text{with } v_{r1} = v_{r0} + n_r, s_{r1}^2 = \frac{v_{r0}s_j^2 + ns_r^2}{v_{r0} + n_r}, \tag{K.11}$$

where $\mathbf{R} = (R_1, \dots, R_T)$, with $R_t = \sum_{j=1}^{J_t}(p_{jt} \times r_{jt}) - r_t^0$, $ns_r^2 = \boldsymbol{\omega}_j'\boldsymbol{\omega}_j$, with $\boldsymbol{\omega}_j = (\omega_{j1}, \dots, \omega_{jT})'$, and n_r is the number of observations for each firm.

6. Generate $\bar{\beta}, \sigma_\beta^2$,

Given β_j and σ_j^2, the hyper-parameters of $\bar{\beta}$ and σ_β^2 can also be accomplished by using the Gibbs sampler. Since only one fixed coefficient and one error term are required to be estimated in the simplest case of the CAPM, we still draw $\bar{\beta}$ and σ_β^2 from the univariate linear regression, which is given by,

$$\beta_j = \bar{\beta} + v_j \qquad v_j \sim N\left(0, \sigma_\beta^2\right), \tag{K.12}$$

and the posteriors are,

$$\bar{\beta}|\sigma_\beta^2, \beta_j, \sigma_j^2 \sim N\left(\tilde{\tilde{\beta}}, \sigma_\beta^2\left(1+\frac{1}{\sigma_{\bar{\beta}}^2}\right)^{-1}\right) \text{with } \tilde{\tilde{\beta}} = \left(1+\frac{1}{\sigma_{\bar{\beta}}^2}\right)^{-1}\left(\hat{\beta}+\frac{1}{\sigma_{\bar{\beta}}^2}\bar{\bar{\beta}}\right), \tag{K.13}$$

$$\sigma_\beta^2|\bar{\beta}, \beta_j, \sigma_j^2 \sim \frac{v_{\beta 1} s_{\beta 1}^2}{\chi_{v_{\beta 1}}^2} \qquad \text{with } v_{\beta 1} = v_{\beta 0} + n_\beta, s_{\beta 1}^2 = \frac{v_{\beta 0} s_{\beta 0}^2 + n s_\beta^2}{v_{\beta 0} + n_\beta}, \tag{K.14}$$

where $ns_\beta^2 = \mathbf{v}'\mathbf{v}$, with $\mathbf{v} = (v_1, \dots, v_{J_t})'$, and n_β is the number of firms.

Appendix L Data Sources and Variable Definitions in Chapter 3

Data on capacity expansions are obtained from the World Fab Watch reports provided by Semiconductor Equipment and Materials International's (SEMI) Industry Research and Statistics department, while index shares are taken from iShares sponsored by the Black Rock Institutional Trust Company, which are weightings of stock in SOX based on the adjusted market value. Other financial data are collected from either annual reports of listed firms, or Datastream, a database providing firms' public information.

To be specific, stock return is defined by the percentage of change in price to last period's price of the stock, which is consistent with literature in the financial field. A leverage ratio is typically referred to as the financial measurement of debt variable. It is scaled by firm asset to ensure the better smoothness. Besides, firm size, strategic holdings, asset efficiency, ROA, and inventory turnover are chosen to estimate firm attributes. Based on the study of Kesavan et al. (2010), gross margin, accounts payable to inventory, slack resources, sales per share, financial activities, and inventory performance are used to forecast sales at the firm level. Financial characteristics are measured by EPS, cash flow margin, and Tobin's Q. Moreover, ROS and operating profitability are regarded as proxies of profit shifters, while SGA/asset ratio and COGS/asset ratio are used to evaluate cost shifters. The definitions of individual variables are shown in Table L.1.

Table L.1: Variable definitions and measurement

Category	Variable	Symbol	Definition/Measurement
Endogenous Variables	Capacity Expansion	CE	$\mathrm{Z}(\mathrm{Capacity\ Expansion}_t)$
	Stock Return	SR	$(\mathrm{Price}_t - \mathrm{Price}_{t-1})/\mathrm{Price}_t$
	Leverage Ratio	LR	$\mathrm{Debt}_t/\mathrm{Asset}_t$
Firm Attributes	Firm Size	FS	$\log(\mathrm{Employee\ Number}_t)$
	Strategic Holdings	SH	NOSHST
	Asset Efficiency	AE	$\mathrm{Sales}_t/\mathrm{Asset}_t$
	ROA	ROA	$\mathrm{EBIT}_t/\mathrm{Asset}_{t-1}$
	Inventory Turnover	IT	$\mathrm{COGS}_t/\mathrm{Inventory}_{t-1}$

Appendix L

Sales Forecasts	Gross Margin	GM	$(\text{Sales}_t - \text{COGS}_t)/\text{Sales}_t$
	Accounts Payable to Inventory	API	$\text{Accounts Payable}_t/\text{Inventory}_t$
	Slack Resources	SR	$\log(\text{Cash and Short Term Investments}_t + \text{Total Receivables}_t)$
	Sales per Share	SPS	$\text{Sales}_t/\text{Shares Outstanding}_t$
	Financial Activities	FA	$\text{Net Proceeds from Sale}_t/\text{Asset}_t$
	Inventory Performance	IP	$\text{Inventory}_t/\text{Sales}_t$
Financial Characteristics	EPS	EPS	$\text{Net Income}_t/\text{Shares Outstanding}$
	Cash Flow Margin	GFM	$\text{Cash Flow}_t/\text{Sales}_t$
	Tobin's Q	TQ	$\text{Market Value}_t/\text{Asset}_t$
Profit Shifters	ROS	ROS	$\text{EBIT}_t/\text{Sales}_{t-1}$
	Operating Profitability	OP	$\text{Operating Profit}_t/\text{Equity}_t$
Cost Shifters	SGA/Asset Ratio	SA	$\text{SGA}_t/\text{Asset}_t$
	COGS/Asset Ratio	CA	$\text{COGS}_t/\text{Asset}_t$

Notes: $\text{Z}(\cdot)$ is the normalisation of values. NOSHST refers to the percentage of total shares in issue held strategically and not available to ordinary shareholders.

Appendix M Algorithm of Computing Counterfactual Equilibria in Chapter 3

In the counterfactual analyses for the effect of capacity expansion on profit, stock return, and firm value, respectively, the following procedures are used to evaluate the counterfactual equilibria with the change of the capacity expansion value, which are,

1. Given the estimated parameters for each iteration n, calculate firm j's debt at period t, d_{jt}, with the change of capacity expansion levels Δk_{jt} in a range of -1 and 4, for $\forall j \in L(J_t), t \in L(T)$. The formula used to estimate the debt is the combination of equations (66) to (68).
2. For each iteration n, start with an initial guess of each firm j's stock return at period t, r_{jt}^0. When the value of capacity expansion Δk_{jt} is changed in a range of -1 and 4, for $\forall j \in L(J_t), t \in L(T)$, compute the corresponding index share p_{jt} by solving equation (4) with the value of debt calculated in step 1.
3. Given the estimated parameters and index share p_{jt} for each iteration n, re-calculate the stock return r_{jt}^1 based on the CAPM derived by equation (72).
4. Update r_{jt}^0 with r_{jt}^1 in each iteration n, and repeat the above two steps until convergence, which is $\sum_{t=1}^{T} \sum_{j=1}^{J_t} \left| r_{jt}^1 - r_{jt}^0 \right| \leq \mathrm{tol} = 10^{-10}$. We thus obtain the equilibria of index share and stock return for each iteration n.
5. By using equation (60), calculate the profit π_{jt} with the estimated parameters and the equilibrium of index share for each iteration n.
6. By using equation (101), calculate the firm value V_{jt} with the estimated parameters, the equilibria of stock return and profit calculated in steps 4 and 5 for each iteration n.
7. Repeat the above steps to obtain the equilibria of profit, stock returns, and firm value for all iterations.

Appendix N Determinants of Jacobian Matrices for Models in Chapter 4

The determinant of the Jacobian matrix used to transform from $\boldsymbol{\eta}_t$ to $\Delta\mathbf{k}_t$ is given by,

$$J_{(\boldsymbol{\eta}_t \to \Delta\mathbf{k}_t)} = \|\nabla_{\Delta\mathbf{k}_t}\boldsymbol{\eta}_t\| = \left\| \begin{bmatrix} \frac{\partial\eta_{1t}}{\partial\Delta k_{1t}} & \cdots & \frac{\partial\eta_{1t}}{\partial\Delta k_{J_t t}} \\ \vdots & \ddots & \vdots \\ \frac{\partial\eta_{J_t t}}{\partial\Delta k_{1t}} & \cdots & \frac{\partial\eta_{J_t t}}{\partial\Delta k_{J_t t}} \end{bmatrix}_{J_t\times J_t} \right\|, \tag{N.1}$$

where the partial derivatives are given by,

$$\frac{\partial\eta_{jt}}{\partial\Delta k_{lt}} = \frac{\partial\Delta k_{jt}}{\partial\Delta k_{lt}} - \max\left(\mu_1\frac{\partial p_{jt}}{\partial\Delta k_{lt}} \times \exp\left(\tau Z^{-1}\left(\frac{\exp(\mathbf{w}_{jt}\boldsymbol{\gamma})}{1+\exp(\mathbf{w}_{jt}\boldsymbol{\gamma})}\right)\right), \frac{-g_1}{\exp(\mathbf{s}_{jt}\boldsymbol{\rho})} \times \frac{\partial p_{jt}}{\partial\Delta k_{lt}}\right), \tag{N.2}$$

$$\frac{\partial p_{jt}}{\partial\Delta k_{lt}} = \begin{cases} \frac{1}{N_p}\sum_{i=1}^{N_p}\alpha_i^k p_{ijt}(1-p_{ijt}) & \text{if } l=j \\ -\frac{1}{N_p}\sum_{i=1}^{N_p}\alpha_i^k p_{ijt}p_{ilt} & \text{if } l\neq j \end{cases}, \tag{N.3}$$

$$p_{ijt} = \frac{\exp(\delta_{jt}+\mathbf{X}_{jt}\mathbf{v}_i)}{1+\sum_{j=1}^{J_t}\exp(\delta_{jt}+\mathbf{X}_{jt}\mathbf{v}_i)}. \tag{N.4}$$

α_i^k is the parameter of capacity expansion in the utility function (1).

The determinant of the Jacobian matrix used to transform from $\mathbf{P}_t$ to $\boldsymbol{\xi}_t$ is given by,

$$J_{(\mathbf{P}_t\to\boldsymbol{\xi}_t)} = J_{(\mathbf{p}_t\to\boldsymbol{\xi}_t)} = \|\nabla_{\boldsymbol{\xi}_t}\mathbf{p}_t\| = \left\| \begin{bmatrix} \frac{\partial p_{1t}}{\partial\xi_{1t}} & \cdots & \frac{\partial p_{1t}}{\partial\xi_{J_t t}} \\ \vdots & \ddots & \vdots \\ \frac{\partial p_{J_t t}}{\partial\xi_{1t}} & \cdots & \frac{\partial p_{J_t t}}{\partial\xi_{J_t t}} \end{bmatrix}_{J_t\times J_t} \right\|, \tag{N.5}$$

where the first equation is satisfied due to the fact that the index share p_{jt} is assumed to be equal to the share observations P_{jt} based on the BLP model proposed by Berry et al. (1995), and the partial derivatives are specified as,

$$\frac{\partial p_{jt}}{\partial \xi_{lt}} = \begin{cases} \dfrac{1}{N_p}\displaystyle\sum_{i=1}^{N_p} p_{ijt}\left(1 - p_{ijt}\right) & \text{if } l = j \\ -\dfrac{1}{N_p}\displaystyle\sum_{i=1}^{N_p} p_{ijt}p_{ilt} & \text{if } l \neq j \end{cases}. \qquad (\mathrm{N.6})$$

It is found that the Jacobian matrix is only a function of $\mathbf{\Sigma}_{\alpha}$ when P_{jt} and $\mathbf{X}_{jt}$ are given, as δ_{jt} is obtained by using the BLP Contraction Mapping conditional on the parameter $\mathbf{\Sigma}_{\alpha}$.

Appendix O MCMC Algorithm for Models in Chapter 4

1. Generate $\boldsymbol{\varphi}$

A RW Metropolis chain is used to generate draws of $\boldsymbol{\varphi}$, and the equation is,

$$\boldsymbol{\varphi}^{\text{new}} = \boldsymbol{\varphi}^{\text{old}} + \text{MVN}(0, s_1^2 \boldsymbol{\Sigma}_1), \tag{O.1}$$

where s_1^2 is a scaling constant and $\boldsymbol{\Sigma}_1$ is the candidate covariance matrix.

The posteriors used for drawing $\boldsymbol{\varphi}$ for both cases are specified as,

$$\pi(\boldsymbol{\varphi} | \sigma_s^2, \overline{\boldsymbol{\alpha}}, \boldsymbol{\theta}) \propto L\left(\boldsymbol{\varphi}, \sigma_s^2, \overline{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha, \sigma_d^2\right) \times \pi(\boldsymbol{\varphi}). \tag{O.2}$$

2. Generate $\boldsymbol{\theta}$

A RW Metropolis chain is used to generate draws of $\boldsymbol{\theta}$, and the equation is,

$$\boldsymbol{\theta}^{\text{new}} = \boldsymbol{\theta}^{\text{old}} + \text{MVN}(0, s_2^2 \boldsymbol{\Sigma}_2), \tag{O.3}$$

where s_2^2 is a scaling constant and $\boldsymbol{\Sigma}_2$ is the candidate covariance matrix.

The posterior used for drawing $\boldsymbol{\theta}$ is specified as,

$$\pi\left(\boldsymbol{\theta} | \boldsymbol{\varphi}, \overline{\boldsymbol{\alpha}}, \sigma_d^2\right) \propto L\left(\boldsymbol{\varphi}, \sigma_s^2, \overline{\boldsymbol{\alpha}}, \boldsymbol{\Sigma}_\alpha, \sigma_d^2\right) \times \pi(\boldsymbol{\theta}). \tag{O.4}$$

3. Generate σ_s^2

The variance of error in capacity expansion equation is drawn from the inverted gamma distribution, and the corresponding posterior is,

$$\sigma_s^2 | \boldsymbol{\varphi} \sim \frac{v_{s1} s_{s1}^2}{\chi_{v_{s1}}^2} \text{ with } v_{s1} = v_{s0} + n, s_{s1}^2 = \frac{v_{s0} s_{s0}^2 + n s_s^2}{v_{s0} + n}, \tag{O.5}$$

where $n s_s^2 = \boldsymbol{\eta}' \boldsymbol{\eta}$, with $\boldsymbol{\eta} = (\eta_{11}, \dots, \eta_{J_1 1}, \dots, \eta_{J_T T})'$, and n is the number of observations.

4. Generate $\overline{\boldsymbol{\alpha}}$ and σ_d^2

A Gibbs sampler is employed to implement draws of $\overline{\boldsymbol{\alpha}}$ and σ_d^2 based on the univariate regression, which is given by,

$$\delta_{jt} = \mathbf{X}_{jt} \overline{\boldsymbol{\alpha}} + \xi_{jt} \quad \xi_{jt} \sim N\left(0, \sigma_d^2\right). \tag{O.6}$$

Appendix O

The posteriors used to draw $\overline{\boldsymbol{\alpha}}$ and σ_d^2 are specified as,

$$\overline{\boldsymbol{\alpha}}|\boldsymbol{\theta},\sigma_d^2 \sim N\left(\tilde{\boldsymbol{\alpha}},\sigma_d^2(\mathbf{X}'\mathbf{X}+\mathbf{V}_{\overline{\alpha}})^{-1}\right) \text{ with } \tilde{\boldsymbol{\alpha}}=(\mathbf{X}'\mathbf{X}+\mathbf{V}_{\overline{\alpha}})^{-1}\,(\mathbf{X}'\mathbf{X}\hat{\boldsymbol{\alpha}}+\mathbf{V}_{\overline{\alpha}}\overline{\overline{\boldsymbol{\alpha}}}), \tag{O.7}$$

$$\sigma_d^2|\overline{\boldsymbol{\alpha}},\boldsymbol{\theta} \sim \frac{v_{d1}s_{d1}^2}{\chi_{v_{d1}}^2} \qquad \text{with } v_{d1}=v_{d0}+n_d, s_{d1}^2=\frac{v_{d0}s_{d0}^2+ns_d^2}{v_{d0}+n}, \tag{O.8}$$

where $\mathbf{X}=\left(\mathbf{X}'_{11},\dots.,\mathbf{X}'_{J_1 1},\dots,\mathbf{X}'_{J_T T}\right)'$, $ns_d^2=\boldsymbol{\xi}'\boldsymbol{\xi}$, with $\boldsymbol{\xi}=(\xi_{11},\dots,\xi_{J_1 1},\dots,\xi_{J_T T})'$, and n is the number of observations.

Appendix P Data Sources and Variable Definitions in Chapter 4

Data on capacity expansions are obtained from the World Fab Watch reports provided by Semiconductor Equipment and Materials International's (SEMI) Industry Research and Statistics department, while index shares are taken from iShares sponsored by the Black Rock Institutional Trust Company, which are weightings of stock in SOX based on the adjusted market value. Other financial data are collected from either annual reports of listed firms, or Datastream, a database providing firms' public information.

To be specific, stock return is defined by the percentage of change in price to last period's price of the stock, which is consistent with literature in the financial field. A leverage ratio is typically referred to as the financial measurement of debt repayment. It is scaled by firm asset to ensure the better smoothness. Besides, firm size, strategic holdings, asset efficiency, ROA, and inventory turnover are chosen to estimate firm attributes. Based on the studies of Kesavan et al. (2010) and Roth (2013), financial activities, book value per share, gross margin, and inventory are used to forecast sales in firm level, and financial characteristics are measured by inventory/asset ratio, B/M ratio, cash flow margin, and slack resources. Moreover, EPS and EBITDA/sales ratio are regarded as proxies of profit shifters, while COGS/asset ratio and sales per share are used to evaluate cost shifters. The detailed definitions of individual variables are specified in Table P.1.

Table P.1: Variable definitions and measurement

Category	Variable	Symbol	Definition/Measurement
	Stock Return	SR	$(\text{Price}_t - \text{Price}_{t-1})/\text{Price}_t$
	Leverage Ratio	LR	$\text{Debt}_t/\text{Asset}_t$
Firm Attributes	Firm Size	FS	$\log(\text{Employee Number}_t)$
	Strategic Holdings	SH	NOSHST
	Asset Efficiency	AE	$\text{Sales}_t/\text{Asset}_t$
	ROA	ROA	$\text{EBIT}_t/\text{Asset}_{t-1}$
	Inventory Turnover	IT	$\text{COGS}_t/\text{Inventory}_{t-1}$
Sales Forecasts	Financial Activities	FA	$\text{Net Proceeds from Sale}_t/\text{Asset}_t$
	Book Value per Share	BVPS	$\text{Equity}_t/\text{Shares Outstanding}_t$
	Gross Margin	GM	$(\text{Sales}_t - \text{COGS}_t)/\text{Sales}_t$
	Inventory	IN	$\log(\text{Inventory}_t)$
Financial Characteristics	Inventory/Asset Ratio	I/A	$\text{Inventory}_t/\text{Asset}_t$
	B/M Ratio	B/M	$\text{Equity}_t/\text{Market Cap}_t$
	Cash Flow Margin	GFM	$\text{Cash Flow}_t/\text{Sales}_t$

	Slack Resources	SR	$\log(\text{Cash and Short Term Investments}_t + \text{Total Receivables}_t)$
Profit Shifters	EPS	EPS	$\text{Net Income}_t/\text{Shares Outstanding}_t$
	EBITDA/Sales Ratio	E/S	$\text{EBITDA}_t/\text{Sales}_{t-1}$
Unit Profits	COGS / Asset Ratio	C/A	$\text{COGS}_t/\text{Asset}_t$
	Sales per Share	SPS	$\text{Sales}_t/\text{Shares Outstanding}_t$

Notes: $Z(\cdot)$ is the normalisation of values. NOSHST refers to the percentage of total shares in issue held strategically and not available to ordinary shareholders.

Appendix Q Algorithm of Computing Counterfactual Equilibria in Chapter 4

In the counterfactual analyses for the effect of fixed cost on capacity expansion and firm profit, respectively, the following procedures are used to evaluate the counterfactual equilibria with the change of the fixed cost value, which are,

1. For each iteration n, start with an initial guess of each firm j's capacity expansion at period t, Δk_{jt}^{0}, and compute the corresponding index share p_{jt} by solving equation (4).
2. Given the estimated parameters and index share p_{jt} for each iteration n, re-calculate the capacity expansion Δk_{jt}^{1} derived by equations (104) to (107), with the change of fixed cost A_{jt} for $\forall j \in L(J_t), t \in L(T)$.
3. Update Δk_{jt}^{0} with Δk_{jt}^{1}, and repeat the above two steps until the convergence, which is, $\sum_{t=1}^{T} \sum_{j=1}^{J_t} \left| \Delta k_{jt}^{1} - \Delta k_{jt}^{0} \right| \leq \text{tol} = 10^{-10}$. We thus obtain the equilibria of capacity expansion and index share for each iteration n.
4. By using equation (102), calculate profits π_{jt} depending on different settings of h_{jt} with the estimated parameters and the equilibria calculated in step 3 for each iteration n.
5. Repeat the above steps to obtain the equilibria of capacity expansion and profits for all iterations.

List of References

Abel, A. B., J. C. Eberly. 1998. The mix and scale of factors with irreversibility and fixed costs of investment. McCallum, Plosser, eds. *Carnegie-Rochester Conference Series on Public Policy*, Vol. 48. Elsevier Science, 101–135.

Aharoni, G., Grundy, B., Zeng, Q. 2013. Stock returns and the Miller Modigliani valuation formula: Revisiting the Fama French analysis. *Journal of Financial Economics*, 110(2), 347-357.

Ahmed, S., Garcia, R. 2003. Dynamic capacity acquisition and assignment under uncertainty. *Annals of Operations Research*, 124(1-4), 267-283.

Ahmed, S., King, A. J., Parija, G. 2003. A multi-stage stochastic integer programming approach for capacity expansion under uncertainty. *Journal of Global Optimization*, 26(1), 3-24.

Ahmed, S., Sahinidis, N. V. 2003. An approximation scheme for stochastic integer programs arising in capacity expansion. *Operations Research*, 51(3), 461-471.

Anderson, E. J., Sunny Yang, S. J. 2015. The timing of capacity investment with lead times: When do firms act in unison?. *Production and Operations Management* 24(1) 21-41.

Angelus, A., Porteus, E. L. 2002. Simultaneous capacity and production management of short-life-cycle, produce-to-stock goods under stochastic demand. *Management Science*, 48(3), 399-413.

Anupindi, R., Jiang, L. 2008. Capacity investment under postponement strategies, market competition, and demand uncertainty. *Management Science*, 54(11), 1876-1890.

Asano, H. 2002. An empirical analysis of lumpy investment: the case of US petroleum refining industry. *Energy Economics*, 24(6), 629-645.

Atamtürk, A., Hochbaum, D. S. 2001. Capacity acquisition, subcontracting, and lot sizing. *Management Science*, 47(8), 1081-1100.

Aylward, A., Glen, J. 2000. Some international evidence on stock prices as leading indicators of economic activity. *Applied Financial Economics*, 10(1) 1-14.

Aytac, B., Wu, S. D. 2013. Characterization of demand for short life-cycle technology products. *Annals of Operations Research*, *203*(1), 255-277.

Bahinipati, B. K., Deshmukh, S. G. 2012. E-markets and supply chain collaboration: a literature-based review of contributions with specific reference to the semiconductor industries. *Logistics Research*, *4*(1-2), 19-38.

Bahinipati, B. K., Kanda, A., Deshmukh, S. G. 2009. Horizontal collaboration in semiconductor manufacturing industry supply chain: An evaluation of collaboration intensity index. *Computers and Industrial Engineering*, *57*(3), 880-895.

Barahona, F., Bermon, S., Günlük, O., Hood, S. 2005. Robust capacity planning in semiconductor manufacturing. *Naval Research Logistics (NRL)*, 52(5), 459-468.

Bean, J. C., Higle, J. L., Smith, R. L. 1992. Capacity expansion under stochastic demands. *Operations Research*, 40(3-supplement-2), S210-S216.

Benavides, D. L., Duley, J. R., Johnson, B. E. 1999. As good as it gets: optimal fab design and deployment. *IEEE Transactions on Semiconductor Manufacturing*, 12(3), 281-287.

Berk, J., DeMarzo, P., Harford, J., Ford, G., Mollica, V., Finch, N. 2013. *Fundamentals of corporate finance*. Pearson Higher Education AU.

Berry, S. T. 1994. Estimating discrete-choice models of product differentiation. *The RAND Journal of Economics*, 242-262.

Berry, S., Levinsohn, J., Pakes, A. 1995. Automobile prices in market equilibrium. *Econometrica: Journal of the Econometric Society*, 841-890.

Bihlmaier, R., Koberstein, A., Obst, R. 2009. Modeling and optimazing of strategic and tactical production planning in the automotive industry under uncertainty. In *Supply Chain Planning* (pp. 1-26). Springer, Berlin, Heidelberg.

Birge, J. R. 2014. OM forum—Operations and finance interactions. *Manufacturing and Service Operations Management*, 17(1), 4-15.

Birge, J. R., Louveaux, F. 2011. *Introduction to stochastic programming*. Springer Science and Business Media.

Birge, J. R., Xu, X. 2011. Firm profitability, inventory volatility, and capital structure. *SSRN*, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1914690

Black, F. 1972. Capital market equilibrium with restricted borrowing. *The Journal of Business*, 45(3), 444-455.

Bodie, Z., Kane, A., Marcus, A. J. 2011. *Investment and portfolio management*. McGraw-Hill Irwin.

Boyabatlı, O., Toktay, L. B. 2011. Stochastic capacity investment and flexible vs. dedicated technology choice in imperfect capital markets. *Management Science*, 57(12), 2163-2179.

Brooks, S., Gelman, A., Jones, G., Meng, X. L. (Eds.). 2011. *Handbook of markov chain monte carlo*. CRC press.

Buffa, E.S. 1983. *Modern Production/Operations Management*. Wiley, New York.

Buzacott, J. A., Zhang, R. Q. 2004. Inventory management with asset-based financing. *Management Science*, 50(9), 1274-1292.

Cachon, G. P. 2003. Supply chain coordination with contracts. *Handbooks in operations research and management science*, *11*, 227-339.

Cachon, G. P., Lariviere, M. A. 1999. Capacity choice and allocation: Strategic behavior and supply chain performance. *Management Science*, 45(8), 1091-1108.

Çatay, B., Erengüç, Ş. S., Vakharia, A. J. 2003. Tool capacity planning in semiconductor manufacturing. *Computers and Operations Research*, 30(9), 1349-1366.

Chakravarty, A. K. 2005. Global plant capacity and product allocation with pricing decisions. *European Journal of Operational Research*, 165(1), 157-181.

Chen, T. L., Lin, J. T., Fang, S. C. 2010. A shadow-price based heuristic for capacity planning of TFT-LCD manufacturing. *Journal of Industrial and Management Optimization*, 6(1), 209-239.

Chen, T. L., Lu, H. C. 2012. Stochastic multi-site capacity planning of TFT-LCD manufacturing using expected shadow-price based decomposition. *Applied Mathematical Modelling*, 36(12), 5901-5919.

Chen, Y. Y., Chen, T. L., Liou, C. D. 2013. Medium-term multi-plant capacity planning problems considering auxiliary tools for the semiconductor foundry. The International *Journal of Advanced Manufacturing Technology*, 64(9-12), 1213-1230.

Chen, X., Simchi-Levi, D. 2004. Coordinating inventory control and pricing strategies with random demand and fixed ordering cost: The finite horizon case. *Operations Research*, 52(6), 887-896.

Chen, Z. L., Li, S., Tirupati, D. 2002. A scenario-based stochastic programming approach for technology and capacity planning. *Computers and Operations Research*, 29(7), 781-806.

Chod, J., Lyandres, E. 2011. Strategic IPOs and product market competition. *Journal of Financial Economics,* 100(1), 45-67.

Choi, J. J., Hauser, S., Kopecky, K. J. 1999. Does the stock market predict real activity? Time series evidence from the G-7 countries. *Journal of Banking and Finance*, 23(12) 1771-1792.

Christie, R. M., Wu, S. D. 2002. Semiconductor capacity planning: stochastic modelingand computational studies. *IIE Transactions*, 34(2), 131-143.

Chronopoulos, M., De Reyck, B., Siddiqui, A. 2011. Optimal investment under operational flexibility, risk aversion, and uncertainty. *European Journal of Operational Research*, 213(1), 221-237.

DeAngelo, H., DeAngelo, L., Whited, T. M. 2011. Capital structure dynamics and transitory debt. *Journal of Financial Economics*, *99*(2), 235-261.

Dierickx, I., Cool, K. 1989. Asset stock accumulation and the sustainability of competitive advantage: reply. *Management Science*, 35(12).

Dieseldorff, C. 2019. Despite Uncertainty, Long-Term semiconductor market outlook remains bright. Available at: http://blog.semi.org/business-markets/despite-uncertainty-long-term-semiconductor-market-outlook-remains-bright

Dixit, A. 1995. Irreversible investment with uncertainty and scale economies. *Journal of Economic Dynamics and Control*, 19(1-2), 327-350.

Dotan, A., Ravid, S. A. 1985. On the interaction of real and financial decisions of the firm under uncertainty. *The Journal of Finance*, 40(2), 501-517.

Dubé, J. P., Fox, J. T., Su, C. L. 2012. Improving the numerical performance of static and dynamic aggregate discrete choice random coefficients demand estimation. *Econometrica*, *80*(5), 2231-2267.

Erkoc, M., Wu, S. D. 2004. Capacity reservation across multiple buyers. *Working paper*, Lehigh University, Bethlehem, PA.

Erlenkotter, D. 1972. Economic integration and dynamic location planning. *The Swedish Journal of Economics*, 74, 8-18.

Erlenkotter, D., Sethi, S., Okada, N. 1989. Planning for surprise: Water resources development under demand and supply uncertainty I. The general model. *Management Science*, 35(2), 149-163.

Fama, E. F., French, K. R. 1993. Common risk factors in the returns on stocks and bonds. *Journal of Financial Economics*, 33(1), 3-56.

Fama, E. French, K. 2015. A five-factor asset pricing model. *Journal of Financial Economics*, 116(1), pp.1-22.

Fleischmann, B., Ferber, S., Henrich, P. 2006. Strategic planning of BMW's global production network. *Interfaces*, 36(3), 194-208.

Fowler, J. W., Mönch, L., Ponsignon, T. 2015. Discrete-event simulation for semiconductor wafer fabrication facilities: a tutorial. *International Journal of Industrial Engineering: Theory, Application and Practice*, *22*(5), 661-682.

Gaimon, C., Burgess, R. H. 2003. Analysis of the lead time and learning for capacity expansions. *Production and Operations Management*, 12(1), 128-140.

Gaur, V., Kesavan, S., Raman, A., Fisher, M. L. 2007. Estimating demand uncertainty using judgmental forecasts. Manufacturing and Service Operations Management 9(4) 480-491.

Gelman, A. 2015. The connection between varying treatment effects and the crisis of unreplicable research: A Bayesian perspective. *Journal of Management*, 41(2), 632-643.

Geng, N., Jiang, Z., Chen, F. 2009. Stochastic programming based capacity planning for semiconductor wafer fab with uncertain demand and capacity. *European Journal of Operational Research*, 198(3), 899-908.

Geng, N., Jiang, Z. 2009. A review on strategic capacity planning for the semiconductor manufacturing industry. *International Journal of Production Research*, 47(13), 3639-3655.

Ghemawat, P. 1984. Capacity expansion in the titanium dioxide industry. *The Journal of Industrial Economics*, 145-163.

Goyal, M., Netessine, S. 2007. Strategic technology choice and capacity investment under demand uncertainty. *Management Science*, 53(2), 192-207.

Harrison, J. M., Van Mieghem, J. A. 1999. Multi-resource investment strategies: Operational hedging under demand uncertainty. *European Journal of Operational Research*, 113(1), 17-29.

Hau, H., Massa, M., Peress, J. 2009. Do demand curves for currencies slope down? Evidence from the MSCI global index change. *The Review of Financial Studies*, 23(4) 1681-1717.

Hax, A. C., Candea, D. 1984. *Production and Inventory Management*. Prentice-Hall.

Hendricks, K. B., Singhal, V. R. 2008. The effect of product introduction delays on operating performance. *Management Science*, 54(5), 878-892.

Hendricks, K. B., Singhal, V. R. 2009. Demand-supply mismatches and stock market reaction: Evidence from excess inventory announcements. *Manufacturing and Service Operations Management*, 11(3), 509-524.

Hendricks, K. B., Singhal, V. R., Wiedman, C. I. 1995. The impact of capacity expansion on the market value of the firm. *Journal of Operations Management*, 12(3-4), 259-272.

Hendricks, K. B., Singhal, V. R., Zhang, R. 2009. The effect of operational slack, diversification, and vertical relatedness on the stock market reaction to supply chain disruptions. *Journal of Operations Management*, 27(3), 233-246.

Hennessy, C. A., Whited, T. M. 2005. Debt dynamics. *The Journal of Finance*, 60(3), 1129-1165.

Henry, Ó. T., Olekalns, N., Thong, J. 2004. Do stock market returns predict changes to output? Evidence from a nonlinear panel data model. *Empirical Economics*, 29(3) 527-540.

Hiller, R. S., Shapiro, J. F. 1986. Optimal capacity expansion planning when there are learning effects. *Management Science*, 32(9), 1153-1163.

Ho, T. H., Savin, S., Terwiesch, C. 2002. Managing demand and sales dynamics in new product diffusion under supply constraint. *Management Science*, 48(2), 187-206.

Hood, S. J., Bermon, S., Barahona, F. 2003. Capacity planning under demand uncertainty for semiconductor manufacturing. *IEEE Transactions on Semiconductor Manufacturing*, 16(2), 273-280.

Hopewell, S. 2004. *Impact of grey literature on systematic reviews of randomized trials* (Doctoral dissertation, University of Oxford).

Hopp, W. J., Spearman, M. L. 2011. *Factory physics*. Waveland Press.

Howell, J. R., Allenby, G. M. 2015. Choice models with fixed costs. *Working Paper*. Retrieved from https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2024972.

Huang, K., Ahmed, S. 2009. The value of multistage stochastic programming in capacity planning under uncertainty. *Operations Research*, 57(4), 893-904.

Hwang, B. N., Huang, C. Y., Wu, C. H. 2016. A TOE approach to establish a green supply chain adoption decision model in the semiconductor industry. *Sustainability*, *8*(2), 168.

Jeffreys, H. 1998. *The theory of probability*. OUP Oxford.

Jiang, R., Manchanda, P., Rossi, P. E. 2009. Bayesian analysis of random coefficient logit models using aggregate data. *Journal of Econometrics*, 149(2), 136-148.

Jones, G. T. 1972. *Simulation and business decisions*. Penguin.

Julka, N., Baines, T., Tjahjono, B., Lendermann, P., Vitanov, V. 2007. A review of multi-factor capacity expansion models for manufacturing plants: Searching for a holistic decision aid. *International Journal of Production Economics*, 106(2), 607-621.

Karabuk, S., Wu, S. D. 2003. Coordinating strategic capacity planning in the semiconductor industry. *Operations Research*, 51(6), 839-849.

Kaul, A., Mehrotra, V., Morck, R. 2000. Demand curves for stocks do slope down: New evidence from an index weights adjustment. *The Journal of Finance*, 55(2), 893-912.

Kesavan, S., Gaur, V., Raman, A. 2010. Do inventory and gross margin data improve sales forecasts for US public retailers?. *Management Science*, 56(9), 1519-1533.

Kilger, C., Meyr, H., & Stadtler, H. 2015. *Supply chain management and advanced planning: concepts, models, software, and case studies*. Springer.

Kim, J., Allenby, G. M., Rossi, P. E. 2002. Modeling consumer demand for variety. *Marketing Science*, 21(3), 229-250.

Kulatilaka, N., Perotti, E. C. 1998. Strategic growth options. *Management Science*, 44(8), 1021-1031.

Kuo, C. W., Yang, S. J. S. 2013. The role of store brand positioning for appropriating supply chain profit under shelf space allocation. *European Journal of Operational Research*, *231*(1), 88-97.

La Cruz, W., Martínez, J., Raydan, M. 2006. Spectral residual method without gradient information for solving large-scale nonlinear systems of equations. *Mathematics of Computation*, 75(255), 1429-1448.

Lederer, P. J., Singhal, V. R. 1994. The effect of financing decisions on the choice of manufacturing technologies. *International Journal of Flexible Manufacturing Systems*, 6(4), 333-360.

Levine, R., Zervos, S. 1999. *Stock market development and long-run growth*. The World Bank.

Li, S., Tirupati, D. 1994. Dynamic capacity expansion problem with multiple products: Technology selection and timing of capacity additions. *Operations Research*, 42(5), 958-976.

Lieberman, M. B. 1987. Postentry investment and market structure in the chemical processing industries. *The RAND Journal of Economics*, 533-549.

Lin, J. T., Chen, T. L., Chu, H. C. 2014. A stochastic dynamic programming approach for multi-site capacity planning in TFT-LCD manufacturing under demand uncertainty. *International Journal of Production Economics*, 148, 21-36.

Lin, J. T., Wu, C. H., Chen, T. L., Shih, S. H. 2011. A stochastic programming model for strategic capacity planning in thin film transistor-liquid crystal display (TFT-LCD) industry. *Computers and Operations Research*, 38(7), 992-1007.

Lintner, J. 1969. The valuation of risk assets and the selection of risky investments in stock portfolios and capital budgets: A reply. *The Review of Economics and Statistics*, 222-224.

Lippman, S. A., McCardle, K. F. 1997. The competitive newsboy. *Operations Research*, 45(1), 54-65.

Luss, H. 1982. Operations research and capacity expansion problems: A survey. *Operations Research*, 30(5), 907-947.

Luss, H. 1984. Capacity expansion planning for a single facility product line. *European Journal of Operational Research*, 18(1), 27-34.

Luss, H. 1986. A heuristic for capacity expansion planning with multiple facility types. *Naval Research* Logistics, 33(4), 685-701.

Manne, A. S. 1961. Capacity expansion and probabilistic growth. *Econometrica*, 29(4) 632-649.

Manne, A. S. 1967. Two producing areas-constant cycle time policies. In *Investments for Capacity Expansion: Size, Location and Time-Phasing* (pp. 193-209). MIT Press, Cambridge, MA.

Martínez-Costa, C., Mas-Machuca, M., Benedito, E., Corominas, A. 2014. A review of mathematical programming models for strategic capacity planning in manufacturing. *International Journal of Production Economics*, 153, 66-85.

Meyr, H., Wagner, M., Rohde, J. 2015. Structure of advanced planning systems. In *Supply chain management and advanced planning* (pp. 99-106). Springer, Berlin, Heidelberg.

Mitra, S., Pinto, J. M., Grossmann, I. E. 2014. Optimal multi-scale capacity planning for power-intensive continuous processes under time-sensitive electricity prices and demand uncertainty. Part I: Modeling. *Computers and Chemical Engineering*, 65, 89-101.

Modigliani, F., Miller, M. H. 1958. The cost of capital, corporation finance and the theory of investment. *The American Economic Review*, 48(3), 261-297.

Mönch, L., Fowler, J. W., Mason, S. J. 2012. *Production planning and control for semiconductor wafer fabrication facilities: modeling, analysis, and systems* (Vol. 52). Springer Science and Business Media.

Moon, I., Silver, E. A. 2000. The multi-item newsvendor problem with a budget constraint and fixed ordering costs. *Journal of the Operational Research Society*, 51(5), 602-608.

Moschini, G. 1995. Units of measurement and the Stone index in demand system estimation. *American Journal of Agricultural Economics*, 77(1) 63-68.

Nevo, A. 2000. A practitioner's guide to estimation of random-coefficients logit models of demand. *Journal of Economics and Management Strategy*, 9(4), 513-548.

Novy-Marx, R. 2013. The other side of value: The gross profitability premium. *Journal of Financial Economics*, 108(1), 1-28.

Olhager, J., Rudberg, M., Wikner, J. 2001. Long-term capacity management: Linking the perspectives from manufacturing strategy and sales and operations planning. *International Journal of Production Economics*, 69(2), 215-225.

Olivares, M., Terwiesch, C., Cassorla, L. 2008. Structural estimation of the newsvendor model: an application to reserving operating room time. *Management Science*, 54(1), 41-55.

Papageorgiou, L. G., Rotstein, G. E., Shah, N. 2001. Strategic supply chain optimization for the pharmaceutical industries. *Industrial and Engineering Chemistry Research*, 40(1), 275-286.

Paraskevopoulos, D., Karakitsos, E., Rustem, B. 1991. Robust capacity planning under uncertainty. *Management Science*, 37(7), 787-800.

Pindyck, R. S. 1988. Irreversible investment, capacity choice, and the value of the firm. *The American Economic Review,* 78(5), 969-985.

Pindyck, R. S. 1993. A note on competitive investment under uncertainty. *The American Economic Review*, 83(1), 273-277.

Rajagopalan, S., Soteriou, A. C. 1994. Capacity acquisition and disposal with discrete facility sizes. *Management Science*, 40(7), 903-917.

Rajagopalan, S., Singh, M. R., Morton, T. E. 1998. Capacity expansion and replacement in growing markets with uncertain technological breakthroughs. *Management Science*, *44*(1), 12-30.

Rastogi, A. P., Fowler, J. W., Carlyle, W. M., Araz, O. M., Maltz, A., Büke, B. 2011. Supply network capacity planning for semiconductor manufacturing with uncertain demand and correlation in demand considerations. *International Journal of Production Economics*, 134(2), 322-332.

Rhim, H., Ho, T. H., Karmarkar, U. S. 2003. Competitive location, production, and market selection. *European Journal of Operational Research*, 149(1), 211-228.

Roland, C., Varadhan, R. 2005. New iterative schemes for nonlinear fixed point problems, with applications to problems with bifurcations and incomplete-data problems. *Applied Numerical Mathematics*, 55(2), 215-226.

Roland, C., Varadhan, R., Frangakis, C. E. 2007. Squared polynomial extrapolation methods with cycling: an application to the positron emission tomography problem. *Numerical Algorithms*, 44(2), 159-172.

Rossi, P. E., Allenby, G. M., McCulloch, R. 2012. *Bayesian statistics and marketing*. John Wiley and Sons.

Ryan, S. M. 2004. Capacity expansion for random exponential demand growth with lead times. *Management Science*, 50(6), 740-748.

Samsung. 2016. *Samsung sustainability report 2016*. Retrieved from https://images.samsung.com/is/content/samsung/p5/global/ir/docs/2016-samsung-sustainability-report.pdf.

Satomura, T., Kim, J., Allenby, G. M. 2011. Multiple-constraint choice models with corner and interior solutions. *Marketing Science*, 30(3), 481-490.

Schumpeter, J.A., 1911. *The theory of economic development*. Cambridge, MA: Harvard University Press.

Serin, Y. 2007. Competitive newsvendor problems with the same Nash and Stackelberg solutions. *Operations Research Letters*, 35(1), 83-94.

Sharpe, W. F. 1964. Capital asset prices: A theory of market equilibrium under conditions of risk. *The Journal of Finance*, 19(3), 425-442.

Shulman, A. 1991. An algorithm for solving dynamic capacitated plant location problems with discrete expansion sizes. *Operations Research*, 39(3), 423-436.

Sirhan, G., Johnson, P. R. 1971. A market-share approach to the foreign demand for US cotton. *American Journal of Agricultural Economics*, 53(4) 593-599.

Slack, N., Chambers, S., Johnston, R. 2010. *Operations management*. Pearson education.

Snyder, L. V., Shen, Z. J. M. 2011. *Fundamentals of supply chain theory*. John Wiley & Sons.

Strebulaev, I. A., Whited, T. M. 2012. Dynamic models and structural estimation in corporate finance. *Foundations and Trends in Finance*, *6*(1–2), 1-163.

Su, C. L., Judd, K. L. 2012. Constrained optimization approaches to estimation of structural models. *Econometrica*, 80(5), 2213-2230.

Swaminathan, J. M. 2000. Tool capacity planning for semiconductor fabrication facilities under demand uncertainty. *European Journal of Operational Research*, 120(3), 545-558.

Swaminathan, J. M. 2002. Tool procurement planning for wafer fabrication facilities: a scenario-based approach. *IIE Transactions*, 34(2), 145-155.

Syam, S. S. 2000. Multiperiod capacity expansion in globally dispersed regions. *Decision Sciences*, 31(1), 173-195.

Syntetos, A. A., Babai, Z., Boylan, J. E., Kolassa, S., Nikolopoulos, K. 2016. Supply chain forecasting: Theory, practice, their gap and the future. *European Journal of Operational Research*, *252*(1), 1-26.

Taiwan Semiconductor Manufacturing Company Limited. 2017. *TSMC annual report 2017*. Retrieved from http://www.tsmc.com/english/investorRelations/annual_reports.htm.

Tobin, J. 1969. A general equilibrium approach to monetary theory. *Journal of Money, Credit and Banking*, 1(1), 15-29.

Train, K. E. 2009. *Discrete choice methods with simulation*. Cambridge university press.

Train, K. E., Winston, C. 2007. Vehicle choice behavior and the declining market share of US automakers. *International Economic Review*, 48(4), 1469-1496.

Tsikriktsis, N. 2007. The effect of operational performance and focus on profitability: A longitudinal study of the US airline industry. *Manufacturing and Service Operations Management*, *9*(4), 506-517.

Uzsoy, R., Fowler, J. W., Mönch, L. 2018. A survey of semiconductor supply chain models Part II: demand planning, inventory management, and capacity planning. *International Journal of Production Research*, *56*(13), 4546-4564.

Van Mieghem, J. A. 1999. Coordinating investment, production, and subcontracting. *Management Science*, 45(7), 954-971.

Van Mieghem, J. A. 2003. Commissioned paper: Capacity management, investment, and hedging: Review and recent developments. *Manufacturing and Service Operations Management*, 5(4), 269-302.

Van Mieghem, J. A., Rudi, N. 2002. Newsvendor networks: Inventory management and capacity investment with discretionary activities. *Manufacturing and Service Operations Management*, *4*(4), 313-335.

Varadhan, R., Roland, C. 2008. Simple and globally convergent methods for accelerating the convergence of any EM algorithm. *Scandinavian Journal of Statistics*, 35(2), 335-353.

Villas-Boas, J. M., Zhao, Y. 2005. Retailer, manufacturers, and individual consumers: Modeling the supply side in the ketchup marketplace. *Journal of Marketing Research*, 42(1), 83-95.

Wang, C. T., Su, S. J. 2015. Strategic capacity planning for light emitting diode (LED) supply chains across Taiwan and China. *Journal of the Operational Research Society*, *66*(12), 1989-2003.

Wang, K. J., Hou, T. C. 2003. Modelling and resolving the joint problem of capacity expansion and allocation with multiple resources and a limited budget in the semiconductor testing industry. *International Journal of Production Research*, 41(14), 3217-3235.

Wang, K. J., Lin, S. H. 2002. Capacity expansion and allocation for a semiconductor testing facility under constrained budget. *Production Planning and Control*, 13(5), 429-437.

Wang, K. J., Wang, S. M., Yang, S. J. 2007. A resource portfolio model for equipment investment and allocation of semiconductor testing industry. *European Journal of Operational Research*, 179(2), 390-403.

Wu, S. D., Erkoc, M., Karabuk, S. 2005. Managing capacity in the high-tech industry: A review of literature. *The Engineering Economist*, 50(2), 125-158.

Xu, X., Birge, J. R. 2004. Joint production and financing decisions: modeling and analysis. *Technical Report*, The University of Chicago Booth School of Business, Chicago. Retrieved from http://ssrn.com/abstract=652562.

Xu, X., Birge, J. R. 2008. Operational decisions, capital structure, and managerial compensation: A news vendor perspective. *The Engineering Economist* 53(3) 173-196.

Yang, S., Chen, Y., Allenby, G. M. 2003. Bayesian analysis of simultaneous demand and supply. *Quantitative Marketing and Economics*, 1(3) 251-275.

Yang, S. J. S., Yang, F. C., Wang, K. J., Chandra, Y. 2009. Optimising resource portfolio planning for capital-intensive industries under process-technology progress. *International Journal of Production Research*, 47(10), 2625-2648.

Yang, S. J. S., Anderson, E. J. 2014. Competition through capacity investment under asymmetric existing capacities and costs. *European Journal of Operational Research*, 237(1), 217-230.

Ye, Q., Duenyas, I. 2007. Optimal capacity investment decisions with two-sided fixed-capacity adjustment costs. *Operations Research*, 55(2), 272-283.

You, F., Grossmann, I. E. 2011. Stochastic inventory management for tactical process planning under uncertainties: MINLP models and algorithms. *AIChE Journal*, *57*(5), 1250-1277.

Zhang, R., Zhang, L., Xiao, Y., Kaku, I. 2012. The activity-based aggregate production planning with capacity expansion in manufacturing systems. *Computers and Industrial Engineering*, 62(2), 491-503.