Supply Chain Management in Process Industries: Empirical Investigations for Commodity Markets

THÈSE N^{O} 7190 (2016)

PRÉSENTÉE LE 7 OCTOBRE 2016

AU COLLÈGE DU MANAGEMENT DE LA TECHNOLOGIE
CHAIRE DE TECHNOLOGIE ET GESTION OPÉRATIONNELLE
PROGRAMME DOCTORAL EN MANAGEMENT DE LA TECHNOLOGIE

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

POUR L'OBTENTION DU GRADE DE DOCTEUR ÈS SCIENCES

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ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Suisse
2016

Ich widme diese Dissertation meinen Eltern und meiner Schwester.

Vielen Dank für eure Unterstützung. I ha eu gern.

"The Empires of the Future are the Empires of the Mind"

- *Winston Churchill*

Acknowledgements

A thesis is never solely the achievement of the author alone and this one is certainly no exception. It is a journey, not a destination and I would like to thank the countless people who accompanied, supported, challenged, surprised and inspired me along the way.

I would like to express my deepest appreciation for my thesis advisor, Professor Ralf Seifert, who welcomed me in his team. Without his guidance and expertise, this project would not have succeeded. Furthermore, I am most grateful to my co-advisor, Professor Olov Isaksson, whose technical, but particularly personal support went far beyond his responsibilities.

I am also thankful to my thesis committee, namely Professor Matthias Finger, Professor Carlos Cordón and Professor Christopher Tucci, for their time, dedication and valuable input. I would like to thank the Swiss National Fund (SNF) and McKinsey & Co. for their financial support.

Benjamin Franklin, one of the Founding Fathers of the United States, once said: "For every minute spent organizing, an hour is earned." With this in mind, I would like to thank the following people for helping me earn years and years. I am very appreciative of all the support, organization and guidance I received from Lindsay, Sacha and Douglas at IMD; Lara and Sabrina from McKinsey & Co.; Barbara, Margaret, Alexandra and Ilona from CDM – EPFL.

Pursuing a PhD is an individual project, but not an individual experience. It would not have been the same without my exceptional colleagues. I will cherish many fond memories making me one of the lucky who enjoyed coming to work every morning. I would like to particularly thank those who shared so many moments inside, and especially outside of CDM: Abhik, Giada, Monica, Claudia, Joana ("crazy Jo"), Viet ("the Tiger"), Amin, Merve ("continuous dancer"), Charles, Gianluigi, Mary-Jean, Nettra, Isik and Emilio.

I obviously want to mention my "*fratelli italiani*" and the "*German Tower*" (Gio, Ste, Peppe and Florian), with whom I probably spent more time than anyone else. What a ride it has been; I could not be more thankful for having found friends like you.

One of the most versatile and famous orators of ancient Rome, Marcus Tullius Cicero, mentioned in one of his pieces: "Life is nothing without friendship." In that spirit, I would like to mention friends who turned this period of my life into such a memorable and unforgettable experience. I am thinking of…

…Sigi and Andi, because you are my rat pack and one has only so many friends with whom you are able to do things like there was no tomorrow.

…Steph, Rachel and Oli, because of all the (very) late nights out, the gossip over lunches and spontaneous meet ups at Satellite without which the EPFL experience would not be complete.

…Marie, Karine, Holly, Nico and Maxence, because whenever we meet, it's like we saw each other just yesterday.

…Matthias, because before having kids of your own, you looked after me for years.

…Adrian, because philosophizing about literally any possible subject for hours is where true inspiration comes from.

…Micha, because *somos hermanos*.

This PhD was initiated three years ago, but started a long time before that, with the education and inspiration my family provided me with. I dedicate this thesis to you because it would not have been possible without you.

Alexandra, ma vie, as without you, everything is nothing.

"It's been quite a ride. I loved every minute of it." (Charlton Heston)

Lausanne, le 29 Juillet 2016

Abstract

Process industries have thrived in recent decades, but structural changes in the markets are currently putting both growth and profitability at risk. In a period of tumbling prices, supply chain management is increasingly viewed as an essential lever for creating a sustainable competitive advantage. In process industries, which by definition involve manufacturing, supply chain related costs are, as a percentage of sales, on average more than twice as high as in consumer industries. Yet, despite the interest in improving their supply chain function, many firms in these sectors struggle to implement best practices because of industry-specific constraints. Historically, the majority of supply chain frameworks has been based on consumer industries and often does not take into account the context of process industries. The objective of this dissertation is to close this gap and give practitioners guidance on their supply chain transformations:

- What are the ***predominant characteristics of process industries*** that impact the supply chain management environment?
- How can the particular market environment of process industries be translated into an adequate ***supply chain strategy***?
- In process industries, what are the ***operational implications of investment decisions related to strategic asset development?***

Chapter 2 explores how properties specific to process industries drive inventory. Inventory management is a powerful way to improve profitability in challenged process industries. For instance, an inventory reduction of 10% in the primary metal sector would, ceteris paribus, increase the return on assets (ROA) by 78%[1]. Our empirical results show that factors such as capital

[1] COMPUSTAT North American and Global public financial accounting data for 2013

intensity and transportation costs have a particularly strong impact on the supply chains in process industries. This illustrates that supply chain management in process industries is subject to – and follows – different dynamics than other sectors.

Chapter 3 incorporates these insights and demonstrates why process industries need different approaches than consumer industries when it comes to strategic supply chain management. More specifically, we identify four market archetypes that shape the supply chain management strategy of companies. Based on 24 in-depth interviews with supply chain managers and a survey of 477 respondents, the chapter investigates the positive effects on performance of companies that adopt a supply chain strategy characterized by the market archetypes. This strategic alignment is still lagging behind in process industries, since only 32% of the surveyed companies have a supply chain that best reflects their business environment, which is about 40% lower than in consumer industries and indicates the enormous improvement potential that supply chain management holds for process industries. The chapter concludes with two recommendations for managers in process industries seeking to successfully transform their supply chains.

Chapter 4 looks at the impact of such transformative decisions on firms in process industries. In commoditized sectors, manufacturing is a core competency, and the related fixed assets are crucially important in securing a company's market position. But the required investments in these assets are particularly high, imposing fixed costs and implying operational constraints. Our empirical models show that companies follow with their investments the market prices, trading off volume flexibility and asset development. We present evidence that when we combine these two operational implications and examine their impact on the stock market valuation, the long-term effect on asset development overshadows the short-term impact on volume flexibility. This illustrates a potential conflict of short-term versus long-term interests as managers are incentivized to over proportionally increase/reduce investments into fixed assets in times of increasing/decreasing market prices to boost the share price in the short-term.

Keywords: process industries; commodity markets; supply chain management; industry characteristics; empirical research

Kurzfassung

Die Prozessindustrien erlebten einige äusserst erfolgreiche Dekaden, aber strukturelle Veränderungen in den Märkten gefährden deren Profitabilität und Wachstumsaussichten. In Zeiten fallender Rohstoffpreise wird das Versorgungskettenmanagement immer mehr als unentbehrliches Mittel angesehen, um sich einen nachhaltigen Wettbewerbsvorteil zu verschaffen. In Prozessindustrien, welche naturgemäss produktionslastig sind, sind die Lieferkettenkosten prozentual gemessen am Umsatz mehr als doppelt so hoch verglichen mit Konsumentenindustrien. Viele Firmen in den Prozessindustrien straucheln, trotz gestiegenem Interesse, bei der Umsetzung bewährter Lieferkettenpraktiken aufgrund industriespezifischer Einschränkungen. Die überwiegende Mehrheit dieser Leitfäden wurde auf Konsumentenindustrien zugeschnitten, wobei der prozessindustriespezifische Kontext nicht miteinbezogen wurde. Ziel dieser Dissertation ist es diese Lücke zu schliessen und Managern Richtlinien für ihre jeweiligen Lieferkettentransformationen aufzuzeigen:

- Was sind die ***tonangebenden Industriecharakteristika***, welche das Versorgungskettenmanagement ***in den Prozessindustrien*** beeinflussen?
- Wie kann dieses spezifische Marktumfeld, welches in den Prozessindustrien herrscht, in eine ***adäquate Lieferkettenstrategie*** umgesetzt werden?
- Was sind die ***operationellen Auswirkungen von strategischen Investitionsentscheiden in die Produktionsinfrastruktur***?

Kapitel 2 erörtert wie prozessindustriespezifische Eigenheiten die Lagerbestände von Unternehmen beeinflussen. Geschicktes Inventarmanagement ist ein effektives Mittel, um die Profitabilität in Prozessindustrien zu verbessern. Zum Beispiel würde eine Verminderung der Lagerbestände um

10% in der Metalfabrikation die Gesamtkapitalrendite, ceteris paribus, um 78% erhöhen[2]. Unsere empirischen Resultate zeigen, dass zum Beispiel Kapitalintensität und Transportkosten in den Prozessindustrien einen besonders starken Einfluss auf die Lieferketten ausüben. Dies zeigt auf, dass das Versorgungskettenmanagement in Prozessindustrien einzigartien Kräften unterliegt.

Kapitel 3 baut auf diesen Resultaten auf und illustriert wieso Prozessindustrien differenzierte strategische Ansätze fürs Versorgungskettenmanagement benötigen. Wir haben vier Marktarchetypen identifiziert, welche unterschiedliche Strategien fürs Versorgungskettenmanagement beanspruchen. Dies geschah basierend auf 24 Gesprächen mit erfahrenen Lieferkettenmanagern und 477 beantworteten Umfragebögen. Der Artikel untersucht den positiven Einfluss auf die Leistung der Lieferketten von Unternehmen, welche ihre Lieferkettenstrategie entsprechend ihrem Marktarchetyp konzipieren. Dieses strategische Abgleichen hinkt in den Prozessindustrien immer noch hinterher, da nur gerade 32% der befragten Firmen eine Lieferkettenkonfiguration aufweisen, welche in optimaler Weise ihrem wirtschaftlichen Umfeld entspricht. Dieser Wert ist circa 40% tiefer als in Konsumentenindustrien und deutet auf das grosse Optimierungspotential hin, welches das Versorgungskettenmanagement für Prozessindustrien bereithält. Das Kapitel beschliesst mit zwei praktischen Empfehlungen für Manager, welche ihre Lieferketten zu transformieren und optimieren gedenken.

Kapitel 4 untersucht, wie sich solch transformativen Entscheide auf Firmen in Prozessindustrien auswirken. In Rohstoffmärkten ist die Produktion naturgemäss eine Kernkompetenz eines jeden Unternehmens. Die damit einhergehenden Investitionen in die Produktionsinfrastruktur sind einerseits von existentieller Wichtigkeit für die Sicherung der Marktposition, andererseits sind diese in den Prozessindustrien ausserordentlich hoch und bürden Unternehmen hohe Fixkosten und operationelle Einschränkungen auf. Unsere empirischen Modelle zeigen, dass Unternehmen mit ihren

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[2] COMPUSTAT North American and Global public financial accounting data for 2013

Investitionen den Marktpreisen folgen und dabei einen Kompromiss zwischen Produktionsflexibilität und Produktionskapazität eingehen müssen. Wir belegen, dass in Kombination dieser zwei operationellen Effekte, der langfristige Einfluss auf die Produktionskapazität sich stärker im Aktienpreis widerspiegelt. Dies zeigt einen möglichen Konflikt zwischen kurz- und langfristigen Interessen auf, dem Manager unterliegen, da sie verleitet sein können, den Aktienkurs kurzfristig nach oben zu treiben durch überproportionale Investitionserhöhungen/-reduzierungen.

Schlüsselbegriffe: Prozessindustrien; Rohstoffmärkte; Lieferkette; Industriecharakteristika; Empirische Forschung

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Chapter 1

Introduction

"In the market environment of recent years with high prices and constantly increasing demand, supply chain management was not our first priority; our company focused on the commercial functions and growing sales volumes. But with prices currently tumbling, the tide is turning, margin improvement is key and supply chain management has gained a lot of traction in the industry." This statement by the Head of European Logistics of a major cement producer indicates the increased importance of and interest in supply chain management in process industries and commodity sectors.

Process industries, by definition, treat materials through biological, chemical or physical processes. They include highly commoditized sectors such as mining, oil & gas and primary metal making. Process industries are generally manufacturing intensive and are often positioned at the very beginning of their respective value chains. In this dissertation we focus mainly on commodity markets for two reasons: (i) they constitute a more homogenous industry cluster with similar industry characteristics such as capital intensity and (ii) the market dynamics and price-making mechanism are particularly direct (in contrast to differentiated consumer industries, in which for example marketing efforts and pricing power smooth out price volatility). However, in Chapter 1 we describe predominant industry characteristics and show that several conclusions can be generalized for "less typical" process industries such as the chemical and pharmaceutical industries.

Commodity markets have experienced eventful times since the turn of the century, a period commonly referred to as the commodity supercycle, with prices sharply increasing after 2005 before strongly decreasing again after 2011. Looking at the balance sheet of companies in these sectors that have high fixed costs combined with low pricing power can go a long way toward explaining why such price swings have such a strong impact.

In a series of 24 interviews we conducted with senior supply chain managers across process industries, respondents confirmed their intention to scale up supply chain efforts and capabilities as a means to protect profitability. These sectors have historically focused mainly on efficient logistics. In its modern definition, supply chain management, being positioned at the core of the company, covers a much broader spectrum of responsibilities, including managing the interaction of internal business functions and the relationship with clients and suppliers. In our interviews, many supply chain managers reported on the struggles they had faced during these transformations, particularly when implementing new best practices.

The impetus for this dissertation came from the growing importance of and interest in supply chain management in process industries, as a result of declining margins and the difficulties encountered in transforming supply chain functions. The dissertation seeks to study supply chain management in process industries, aims to support practitioners in their optimization efforts and is based on the underlying hypothesis that process industries are different and therefore need a tailored approach to supply chain management.

The established literature on supply chain management overwhelmingly focuses on industries acting far down the value chain, close to the end consumers – we refer to them as "consumer industries" throughout this dissertation. The supply chain conditions in these industries are completely different from those in process industries, where acting at the beginning of the value chain, feeding into a multitude of markets and being multiple echelons away from the end consumer do not allow the same level of precision and coherence in terms of demand outlooks. Another difference can be found in their respective cost structures. Process industries require manufacturing-related fixed assets. These impose a high share of fixed costs, which incentivizes companies to sweat the assets, run production at constantly high utilization rates and capture economies of scale.

Consumer industries often involve less asset-intensive assembly activities, leading to a cost structure that is driven by variable costs and providing companies with a higher degree of manufacturing volume flexibility.

This anecdotal evidence drawn from the industry interviews leads to the first research question, discussed in Chapter 2: What are the predominant characteristics of process industries that impact the supply chain management environment? With our industrial partners, we identified seven process-industry-specific properties that drive inventory performance and impact the degrees of freedom of supply chain management in these industries. We developed a simultaneous equation model (SEM) illustrating the interactions between demand, profitability and inventory and applied it to four process industries and four consumer industries. The SEM was populated with publicly available financial accounting, credit rating, stock market and trading data. Our model not only contributes to the growing stream of empirical supply chain literature that relies on secondary data by enhancing the theoretical understanding of inventory dynamics, but also outlines the practical frame and limitations these constraints have set for companies in process industries. It gives supply chain managers a tool to compare inventory performance while controlling for inherent industry-specific constraints. Our results indicate that capital intensity, capital costs, transportation costs, delivery time, price volatility, demand uncertainty and gross margin indeed have a significant impact on inventory in process industries and that this impact is stronger than in consumer industries.

These findings have to be taken into account when a company embarks on a supply chain transformation and defines an aspirational supply chain set-up. The existing supply chain literature names strategic alignment as one of the major cornerstones for achieving superior supply chain performance. This leads directly to our second research question, explored in Chapter 3: How can the particular market environment of process industries be translated into an adequate supply chain strategy? Marshall Fisher laid down the foundations of modern strategic supply chain management with the Fisher matrix in his highly cited article (Fisher 1997). He suggests that functional products are optimally handled by a cost efficient supply chain, whereas innovative products are better served by a responsive supply chain. Practitioners indicated during our interviews that depending on the industry context, efficient and responsive supply chains are interpreted and implemented in different ways.

Based on the original Fisher Matrix, which focuses on consumer industries, we defined the counterparts of responsive and efficient supply chain management for process industries. More specifically, we identified four market archetypes along with two predominant properties (i.e. pricing power and strategic focus) and developed corresponding supply chain approaches. We created a database based on a survey with 477 respondents across 13 industries to test the impact of strategic alignment (when the supply chain focus of a company corresponds to the supply chain strategy defined for its market archetype) and to identify the determinants for superior holistic supply chain performance (better service at lower cost).

We found that companies with aligned supply chains are indeed more likely to outperform their peers and that this effect was even stronger for process industries than for consumer industries. The strategic alignment is still lagging behind in process industries, since only 32% of the surveyed companies have a supply chain that best reflects their business environment. This is about 40% lower than the corresponding value for strategic alignment in consumer industries and indicates the enormous improvement potential that supply chain management holds for process industries. Our results show that the most efficient way for a company to align its supply chain and improve performance is to invest in demand forecasting capabilities. These findings give managers practical guidelines when they are defining their strategy and transforming their supply chain function.

Having established these insights into strategic supply chain management, our third research question, detailed in Chapter 4, aims to look at the implementation of such strategic choices in process industries: In process industries, what are the operational implications of investment decisions related to strategic asset development? Prices across many commodity markets have been tumbling since 2011, causing companies to reduce their investments in manufacturing assets. In commodity sectors, manufacturing excellence is a core competency and crucially important in securing a company's competitive advantage. The associated fixed assets and the capital expenditures (CAPEX) required to develop them are not only essential for a company's market position but also impose particularly high fixed costs. When making these investment decisions, managers face a trade-off between short-term financial relief and manufacturing volume flexibility versus long-term asset development and capacity growth. In order to illustrate this, we developed empirical models which link market prices with capital expenditures, production capacity and manufacturing flexibility, and which illustrate the impact on a firm's short- and long-term stock performance. Our results confirm that companies invest in accordance with price cycles. We show that combining the abovementioned implications, the negative effect on asset development overshadows – in the long term – the enhancing impact on manufacturing flexibility. These findings should be taken into account in CAPEX decisions and could encourage companies to develop more steady investment plans.

In Chapter 5, we consolidate the theoretical and practical insights gained from this dissertation and draw overarching conclusions on how to improve supply chain management in process industries, from strategy to implementation.

Chapter 2

Inventory Dynamics in Process Industries: An Empirical Investigation

2.1 Introduction & Contribution

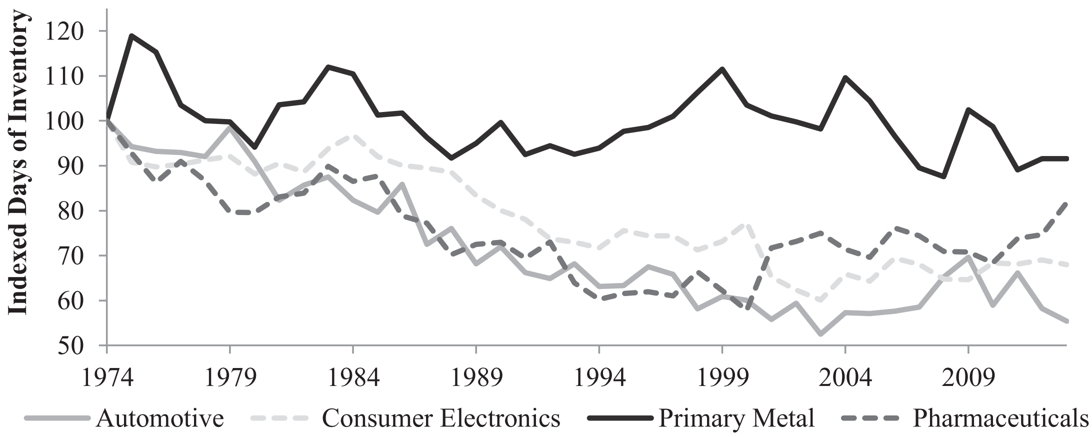
Process industries – ranging from steel and mining to chemicals and pharmaceuticals – transform materials through physical, chemical or biological processes. Price levels in many of these sectors were high during the 2000s (the commodities boom or so-called commodities super-cycle), driven by strong demand growth from emerging countries. Currently many of these industries are experiencing structural changes, and this is putting profitability at risk. The steel and iron ore industries are struggling with significant overcapacities triggered by a decrease in demand. Pharmaceutical companies are facing increasing commoditization as a considerable part of revenues is going off-patent in the coming years. In this context, supply chain related costs are often regarded as a crucial improvement lever to protect the bottom line. Transportation, direct labor and inventory holding costs account for up to 11% of sakes in pharmaceuticals, 11% in mining, 12% in specialty chemicals and 20% in carbon steel.[3] This is considerably higher than in consumer industries such as retail (5%) and automotive (6%). Considering that process industries (excluding pharmaceuticals)

[3] Industry week benchmarking database, Dow Jones Reuters Business Interactive LLC, Factiva, Cefic.

globally account for about €2750 billion of annual revenues, the value at stake is high.[4] Inventory management is of particular interest in process industries, in which inventories account for up to 56.7% of net working capital[5]. For instance, an inventory reduction of 10% in the primary metal sector would, ceteris paribus, increase the return on assets (ROA) by 78.0%.[6]

In general, inventory levels have steadily decreased in previous decades (Figure 1), but the magnitude of these reductions has varied significantly across industries (Chen et al. 2005). The automotive and consumer electronics industries have considerably reduced their inventory levels in the past 40 years and inspired a vast number of supply chain management frameworks. However, many process industries seem to be lagging behind.

Figure 1 Median Days of Inventory, FY1974–2013[7], Indexed on 1974



At the beginning of our study we conducted 24 exploratory interviews with senior supply chain managers across process industries. They revealed two potential explanations: (i) a lack of management focus on supply chain management in the past because of high margins and a focus on topline growth and (ii) process industry specific characteristics that impede the adoption of best practices from other industries. One example is the generally high capital expenditure (CAPEX)

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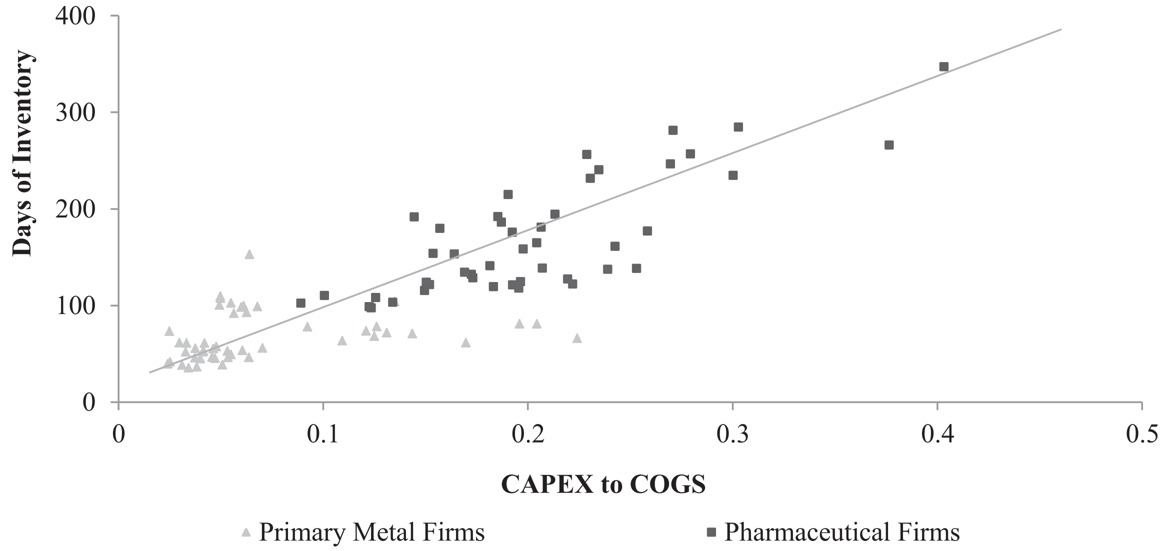
[4] Cefic – European Chemical Industry Council (www.cefic.org) figure for 2012
[5] COMPUSTAT North American and Global public financial accounting data for 2013; including pharmaceutical, chemical, primary metal and mining firms
[6] COMPUSTAT North American and Global public financial accounting data for 2013
[7] COMPUSTAT North American and Global public financial accounting data

requirement in process industries (Figure 2), which forces firms to run production constantly at high utilization rates, and in turn impacts production flexibility, increases batch size and lowers inventory turnover performance (Cachon and Fisher 2000).

Figure 2 Inventory vs. CAPEX Intensity for Major Primary Metal and Pharmaceutical Firms



Optimizations in process industries e.g., increasing production flexibility, which are naturally positioned towards the beginning of their respective value chains, are particularly interesting as they have positive spillover effects on the industries downstream.

The objectives of this paper are two-fold: (i) a theoretical contribution by adding a conceptual model explaining inventory variances to literature that strives to advance supply chain management in process industries, and (ii) a practical tool for managers to test strategic supply chain alignment with industry standards and benchmark inventory performance beyond industry borders. This supports them in prioritizing levers to pull to efficiently optimize inventory depending on the business context.

2.2 Literature Review

Two streams of literature are particularly relevant for our study. First, our work builds on previous research on supply chain management in process industries. Second, we draw on the growing stream of literature that empirically investigates the relationship between firm characteristics and inventory. The empirical literature on inventory management focusing on process industries however is scarce.

2.2.1 Operations and Supply Chain Management in Process Industries

There are three types of operations management research that focus on process industries: (i) conceptual work categorizing firms according to industry characteristics, (ii) analytical work generally focusing on a single sector and (iii) empirical studies aiming to confirm analytical findings (Van Donk and Fransoo 2006). The first stream of literature, embodying conceptual work, was pioneered by Taylor (1979) and Taylor et al. (1981), who classify process industries according to properties such as batch size or degree of commoditization. Fransoo and Rutten (1994) expand on this definition by distinguishing between flow and batch production industries. Van Rijn (1993) derives a list of characteristics that impact forecasting, material requirements planning (MRP) and capacity planning (a major business driver in process industries due to generally high levels of CAPEX). The modeling based literature is reviewed by Shah (2005) and Papageorgiou (2009). An exemplary study in this field was conducted by Van Donk (2001), who applies the decoupling point principle to process industries to support practitioners in the transformation from make-to-stock to make-to-order processes. Dennis and Meredith (2000a, 2000b) take the approach of defining industry groups in the abovementioned conceptual papers and empirically testing them. They define seven clusters, ranging from job shop production to continuous flow shops.

2.2.2 Empirical Models of Inventory Management

There is a growing amount of literature on empirical models of inventory management based on secondary data. Balakrishnan et al. (1996) perform an econometrical analysis of firms that implemented just-in-time processes and find that this positively influences inventory performance. Huson and Nanda (1995) run a similar study but reach the opposite conclusion. Rajagopalan and Malhotra (2001) develop an empirical model looking at inventory trends from 1961 to 1994 for

U.S. manufacturers and study the trends at industry level for different inventory types (raw material, work in progress [WiP], finished goods). Hendricks and Singhal (2003) use event study methodology to investigate the link between supply chain management, operational and financial performance and find that supply chain disruptions have a considerable negative impact on shareholder value. Moreover, Chen et al. (2005) investigate inventory levels of American manufacturing and retail/wholesale firms and find that abnormally high inventory levels have a negative impact on financial returns. They find there has been a declining inventory trend of 2% per annum since the early 1980s in the manufacturing sector, whereas a similar trend in retail services started only after 1995 (Chen et al. 2007). Gaur et al. (2005) identify capital intensity, gross margin and sales surprise as inventory drivers. Roumiantsev and Netessine (2007b) determine demand uncertainty, lead times and gross margins as being positively associated with inventory levels in retail services. Kesavan et al. (2010) develop a simultaneous equations model (SEM) relating cost of goods sold (COGS), gross margin and inventory to forecast sales. They achieve higher forecast accuracy than financial analysts. Jain et al. (2013) use a similar SEM model to relate global sourcing to inventory levels. They find that global (vs. domestic) sourcing is positively correlated with inventory, which can be mitigated by diversifying the supplier base.

2.3 Theory & Hypothesis

This section develops the conceptual inventory driver framework explaining inventory variations (not absolute inventory levels) among process industries. To test the assumed heterogeneity of inventory dynamics across industries, we defined comparison clusters to derive differences.

2.3.1 Industry Clusters

We defined four industry clusters (each consisting of two industries) based on two criteria which have a direct impact on the supply chain: distance to end consumer and product differentiation. Most operations management research is conducted in sectors that are close to the end consumer (e.g., retail services, consumer electronics). Process industries mainly operate in a business-to-business (B2B) environment at the beginning of their respective value chain. This has a direct impact on the supply chain dynamics since, for example, demand visibility over multiple echelons is lower. We therefore distinguished between consumer industries and process industries depending on their distance from the end consumer. Accounts receivable are an indicator of the type of relations a firm has with its customers and increases with the distance to the end consumer (Seifert et al. 2013). Consumer industries have on average a receivables-to-sales ratio of 0.13, compared with 0.20 in process industries. Fisher (1997) argues that the degree of innovativeness of a product also has a direct impact on the supply chain; we therefore distinguish between basic industries and advanced industries. Sales, general and administrative costs (SG&A) indicate the level of distinctiveness of a product, since they include marketing expenditure. Basic industries have an average SG&A-to-inventory ratio of 2.3, compared with 5.6 for advanced industries. Our study focuses on process industries and we use consumer industries to compare and confirm that process industries follow different dynamics.

Figure 3 Industry Clusters Defined Along Two Dimensions and Consisting of Two Sectors Each

Product Differentiation

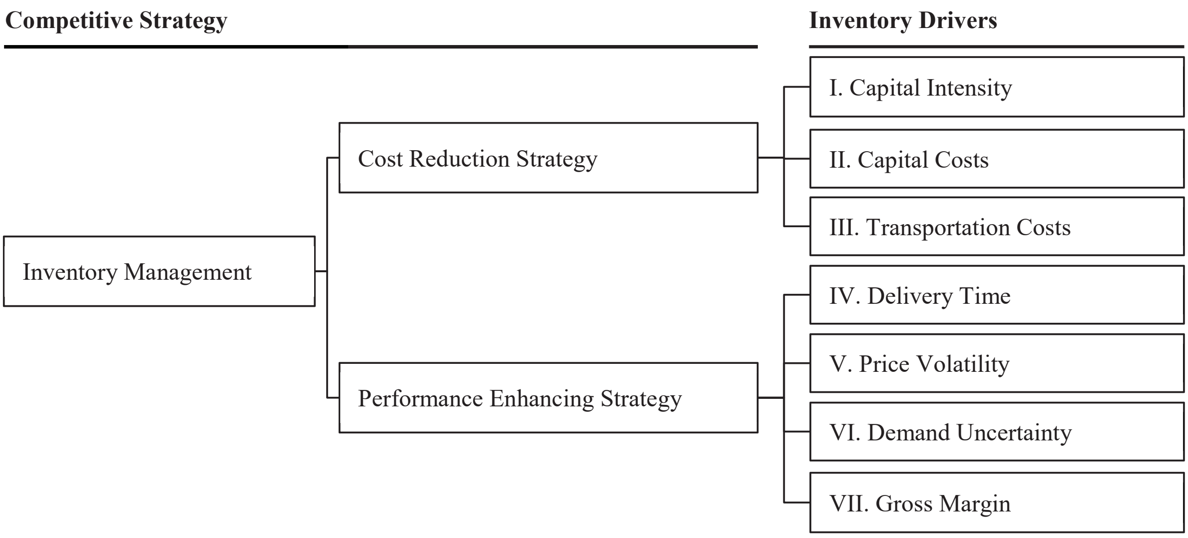
Distance to End consumers

Basic Consumer Industries • Retail Services • Apparel & Textiles	**Advanced Consumer Industries** • Consumer Electronics • Automotive & Transportation
Basic Process Industries • Primary Metal • Mining	**Advanced Process Industries** • Pharmaceuticals • Chemicals & Allied Products

2.3.2 Conceptual Inventory Driver Framework

As a starting point for our conceptual inventory driver framework (Figure 4), we separate cost leadership and performance differentiation as generic competitive strategies (Porter 2008). We apply this to supply chain management and distinguish between cost reducing and performance enhancing levers. These strategies are not mutually exclusive and companies can excel along both dimensions (McKinsey & Co. 2008). The hypotheses are empirically tested at the firm level and aggregated at industry level as the inventory drivers are based on and impacted by industry characteristics.

Figure 4 Framework of Supply Chain Strategies and Inventory-driving Characteristics



The cost reduction levers address the major sources of supply chain related costs: manufacturing costs (capital intensity), inventory holding (capital costs) and logistics (transportation costs). The performance enhancing dimensions tackle both internal capabilities such as speed (price volatility) and agility (demand uncertainty) and external performance including customer needs (delivery time) and target service level (gross margin).

2.3.3 Cost Reduction Strategy

We identify three main inventory drivers of a supply chain strategy focusing on cost reduction that are particularly crucial for process industries.

Capital Intensity

Process industries typically involve fixed assets for manufacturing, which leads to high CAPEX intensity (Thonemann and Bradley, 2002). High CAPEX requires high asset utilization rates to generate a positive return on invested capital (ROIC). This in turn leads to large batch sizes, which increase inventory levels and drive down supply chain performance (Vachon and Klassen 2002). Complex manufacturing processes and long set-up times in process industries reduce the flow rate, operational reliability (Cachon and Terwiesch 2006), customer demand fulfillment (Slack et al. 2010) and thus increase safety stock requirements (Abel 1985) and negatively impact profitability (Roumiantsev and Netessine 2005).

HYPOTHESIS I: *Firms with high capital intensity have higher inventory levels.*

Capital Costs

The cost of capital directly impacts a firm's inventory holding costs (Irvine 1981) and therefore its overage cost (Roumiantsev and Netessine 2007b). Classic inventory models stipulate that having higher overage costs implies lower inventory levels.

HYPOTHESIS II: *Firms with high costs of capital have lower inventory levels.*

Transportation Costs

Transportation and inventory holding costs are interdependent (Blumenfeld et al. 1985), since large shipping loads reduce transportation costs, but increase inventory (Burns et al., 1985). Inventory holding costs are driven by factors such as capital costs, warehousing type and product volume, while transportation costs are determined mainly by distance, transportation mode and the value-to-weight ratio. The lower the value-to-weight ratio (the ratio of a product's sales price to its weight), the higher the relative transportation costs (Ghemawat 2001). We expect a U-shaped relationship between inventory levels and transportation costs with a change in a supply chain's modus operandi from efficient and cost focused to agile and prioritizing service levels. On the one hand, low value-to-weight products with high transportation costs are functional and cost optimized through large transportation batches that drive up inventory levels. On the other hand, for innovative products with low relative transportation costs stock availability may be crucial (Fisher 1997), which drives up inventory levels.

HYPOTHESIS IIIa: *Cost focused firms with* ***high*** *transportation costs have higher inventory levels.*

HYPOTHESIS IIIb: *Innovative firms with* ***low*** *transportation costs have higher inventory levels.*

2.3.4 Performance Enhancing Strategy

We identify four inventory drivers impacting a supply chain strategy focusing on enhancing performance and predominant to process industries.

Delivery Time

Delivery time is particularly crucial for many process industries, since they are active in commodity markets with important demand seasonality (Boston Consulting Group 2010). Delivery time is determined by the number of stock-keeping facilities, the inventory level at those facilities and the type of inventory (raw material, WiP, finished goods) (Shu et al. 2005; Daskin et al. 2002). Short delivery time requirements combined with long lead times force companies to move closer to the market (Lee and Billington 1992), have more stock-keeping locations and hold a higher share of finished goods inventory (Van Hoek 2001). In turn, this drives up inventory levels due to lower pooling economies.

HYPOTHESIS IV: *Firms with short delivery time requirements have higher inventory levels.*

Price Volatility

Supply chain practitioners across industries name price volatility among the major risks going forward (Boston Consulting Group 2012; PwC & MIT Forum 2013). Price volatility and speculation are interconnected, as shown for the crude oil market by Hamilton (2009) and Caballero et al. (2008). Price development in commodity markets follows different dynamics (Asche et al. 2003) – price volatility is high and speculation inventory (inventory held in anticipation of price fluctuations) is common. Therefore inventory management in process industries is particularly affected by price volatility.

HYPOTHESIS V: *Firms that experience high price volatility have higher inventory levels.*

Demand Uncertainty

Demand uncertainty intuitively drives up inventory levels as more safety stock is generally needed. The academic process literature has investigated the impact of demand visibility by quantifying the effects of information sharing (Chen and Zheng 1994; Graves 1996; Aviv 2001; Wu and Cheng 2008). Whether this impact is higher or lower in process compared with consumer industries cannot be predicted. On the one hand, the effect is stronger because of these industries' relative position at the beginning of the value chain, which limits end consumer demand visibility and for instance reinforces the bullwhip effect (Isaksson and Seifert 2015). In addition, the impact is enhanced by their generally long lead times (Lee et al. 2000) and the low demand correlation over time (Erkip et al. 1990). On the other hand, low levels of spare production capacity (Gavirneni et al. 1999) and large batch sizes (Cachon and Fisher 2000) reduce this effect.

HYPOTHESIS VI: *Firms with high demand uncertainty have higher inventory levels.*

Gross Margin

Common inventory management models (e.g., the newsvendor model) make a tradeoff between inventory costs and the costs of lost sales. The costs of lost sales increase with the profit margin (Arrow, 1958) and therefore lead to higher safety stock levels.

HYPOTHESIS VII: *Firms earning higher gross margins have higher inventory levels.*

2.4 Variables & Data Sources

2.4.1 Data Sources

The data was sourced from Compustat North America annual and quarterly data, Compustat non-historical segment data, Bloomberg credit rating data, Bloomberg stock market data and the Research and Innovative Technology Administration (RITA) North American Transborder Freight data. The detailed sub-sectors by standard industry classification (SIC) code are given in Table 1. We collected data for the period 2004–2013 limited by the availability of trading data. All firms in the sample are publicly traded in North America. We excluded companies with missing or negative values of COGS, CAPEX, inventory and sales; moreover, we excluded firms for which data is not available for at least three consecutive years (required for sales forecast variable).

Table 1 Description of Data Using SIC Codes

Industry Segment	SIC Code	Examples of firms	#Firms	#Obs
BASIC CONSUMER INDUSTRIES			**319**	**2494**
Retail Services			**228**	**1919**
Building Materials, Hardware, Garden Supply, and Mobile Home Dealers	52	Home Depot, National Home Centers		75
General Merchandise Stores	53	Dillard's, K-Mart, Target, Wal-Mart		257
Food Stores	54	Hannaford Brothers, Kroger, Safeway		299
Apparel and Accessory Stores	56	Harolds, Gap, Ann Taylor		416
Home Furniture, Furnishings, and Equipment Stores	57	Radio Shack, Circuit City, Convertibles		173
Miscellaneous Retail	59	CVS, Amazon.com, Tiffany		699
Apparel & Textiles			**91**	**575**
Textile Mill Products	22	Albany Intl Corp., Mohawk Ind Inc., Hanesbrands Inc.		128
Apparel and Other Textile Products	23	LVMH, VF Corp., PVH Corp., Cintas Corp.		447
ADVANCED CONSUMER INDUSTRIES			**569**	**3910**
Consumer Electronics			**417**	**3189**
Household Appliances	363	Whirlpool Corp., Electrolux AB., Nacco Industries		62
Electric Lighting and Wiring Equipment	364	Cooper Ind., Hubbell Inc., Acuity Brands, Thomas & Betts		133
Household Audio and Video Equipment	365	Sony Corp., Harman International, Universal Electronics		123
Communications Equipment	366	Ericsson, Motorola Solutions Inc., Nortel Networks Corp., Tyco International Ltd., Nokia Corp., Blackberry Ltd.		921
Electronic Components and Accessoires	367	TDK Corp., Texas Instruments Inc., Atmel Corp., Jabil Circuit Inc., STMicroelectronics NV		1650
Miscellaneous Electrical Machinery, Equipment, and Supplies	369	GSI Group Inc., Rofin Sinar Technologies Inc., Spectrum Brands Holdings Inc., Remy International Inc.		300

Automotive & Transportation		**152**	**721**
Motor Vehicles and Motor Vehicle Equipment	371	Ford Motor Co., General Motors Co., Magna International, Nissan Motor Co. Ltd., Continental AG	649
Railroad Equipment	374	Wabtec Corp., Railpower Technologies Corp., Portec Rail Products Inc., Freightcar America Inc.	53
Motorcycles, Bicycles, and Parts	375	Harley-Davidson Inc., Zongshen Pem Power Systems, Kandi Technologies Group	19
BASIC PROCESS INDUSTRIES		**283**	**2073**
Primary Metal		**98**	**755**
Steel Works, Blast Furnaces, and Rolling and Finishing Mills	331	International Rollforms Inc, Omega Steel Inc., Harry Brainum JR., Inc., Nucor	339
Iron & Steel Foundries	332	Mueller Water Products	17
Primary Smelting & Refining of Nonferrous Metals	333	Sterlite Industries, Globe Speciality Metals	101
Secondary Smelting and Refining of Nonferrous Metals	334	Horsehead Holding Corp, Metalico Inc., OM Group Inc.	29
Rolling Drawing & Extruding of Nonferrous Metals	335	Alcan, Alcoa, Global Brass & Copper, Coleman Cable, Novelis	209
Nonferrous Foundries (Castings)	336	Dynacast International, Matthews International Corp.	19
Miscellaneous Primary Metal Products	339	Neo Material Technologies, Molycorp Inc., Harsco Corp	41
Mining		**185**	**1318**
Metal Mining	10	Barrick Gold Corp., NewMont Mining Corp., Teck Resources Ltd., BHP Billiton Group, Anglo American Plc, Rio Tinto Group	1023
Bituminous Coal and Lignite Mining	12	Yanzhou Coal Mining Co Ltd., Consol Energy Inc., Massey Energy Co., Peabody Energy Corp., Alpha Natural Resources Inc.	191
Mining and Quarrying of Nonmetallic Minerals, except Fuels	14	Dominion Diamond Corp., Martin Marietta Materials, Vulcan Materials Corp.	104
ADVANCED PROCESS INDUSTRIES		**720**	**4986**
Pharmaceuticals		**255**	**1641**
Medicinal Chemicals & Botanical Products	2833	Sigma-Aldrich Corp, Pacifichealth Labs, Nutraceutical International	62
Pharmaceutical Preparations	2834	Abbott Labs, BMS, GSK	1008
In Vitro & In Vivo Diagnostic Substances	2835	Gen-Probe Inc., Index Labs, Heska Corp	231
Biological Products, (No Diagnostic Substances)	2836	Amgen Inc., Baxter International, Genzyme Corp.	340
Chemicals & Allied Products		**465**	**3345**
Oil and Gas Extraction	13	Baker Hughes Inc., Weatherford Intl Plc, Halliburton Co., ConocoPhillips, Schlumberger Ltd.	1472
Chemicals & Allied Products	280	Bayer AG, Altana AG, Rhodia, Huntsman Intl LLC, Kronos Worldwide Inc., CIBA Holding AG	91
Industrial Inorganic Chemicals	281	Olin Corp., Axiall Corp., L'Air Liquide SA, Centrus Energy Corp.,	242
Plastics Materials and Synthetic Resins, Synthetic Rubber	282	Dow Chemical, DuPont de Nemours, Schulman Inc., LyondellBasell Ind. NV	181
Soap, Detergents, and Cleaning Preparations; Perfumes, Cosmetics, and Other Toilet Preparations	284	Avon Prod, Colgate-Palmolive Co., Procter & Gamble Co., Unilever Group, L'Oréal SA	278
Paints, Varnishes, Lacquers, Enamels and Allied Products	285	PPG Ind. Inc., Sherwin-Williams Co.,	50
Industrial Organic Chemicals	286	Methanex Corp., Westlake Chemical Corp., Celanese Corp., Braskem SA	228
Agricultural Chemicals	287	Mosaic Corp., CF Ind Holdings Inc., Syngenta AG	166
Miscellaneous Chemical Products	289	RPM Intl Inc., Smith Intl Inc.,	169
Petroleum Refining and Related Industries	29	Hess Corp., BP Plc, Chevron Corp., Exxon Mobil, Husky Energy Inc., Suncor Energy Inc.	468

2.4.2 Variable Definition

To test the aforementioned hypotheses, we developed proxies based on financial accounting, credit rating and trading data. In Section 2.7 Robustness Tests, we apply different definitions of these proxies to confirm the robustness of our findings. Wherever possible, we relied on instruments that have been tested and described in the literature.

In the following definitions, *i* corresponds to the firm index, *t* denotes the fiscal year index and *n* indicates business units within firms. The main dependent variable, inventory, is measured in days of inventory *(DoI)* (Chen et al. 2005).

$$DoI_{it} = \frac{INV_{it}}{COGS_{it}} * 365$$

We measure capital intensity *(CI)* by comparing CAPEX to the cost of goods sold (COGS), measured by the cost of sales. In the cross-industrial context of this study, we prefer a CAPEX-based measure, which represents yearly investments, as opposed to the share of fixed assets which is influenced by depreciation differences in industries.

$$CI_{it} = \frac{CAPEX_{it}}{COGS_{it}}$$

The weighted average cost of capital *(WACC)* is the rate a firm is assumed to pay for capital and is composed of the cost of debt *(CoD)* and cost of equity *(CoE)*.

$$WACC_{it} = \frac{Equity_{it}}{(Equity_{it} + Debt_{it})} * CoE_{it} + \frac{Debt_{it}}{(Equity_{it} + Debt_{it})} * CoD_{it}$$

For firms that have outstanding traded bonds or a credit rating, the cost of debt can be directly estimated. In the former case, the yield-to-maturity on a long-term bond can be used as interest rate. For the latter, the rating and a typical default spread indicate the cost of debt. For all other firms, a synthetic rating can be created based on the interest coverage ratio, which is translated into an interest rate by looking at peer firms with known credit ratings (Damodaran 2009).

$$CoD_{it} \sim ICR_{it} = \frac{EBIT_{it}}{IE_{it}}$$

Calculating the cost of equity is more challenging, since there are no explicit costs as there are for debt. Commonly used approaches are the capital asset pricing model (CAPM), the cost of newly issued stock, the return on equity *(ROE)* and the weighted cost of equity (WACE). We chose to use *ROE* (Damodaran 2010), also known as DuPont Formula, instead of the commonly used CAPM model for two reasons: (i) the CAPM typically requires up to five years of weekly or monthly data to estimate the beta (Damodaran 1999), which excludes many younger firms and (ii) we calculated the cost of equity with the CAPM for the firms with a sufficiently long history of data in section 2.7 Robustness Tests. The spread for the cost of equity, calculated with CAPM or based on ROE never exceeded 2% points and for the WACC, the difference was always smaller than 1% point. Companies with negative ROE were excluded from the study.

$$CoE_{it} \sim ROE_{it} = \frac{Net\ Income_{it}}{Equity_{it}}$$

Transportation costs *(TC)* are reported under SG&A (sales, general & administration), but are not accounted separately. Therefore a proxy measure is needed and we approximated it by the ratio between product weight and production cost. This is calculated by combining the sales price and weight data (giving the Value-to-Weight ratio *(VTW)*) from the North American Transborder Freight database which is weighted at the firm level with sales by business segment.

$$VTW_{it} = \frac{1}{SALES_{it}} \sum_{n} (SALES_{itn} * \frac{PRICE_{itn}}{WEIGHT_{itn}})$$

The value to weight ratio is then used in the calculation of the transportation cost proxy.

$$TC_{it} = \frac{1}{COGS_{it}} * \frac{SALES_{it}}{VTW_{it}} = \frac{1}{(\#units\ sold_{it} * unit\ cost_{it})} * \frac{\#units\ sold_{it} * unit\ price_{it}}{\frac{unit\ price_{it}}{unit\ weight_{it}}} = \frac{unit\ weight_{it}}{unit\ cost_{it}}$$

This value to weight measure, an approximation of the cost per mile, does not take into account the volume of the products or the distance travelled. Data on these topics is very limited and only a few companies report them separately in the annual reports. Therefore they were not extensive enough for our big database. We acknowledge these limitations, but still are convinced, that our measure is innovative and approximates well transportation costs.

Delivery time *(DT)* is approximated by the proportion of sales carried as finished goods inventory. In section 2.7 Robustness Tests we as well included the ratio of finished goods inventory to cost of goods sold. This measure shall approximate the amount of readily available stock due to short delivery time requirements by clients and indicates the market proximity (the more warehouses a company operates, the higher this ratio will be).

$$DT_{it} = \frac{INVFG_{it}}{SALES_{it}}$$

Price volatility *(PV)* can affect the sales price and/or the cost of goods sold. Depending on the market power and business context of a firm, it can hedge this by passing the price movements on to its customers or suppliers. In this case, price volatility has no direct impact on profitability. In most cases, though, a firm will absorb these effects at least partially with its gross margin. Therefore we introduced the standard deviation of the gross margin as a measure of price volatility.

$$PV_{it} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(\frac{SALES_{it} - COGS_{it}}{SALES_{it}} - \mu_{GM})^2}$$

Demand uncertainty *(DU)* is calculated by forecasting sales *(SF)* with the Holt Forecasting Method (Holt 2004) and comparing it to actual sales (Gaur et al. 2005).

$$SF_{it} = a_{it} + b_{it}$$

Where $a_{it} = \alpha * SALES_{i,t-1} + (1-\alpha)(a_{i,t-1} + b_{i,t-1})$ and $b_{it} = \beta\left(a_{i,t} - a_{i,t-1}\right) + (1-\beta)$. α and β are coefficients between 0 and 1. The optimum value for the coefficients, where the mean square error (MSE) is minimized, varied by industry and we obtained the best results with: basic consumer industries (α=0.15; β=0.15), advanced consumer industries (α=0.10; β=0.10), basic process industries (α=0.30; β=0.30) and advanced process industries (α=0.70; β=0.70). This indicates that in process industries most of the forecasting information is contained in the most recent sales, whereas for consumer industries, trends are more long term. This is intuitively correct, as marketing expenditures of consumer industries help to differentiate their business, smooth sales and reduce volatility.

$$DU_{it} = \frac{SF_{it} - SALES_{it}}{SF_{it}}$$

The gross margin *(GM)* is defined as the ratio of gross profit to sales and expresses the intrinsic value and targeted service level of a good or service.

$$GM_{it} = \frac{SALES_{it} - COGS_{it}}{SALES_{it}}$$

Table 2 shows that inventory levels of consumer and process industries are similar, but slightly higher for advanced industries than for basic ones. As defined in section 2.3.1 Industry Clusters, (i) SG&A investments are significantly higher for advanced than for basic industries, while (ii) accounts receivable are higher for consumer than process industries. Furthermore, capital intensity and transportation costs are higher in process industries, which intuitively makes sense because of their important manufacturing activities and the bulky nature of their products, respectively.

Table 2 Descriptive Statistics by Industry 2004–2013

Variable		Unit	BASIC CONSUMER INDUSTRIES	RETAIL SERVICES	APPAREL	ADVANCED CONSUMER INDUSTRIES	CONSUMER ELECTRONICS	AUTOMOTIVE	BASIC PROCESS INDUSTRIES	PRIMARY METAL	MINING	ADVANCED PROCESS INDUSTRIES	CHEMICALS	PHARMACEUTICALS
Days of Inventory	Mean	days	92.95	88.81	106.79	102.76	110.74	65.96	96.06	88.50	100.05	106.31	66.03	184.37
	S.D.		69.02	69.79	64.57	167.86	182.94	46.27	104.46	73.40	117.41	159.73	134.89	174.56
Capital Intensity	Mean	%	0.03	0.03	0.03	0.08	0.09	0.05	0.31	0.06	0.44	0.28	0.38	0.09
	S.D.		0.03	0.03	0.03	0.41	0.45	0.07	0.64	0.13	0.75	1.34	1.63	0.27
Capital Costs	Mean	%	0.05	0.06	0.04	0.01	0.00	0.05	0.03	0.06	0.02	0.07	0.08	0.05
	S.D.		1.17	1.31	0.32	1.54	1.64	0.95	0.60	0.88	0.34	1.00	0.75	1.35
Transportation Costs	Mean	KG/$	0.37	0.42	0.19	0.54	0.62	0.15	1.13	0.41	1.51	2.11	2.76	0.86
	S.D.		0.64	0.69	0.37	19.47	21.47	0.11	1.76	0.41	2.05	3.64	3.65	3.28
Delivery Time	Mean	%	0.07	0.06	0.12	0.06	0.06	0.05	0.05	0.06	0.04	0.05	0.04	0.07
	S.D.		0.10	0.10	0.08	0.10	0.11	0.06	0.13	0.06	0.15	0.10	0.07	0.13
Price Volatility	Mean	%	0.03	0.03	0.03	0.73	0.81	0.36	0.69	0.16	0.97	0.37	0.35	0.43
	S.D.		0.05	0.06	0.04	16.40	17.70	7.84	7.64	2.11	9.31	4.71	4.66	4.80
Demand Uncertainty	Mean	%	0.15	0.15	0.16	0.33	0.35	0.24	0.36	0.30	0.44	0.25	0.26	0.25
	S.D.		0.34	0.37	0.25	0.90	0.97	0.40	1.02	0.62	1.52	0.72	0.75	0.78
Gross Margin	Mean	%	0.34	0.32	0.37	0.31	0.33	0.19	0.21	0.17	0.23	0.37	0.32	0.46
	S.D.		0.13	0.12	0.14	0.43	0.45	0.24	0.58	0.49	0.62	0.63	0.57	0.73
Accounts Receivable	Mean	%	0.07	0.05	0.14	0.20	0.20	0.19	0.14	0.15	0.13	0.20	0.19	0.21
	S.D.		0.09	0.09	0.08	0.24	0.26	0.14	0.15	0.09	0.17	0.34	0.39	0.23
Accounts Payable	Mean	%	0.77	0.83	0.59	1.32	1.36	1.15	1.31	0.66	1.66	4.47	6.09	1.34
	S.D.		1.32	1.37	1.11	6.68	7.35	0.98	3.04	0.83	3.66	14.60	17.65	2.78
SG&A Costs	Mean	%	2.44	2.51	2.21	3.66	4.12	1.54	1.79	0.74	2.35	6.00	5.02	7.90
	S.D.		3.16	3.30	2.61	15.15	16.63	2.56	10.40	1.05	12.80	11.84	10.98	13.16

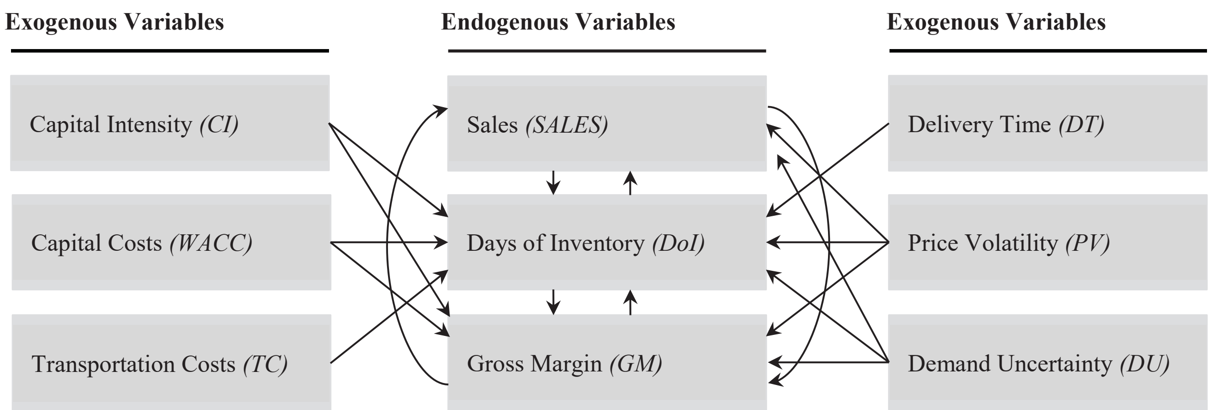
2.5 Methodology

In order to test our set of hypotheses, we applied a simultaneous equation model (SEM). This section describes the model, illustrates the interactions between variables and presents the control variables.

2.5.1 Simultaneous Equation Model

Recent research (Kesavan et al. 2010; Jain et al. 2013) suggests that inventory, gross margin and demand (approximated by sales) influence one another simultaneously. The SEM methodology takes this simultaneity into account. We applied a three-stage least square estimator and used a multiplicative-log model, as in recent inventory-related studies (Gaur et al. 2005; Roumiantsev and Netessine 2007a).

Figure 5 Simultaneous Equations Model: Interaction between Variables



(1) $log(DoI_{it}) = F_i + \alpha_{11} * log(GM_{it}) + \alpha_{12} * log(SALES_{it}) + \alpha_{13} * log\left(DoI_{i,t-1}\right) + \alpha_{14} * log\left(CI_{i,t}\right) + \alpha_{15} * log\left(WACC_{i,t}\right) + \alpha_{16} * log(DT_{it}) + \alpha_{17} * log(PV_{it}) + \alpha_{18} * log(DU_{it}) + \alpha_{19} * log\left(TC_{i,t}\right) + \alpha_{1,10} * log(TC_{it})^2 + \varepsilon_{it}$

(2) $log(GM_{it}) = G_i + \alpha_{21} * log(DoI_{it}) + \alpha_{22} * log(SALES_{it}) + \alpha_{23} * log(GM_{it-1}) + \alpha_{24} * log(CI_{it}) + \alpha_{25} * log(WACC_{it}) + \alpha_{26} * log(PV_{it}) + \alpha_{27} * log(DU_{it}) + \vartheta_{it}$

(3) $log(SALES_{it}) = H_i + \alpha_{31} * log(DoI_{it}) + \alpha_{32} * log(GM_{it}) + \alpha_{33} * log(SALES_{it-1}) + \alpha_{34} * log(PV_{it}) + \alpha_{35} * lo\,g(DU_{it}) + \mu_{it}$

We introduce firm-specific fixed effects (F_i, G_i, H_i), to account for omitted time-invariant firm-level variables, which can cause biased and inconsistent estimates if they are correlated with the error term (Hausman and Taylor 1981).

2.5.2 Interactions between Endogenous Variables

We present the logic behind the relationships between the three endogenous variables – sales, inventory and gross margin. First, we explore the impact of gross margin and sales on inventory. The critical ratio – making a trade-off between overage and underage costs – supports that higher margins lead to higher inventory levels. Higher demand leads to, ceteris paribus, lower days of inventory according to common inventory models (Ettlie 1998; Terjesen et al. 2011). Second, we discuss how inventory and sales affect the gross margin. These relationships are based on our core argumentation that process industries follow different inventory dynamics. Higher inventory in an environment with high price volatility leads to higher profitability: firms can speculate on higher prices as products have long life cycles, and inventory holding costs impact operating profitability but not the gross margin. Higher sales lead to economies of scale in these high fixed cost industries and help companies in commoditized markets to move down the cost curve and improve profitability. Third, we look at the influence of inventory and gross margin on sales. As mentioned in hypothesis 1 on capital intensity, process industries generally run their production at very high utilization levels. This implies that inventory and sales are negatively correlated as the more a company stores, the less it sells and vice versa. Gross margin has a positive impact on sales, since it incentivizes a company to reduce its inventory by selling its speculation stock.

2.5.3 Impact of Exogenous Variables on Endogenous Variables

Furthermore, the exogenous variables, whose effect on inventory are outlined in section 2.3 Theory & Hypothesis, also affect the remaining endogenous variables – gross margin and sales.

Impact of Exogenous Variables on Gross Margin

Capital intensity is a cost driver that squeezes a firm's profitability and is therefore negatively correlated with gross margin. The cost of capital consists of cost of debt and cost of equity. While the first is negatively correlated with gross margin (the higher a company's profitability, the better, ceteris paribus, is its credit rating), the cost of equity is positively associated with gross margin, since at higher margins, higher dividends can be paid out and stock prices increase. Price volatility leads to additional costs due to production and transportation adjustments, which negatively affect gross margin. The same holds true for demand uncertainty, which results in additional underage and overage costs.

Impact of Exogenous Variables on Sales

Price volatility can lower or increase average sales prices depending on spare warehousing capacity and supply chain flexibility. The impact on our sample of firms cannot be predicted. The same holds true for demand uncertainty, which impacts sales volumes and have a positive or negative impact on a firm's sales. This depends on the forecasting accuracy and the time-to-market of a firm.

2.5.4 Control Variables and Econometric Considerations

Firm level data is generally susceptible to omitted variable bias because of the large number of variables impacting the dependent and independent variables. Therefore several control variables are included.

(i) Time dummies were introduced to control for time-related macro effects (Wooldridge 2015).

(ii) Firm size is controlled for by sales and the number of employees as it might impact inventory performance through market power, agility or the implementation of supply chain best practices (Ettlie 1998; Terjesen et al. 2011).

(iii) All three dependent variables are dependent on previous performance, the so-called halo effect (Brown and Perry 1994) and therefore lagged variables were included in the model, which satisfy the conditions for instruments (Kesavan et al. 2010)

(iv) The risk free rate influences the cost of capital and is approximated with the three-month T-Bill rate (Irvine 1981).

(v) The inflation rate is controlled as reported by the Bureau of Labor Statistics in its "Producer Price Index: All Commodities" (Chen et al. 2005).

(vi) Net working capital is an important supply chain management key performance indicator (KPI) on which firms often set targets. For this reason, the three components inventory, accounts receivable and accounts payable are interdependent (Hill et al. 2010).

(vii) Marketing differentiation, which impacts all three endogenous variables, is calculated with the ratio of SG&A costs to sales, since marketing, commercial and sales activities are accounted for within SG&A (Kesavan et al. 2010).

2.6 Analysis

Table 3 shows the correlations between the independent, dependent and control variables on an aggregated industry level. All the variance inflation factors are lower than two and therefore well below the commonly stated tolerated values of 4 to 10 (Menard 2002; Neter et al. 1996; Mason et al. 2003), which indicates that there is no multicollinearity problem in our data set. This also holds true on an individual industry level.

Table 3 Correlation Table of Variables for the Aggregated Database

	DoI	CI	CC	TC	DT	PV	DU	GM	AR	AP	SG&A
Days of Inventory (DoI)	1										
Capital Intensity (CI)	-0.12***	1									
Capital Costs (CC)	-0.052***	-0.049***	1								
Transportation Costs (TC)	-0.25***	0.36***	0.078***	1							
Delivery Time (DT)	0.45***	-0.10***	-0.079***	-0.16***	1						
Price Volatility (PV)	-0.0015	0.25***	-0.10***	0.025**	0.11***	1					
Demand Uncertainty (DU)	-0.0067	0.17***	-0.11***	0.048***	0.036***	0.22***	1				
Gross Margin (GM)	0.32***	-0.038***	0.13***	0.16***	0.035***	-0.24***	-0.12***	1			
Accounts Receivable (AR)	0.065***	0.20***	-0.071***	0.048***	0.067***	0.076***	0.14***	0.063***	1		
Accounts Payable (AP)	-0.66***	0.45***	0.0058	0.40***	-0.28***	0.14***	0.12***	-0.048***	0.18***	1	
SG&A Costs (SG&A)	-0.23***	0.16***	-0.085***	0.16***	-0.14***	0.11***	0.10***	0.31***	0.13***	0.50***	1

N= 10370, * $p<0.05$, ** $p<0.01$, *** $p<0.001$

Table 4 shows the empirical results for the three SEM equations for the two process industry and two consumer industry clusters. We see that for the process industries, on the one hand, all the exogenous variables are highly significant and confirm the stated hypotheses on the inventory drivers. On the other hand, several of these drivers are not significant for the consumer industries (transportation costs for basic consumer industries; capital costs and transportation costs for advanced consumer industries), which were included as comparison group. This supports the hypothesis that inventory management in process industries follows different dynamics and is impacted by a broader set of business characteristics than in consumer industries. We also note that all the relationships between the endogenous variables are highly significant in the described direction (2.5.2 Interactions between Endogenous Variables). This indicates that the three-equation system is a good reflection of reality and of the way firms act. We note that the interactions between the established exogenous variables are in line with the literature (Gaur et al. 2005; Kesavan et al. 2010; Jain et al. 2013).

Table 4 Regression Table for Whole Simultaneous Equations Model and Four Industry Clusters

	Variable	BASIC CONSUMER INDUSTRY – RETAIL & APPAREL (1) DoI	(2) GM	(3) SALESa	ADVANCED CONSUMER INDUSTRY – AUTOMOTIVE & CONS. ELECTRONICS (1) DoI	(2) GM	(3) SALESa	BASIC PROCESS INDUSTRY – PRIMARY METAL & METAL (1) DoI	(2) GM	(3) SALESa	ADVANCED PROCESS INDUSTRY – PHARMACEUTICALS & CHEMICALS (1) DoI	(2) GM	(3) SALESa
Exogenous Variables	Capital Intensity	0.516*	0.0550		0.903***	-0.139***		0.427***	-0.176***		0.613***	-0.157***	
		(0.208)	(0.0303)		(0.0569)	(0.0172)		(0.0527)	(0.0264)		(0.0543)	(0.0175)	
	Capital Costs	-0.0531***	0.00435		-0.00576	0.00991**		-0.116***	0.0610***		-0.0771***	0.0165*	
		(0.0130)	(0.00242)		(0.00866)	(0.00305)		(0.0290)	(0.0163)		(0.0200)	(0.00733)	
	Transportation Costs	-0.0136			-0.0267			-0.224**			-0.224***		
		(0.0533)			(0.0395)			(0.0799)			(0.0372)		
	(Transportation Costs)^2	-0.00201			0.0728***			0.117***			0.0863***		
		(0.0379)			(0.00791)			(0.0279)			(0.0134)		
	Delivery Time	0.264***			2.069***			2.329***			2.290***		
		(0.0567)			(0.107)			(0.171)			(0.217)		
	Price Volatility	0.308***	-0.0298*	-0.420***	0.0966*	-0.0874***	-0.113	0.471***	-0.295***	-0.0444	0.741***	-0.284***	-0.0764**
		(0.0791)	(0.0148)	(0.0947)	(0.0403)	(0.0149)	(0.0637)	(0.0425)	(0.0160)	(0.0407)	(0.0494)	(0.0125)	(0.0273)
	Demand Uncertainty	0.136***	-0.0122***	-0.0373	0.100***	-0.0368***	0.215***	0.319***	-0.158***	0.372***	0.274***	-0.0673***	0.175***
		(0.0255)	(0.00330)	(0.0251)	(0.0190)	(0.00480)	(0.0226)	(0.0410)	(0.0163)	(0.0403)	(0.0365)	(0.0126)	(0.0273)
Endogenous Variables	DoI		0.0313***	-0.119***		0.0635***	-0.0620***		0.0731***	-0.0975***		0.0529***	-0.0282***
			(0.00196)	(0.0148)		(0.00277)	(0.0155)		(0.00718)	(0.0185)		(0.00283)	(0.00817)
	Gross Margin	3.536***		1.017***	0.664***		0.367***	2.151***		0.723***	3.375***		0.199***
		(0.229)		(0.104)	(0.112)		(0.0642)	(0.113)		(0.0664)	(0.129)		(0.0346)
	Sales	-0.0760***	0.000972**		-0.159***	0.00531***		-0.187***	0.00818**		-0.117***	0.00352**	
		(0.0154)	(0.000341)		(0.0144)	(0.000721)		(0.0320)	(0.00262)		(0.0262)	(0.00115)	
	Lagged DoI	0.274***			0.0737***			0.0395*			0.0384**		
		(0.0148)			(0.00997)			(0.0163)			(0.0129)		
	Lagged Gross Margin		0.707***			0.481***			0.204***			0.405***	
			(0.0144)			(0.00936)			(0.0205)			(0.0154)	
	Lagged Sales			0.982***			0.955***			0.920***			0.969***
				(0.00249)			(0.00380)			(0.00620)			(0.00257)
Control Variables	Accounts Payable	-0.509***		0.0805***	-0.330***		0.0564*	-0.320***		0.0806**	-0.350***		0.0267*
		(0.0300)		(0.0182)	(0.0198)		(0.0222)	(0.0342)		(0.0303)	(0.0228)		(0.0104)
	Accounts Receivable	0.474***		-0.0690	0.652***		-0.000776	0.730***		-0.309**	0.462***		-0.163**
		(0.0853)		(0.0510)	(0.0613)		(0.0648)	(0.119)		(0.118)	(0.0954)		(0.0546)
	SG&A Costs	-0.540***	0.0459***	-0.185***	-0.722***	0.0773***	-0.152***	-0.635***	0.123***	-0.244***	-0.570***	0.0597***	-0.0605***
		(0.0321)	(0.00261)	(0.0186)	(0.0185)	(0.00286)	(0.0149)	(0.0334)	(0.0112)	(0.0257)	(0.0225)	(0.00381)	(0.00838)
	Employees	0.000325		0.0000774**	0.00111***		0.000861***	0.00317*		0.00203***	0.00229*		0.000691***
		(0.000195)		(0.0000280)	(0.000322)		(0.000165)	(0.00136)		(0.000423)	(0.000998)		(0.000156)
	Year Dummies		Yes			Yes			Yes			Yes	
	N observations		2494			3910			2073			4986	
	N firms		319			569			283			720	
	Overall R2	97.74%	92.71%	99.20%	94.15%	74.29%	98.04%	85.76%	46.44%	96.64%	89.50%	58.87%	98.59%

a Sales is an endogenous, dependent variable and proxies demand Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 5 Regression Table for Individual Industries Showing Results for the Inventory Equation

	Variable	BASIC CONSUMER INDUSTRY	RETAIL	APPAREL	ADVANCED CONSUMER INDUSTRY	AUTOMOTIVE	CONSUMER ELECTRONICS	BASIC PROCESS INDUSTRY	PRIMARY METAL	MINING	ADVANCED PROCESS INDUSTRY	CHEMICALS	PHARMA-CEUTICALS
		(1) DoI	(1) DoI	(1) DoI	(1) DoI	(1) DoI	(1) DoI	(1) DoI	(1) DoI	(1) DoI	(1) DoI	(1) DoI	(1) DoI
Exogenous Variables	Capital Intensity	0.516*	0.747**	0.974**	0.903***	0.415*	0.927***	0.427***	1.069***	0.420***	0.613***	0.586***	1.005***
		(0.208)	(0.242)	(0.318)	(0.0569)	(0.183)	(0.0619)	(0.0527)	(0.165)	(0.0623)	(0.0543)	(0.0527)	(0.177)
	Capital Costs	-0.0531***	-0.0610***	-0.0464	-0.00576	-0.0240	-0.00718	-0.116***	-0.0795**	-0.152***	-0.0771***	-0.102***	-0.0605
		(0.0130)	(0.0131)	(0.0281)	(0.00866)	(0.0179)	(0.00972)	(0.0290)	(0.0289)	(0.0448)	(0.0200)	(0.0254)	(0.0351)
	Transportation Costs	-0.0136	-0.0444	-0.0205	-0.0267	0.395	-0.0273	-0.224**	0.219	-0.305*	-0.224***	-0.312***	-0.242**
		(0.0533)	(0.0515)	(0.199)	(0.0395)	(0.307)	(0.0430)	(0.0799)	(0.155)	(0.123)	(0.0372)	(0.0448)	(0.0919)
	(Transportation Costs)^2	-0.00201	-0.00666	0.0365	0.0728***	-0.522	0.0726***	0.117***	-0.0503	0.146***	0.0863***	0.144***	0.0884**
		(0.0379)	(0.0378)	(0.121)	(0.00791)	(0.486)	(0.00837)	(0.0279)	(0.119)	(0.0370)	(0.0134)	(0.0146)	(0.0301)
	Delivery Time	0.264***	0.167**	0.997***	2.069***	3.488***	1.965***	2.329***	1.834***	2.410***	2.290***	2.988***	1.566***
		(0.0567)	(0.0579)	(0.153)	(0.107)	(0.311)	(0.116)	(0.171)	(0.261)	(0.218)	(0.217)	(0.267)	(0.410)
	Price Volatility	0.308***	0.203*	0.0994	0.0966*	0.0903	0.107*	0.471***	0.197**	0.436***	0.741***	0.765***	0.146*
		(0.0791)	(0.0808)	(0.181)	(0.0403)	(0.123)	(0.0436)	(0.0425)	(0.0731)	(0.0506)	(0.0494)	(0.0885)	(0.0644)
	Demand Uncertainty	0.136***	0.0967***	0.197***	0.100***	0.184***	0.0865***	0.319***	0.250***	0.188***	0.274***	0.274***	0.213*
		(0.0255)	(0.0284)	(0.0426)	(0.0190)	(0.0365)	(0.0217)	(0.0410)	(0.0654)	(0.0508)	(0.0365)	(0.0375)	(0.0844)
Endogenous Variables	DoI												
	Gross Margin	3.536***	3.176***	1.838***	0.664***	1.728**	0.679***	2.151***	0.864*	2.025***	3.375***	2.407***	8.779***
		(0.229)	(0.254)	(0.448)	(0.112)	(0.567)	(0.117)	(0.113)	(0.420)	(0.129)	(0.129)	(0.165)	(0.480)
	Sales	-0.0760***	-0.110***	-0.0350	-0.159***	-0.134***	-0.168***	-0.187***	-0.173***	-0.242***	-0.117***	-0.134***	-0.292***
		(0.0154)	(0.0187)	(0.0237)	(0.0144)	(0.0284)	(0.0166)	(0.0320)	(0.0425)	(0.0499)	(0.0262)	(0.0280)	(0.0508)
	Lagged DoI	0.274***	0.234***	0.180***	0.0737***	0.158***	0.0550***	0.0395*	0.0108	0.0509*	0.0384**	0.0527***	-0.0214
		(0.0148)	(0.0160)	(0.0234)	(0.00997)	(0.0219)	(0.0112)	(0.0163)	(0.0280)	(0.0201)	(0.0129)	(0.0131)	(0.0307)
	Lagged Gross Margin												
	Lagged Sales												
Control Variables	Accounts Payable	-0.509***	-0.716***	-0.161***	-0.330***	-0.340***	-0.323***	-0.320***	-0.373***	-0.354***	-0.350***	-0.362***	0.256**
		(0.0300)	(0.0396)	(0.0430)	(0.0198)	(0.0472)	(0.0216)	(0.0342)	(0.0706)	(0.0393)	(0.0228)	(0.0230)	(0.0784)
	Accounts Receivable	0.474***	0.302***	0.972***	0.652***	0.528***	0.640***	0.730***	1.802***	0.400**	0.462***	0.522***	0.751***
		(0.0853)	(0.0905)	(0.168)	(0.0613)	(0.121)	(0.0688)	(0.119)	(0.198)	(0.145)	(0.0954)	(0.118)	(0.175)
	SG&A Costs	-0.540***	-0.396***	-0.985***	-0.722***	-0.792***	-0.720***	-0.635***	-0.801***	-0.571***	-0.570***	-0.576***	-0.879***
		(0.0321)	(0.0400)	(0.0373)	(0.0185)	(0.0489)	(0.0204)	(0.0334)	(0.0606)	(0.0389)	(0.0225)	(0.0245)	(0.0561)
	Employees	0.000325	0.000393*	0.00310	0.00111***	0.000884**	0.00158**	0.00317*	0.00225	0.00289	0.00229*	0.00139	0.00352
		(0.000195)	(0.000186)	(0.00168)	(0.000322)	(0.000302)	(0.000592)	(0.00136)	(0.00127)	(0.00278)	(0.000998)	(0.000928)	(0.00334)
	Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	N observations	2494	1919	575	3910	3189	721	2073	755	1318	4986	1641	3345
	N firms	319	228	91	569	417	152	283	98	185	720	255	465

a Sales is a endogenous, dependent variable and proxies demand   Standard errors in parentheses   * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 5 details the results of the regression analysis on an individual industry level for the first equation (inventory equation). We note that the model is well adapted to describe inventory variations between process industries, with the vast majority of exogenous inventory drivers being highly significant. The consumer industries, included as a peer group, once again show lower levels of statistical (economic) significance. Comparing the results of the two process industry clusters with those of the corresponding individual process industries, we observe that they are similar, which indicates that our definition of these clusters is meaningful. In other words, just as the various industry clusters are heterogeneous, so the industries within a single cluster are homogeneous. There are two exceptions to this statement: the non-significance of (i) transportation costs for the primary metal market and the (ii) capital costs for pharmaceutical firms. The first difference is interesting, since many primary metal producers are direct customers of mining companies (for which transportation costs are significant as an inventory driver). We see two potential explanations: first that flexibility becomes the narrative in the steel market as spot markets become increasingly liquid. Therefore purely cost-based logistics optimization is no longer always the top priority. Second that many metal producers are co-located with their customers and transportation costs are negligible. The non-significance of capital costs for pharmaceutical companies can be explained by the structure of the sample. It includes many small companies with highly volatile profits. Profits again directly influence the ROE and in turn the cost of capital. If we exclude small companies (according to the US Census Bureau definition: <50 employees or <10M USD annual sales), capital costs become significant at the 0.05 level.

2.7 Robustness Tests

The robustness of the empirical results was tested on two different levels by applying: (i) alternative estimators and (ii) alternative definitions of the variables (Table 6). We used three distinct regression estimators in addition to the three-stage least square (3SLS) model: a single equation fixed-effect model with robust standard errors, an equation-by-equation OLS estimator, and an equation-by-equation two-stage least square (2SLS) model. The coefficients of the single equation and the OLS model are, as shown by a Hausman test, significantly different from those of the 3SLS model. This indicates that they are likely to be biased and inconsistent due to simultaneity. Looking at the variance-covariance matrix, we state that the error terms appear to be correlated. This is corrected in the third step of the 3SLS estimator with the SUR technique (seemingly unrelated regressions). Therefore we choose the 3SLS estimator as most appropriate.

Table 6 Robustness Test of Model by Applying Varying Definitions of Inventory Driver Variables

Industry Cluster	N	Capital Intensity	Capital Costs	Transportation Costs	(Transportation Costs)^2	Delivery Time	Price Volatility	Demand Uncertainty	Gross Margin	Comment
Original Model										
Basic Process Industry	2073	0.427***	-0.116***	-0.224**	0.117***	2.329***	0.471***	0.319***	2.151***	Three-stage least square (3SLS) fixed effects SEM
Advanced Process Industry	4986	0.613***	-0.0771***	-0.224***	0.0863***	2.290***	0.741***	0.274***	3.375***	
Alternative Estimators										
Basic Process Industry	2073	0.391***	-0.0553	-0.419***	0.163***	2.553***	0.372***	0.301***	1.920***	Equation-by-equation two-stage least square (2SLS) estimator
Advanced Process Industry	4986	0.543***	-0.024	-0.325***	0.109***	2.444***	0.571***	0.300***	3.075***	
Basic Process Industry	2073	0.375***	-0.0272	0.0327	0.0775**	2.513***	0.0613*	0.104**	0.805***	Equation-by-equation OLS estimator
Advanced Process Industry	4986	0.539***	-0.0243	-0.171***	0.139***	2.750***	-0.0265	0.157***	0.790***	
Basic Process Industry	2073	0.187***	-0.0243	0.0547	0.0718**	2.223***	0.0690**	0.0226	0.517***	Single equation fixed-effects model
Advanced Process Industry	4986	0.134***	-0.0187	-0.0907**	0.0756***	2.500***	0.0596*	0.0779***	0.355***	
Alternative Definitions of Exogenous and Endogenous Variables										
Basic Process Industry	2073	0.335***	-0.156***	-0.223**	0.119***	1.501***	0.440***	0.546***	1.878***	DoI average over year
Advanced Process Industry	4986	0.378***	-0.114***	-0.234***	0.0853***	1.417***	0.701***	0.449***	3.173***	
Basic Process Industry	2073	0.165**	-0.120***	-0.286**	0.117***	2.248***	0.530***	0.388***	2.329***	Capital Intensity = CAPEX / Sales
Advanced Process Industry	4986	0.0511	-0.131***	-0.237***	0.0885***	2.314***	0.893***	0.295***	3.435***	
Basic Process Industry	1358	0.411***	-0.139**	-0.233**	0.122***	2.272***	0.531***	0.326***	2.190***	Cost of Equity calculated with CAPM
Advanced Process Industry	3205	0.625***	-0.042**	-0.229***	0.093***	1.845***	0.686***	0.262***	3.163***	
Basic Process Industry	2073	0.492***	-0.115***	-0.204**	0.107***	2.191***	0.435***	0.354***	2.094***	Tax reduction on cost of debt
Advanced Process Industry	4986	0.619***	-0.121***	-0.242***	0.0955***	2.354***	0.717***	0.263***	3.098***	
Basic Process Industry	2073	0.469***	-0.109***	-0.0706***	0.00716**	2.197***	0.414***	0.343***	2.040***	Transportation Costs = COGS / Value-to-Weight
Advanced Process Industry	4986	0.632***	-0.119***	-0.0901***	0.00936***	2.343***	0.763***	0.275***	3.301***	
Basic Process Industry	2073	0.490***	-0.107***	-0.192*	0.0817**	1.235***	0.451***	0.360***	2.096***	Delivery Time = Finished Goods Inventory / COGS
Advanced Process Industry	4986	0.638***	-0.116***	-0.242***	0.0948***	1.168***	0.672***	0.258***	2.977***	
Basic Process Industry	2073	0.539***	-0.118***	-0.312***	0.128***	0.112***	0.493***	0.400***	2.331***	Delivery Time = FG Inv./(Raw Materials + WIP)
Advanced Process Industry	4986	0.597***	-0.102***	-0.255***	0.0973***	0.0501**	1.090***	0.257***	3.412***	
Basic Process Industry	2073	0.543***	-0.106***	-0.221**	0.102***	2.177***	-0.132**	0.398***	1.942***	Price Volatility = S.D. of annual gross margin
Advanced Process Industry	4986	0.737***	-0.114***	-0.249***	0.0957***	2.639***	0.112**	0.289***	2.685***	
Basic Process Industry	2073	0.356***	-0.108***	-0.205**	0.115***	2.355***	0.405***	0.415***	1.996***	Demand Uncertainty = (Forecasted Sales) / Sales
Advanced Process Industry	4986	0.590***	-0.125***	-0.251***	0.0982***	2.239***	0.722***	0.426***	3.107***	
Basic Process Industry	2073	0.521***	-0.0981***	-0.0555	0.0599*	2.375***	0.228***	0.185***	2.430***	Gross margin = -COGS/Sales
Advanced Process Industry	4986	0.337***	-0.145***	-0.219***	0.0893***	2.582***	0.585***	0.236***	3.514***	
Basic Process Industry	2073	0.501***	-0.126***	-0.179**	0.0867***	2.190***	0.424***	0.271***	1.809***	Proxy demand with COGS instead of sales
Advanced Process Industry	4986	0.632***	-0.136***	-0.211***	0.0785***	2.452***	0.697***	0.212***	2.849***	

* p<0.05, ** p<0.01, *** p<0.001

2.8 Post-hoc Analysis

To test the quadratic relationship of transportation costs and inventory, we applied a test recently described in Wharton's datacolada blog.[8] The idea is to take out the quadratic term and to test whether the sign of the coefficient of the linear term changes below or above the turning point. In our case, the sign should change from negative to positive when transportation costs increase. The test was performed for the two process industry clusters. The results in Table 5 show that the sign of the coefficient changes as predicted, which supports the hypothesis of a quadratic relationship. The turning point was calculated with the common expression for quadratic equations and we found vertex values of 0.957 [KG/$] for basic and 1.298 [KG/$] for advanced process industries.

Table 7 Regression Results for the Transportation Cost Quadratic Relationship Validation Test

Model	Sample	N	Capital Intensity	Capital Costs	Transportation Costs	(Transportation Costs)^2	Delivery Time	Price Volatility	Demand Uncertainty	Gross Margin
Basic Process Industry	Full Sample	2073	0.427***	-0.116***	-0.224**	0.117***	2.329***	0.471***	0.319***	2.151***
	Below Turning Point	1396	0.403***	-0.0695**	-0.0755*	N/A	2.134***	0.487***	0.264***	1.867***
	Above Turning Point	677	0.431***	-0.151***	0.216*	N/A	2.680***	0.201***	0.243**	2.265***
Advanced Process Industry	Full Sample	4986	0.613***	-0.0771***	-0.224***	0.0863***	2.290***	0.741***	0.274***	3.375***
	Below Turning Point	3327	0.664***	-0.0475**	-0.120***	N/A	2.092***	0.722***	0.288***	3.643***
	Above Turning Point	1659	0.360***	-0.142***	0.324***	N/A	4.000***	0.770***	0.150***	2.835***

* p<0.05, ** p<0.01, *** p<0.001

2.9 Discussion & Managerial Insights

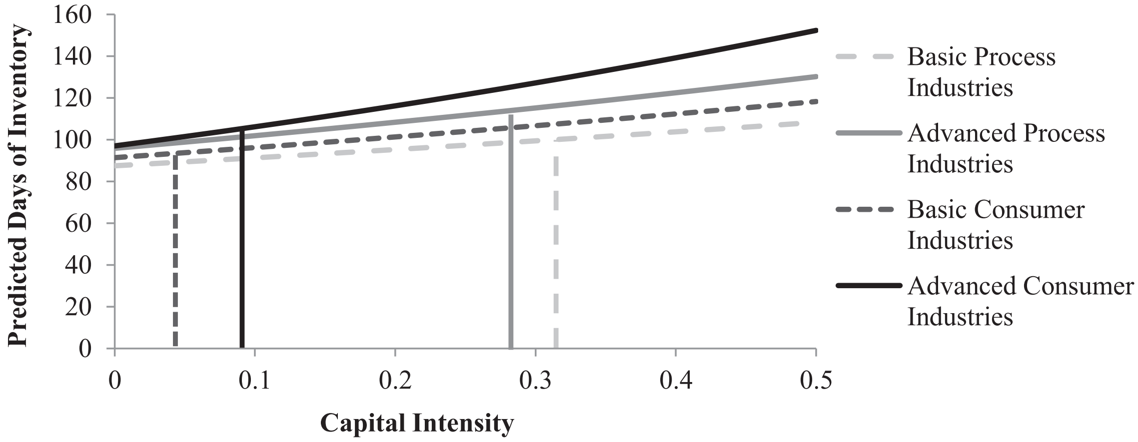
This research aims to enhance the understanding of inventory dynamics in process industries and to find potential levers to improve inventory performance. By identifying seven characteristics that drive inventory we add to the literature that aims to empirically explain inventory levels. Our model enables benchmarking within and between industries while controlling for the industry-specific constraints at the firm level. These insights give guidance to managers on how to set priorities according to best practices and improving inventory performance.

[8] http://datacolada.org/2014/09/17/27-thirty-somethings-are-shrinking-and-other-u-shaped-challenges/

2.9.1 Between Industry Benchmarking to Recognize Constraints

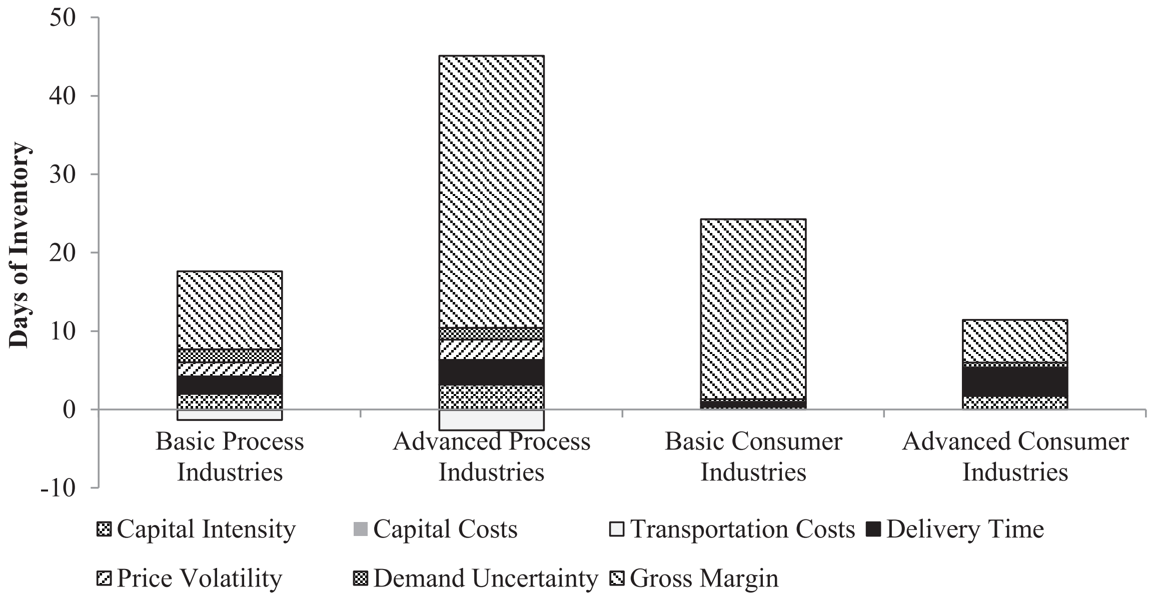
Inventory management performance comparisons across industries are particularly interesting for process industries which are undergoing a shift towards more service oriented supply chains (Shah 2005). This allows them to draw on best practices from other sectors while taking the industry specific setup into account. These inherent characteristics, for example capital intensity, have to be controlled for as the driver profiles across industries are very different (Figure 7) and can explain a considerable share of inventory variations at equal inventory management performance. Figure 6 illustrates the predicted days of inventory at varying capital intensity levels (vertical lines indicating the current mean values). These properties are hard to influence in the short term and set constraints regarding the flexibility of a company's inventory management.

Figure 6 Predicted Days of Inventory for Industry Clusters Depending on Gross Margin Levels



The inventory driver profiles (Figure 7) show that there are significant differences across the defined clusters. The cost reduction related levers (capital intensity, capital and transportation costs) impact process industries, but hardly affect consumer industries. The consumer industries, on which a particularly large body of literature exists, follow the guidelines of common inventory management and optimizing inventory based on margin considerations. A total of 95% of inventory variations in basic consumer industries can be explained by gross margin. Advanced consumer industries are driven by delivery time in addition. Even process industries which are predicted to aspire more service oriented supply chains are considerably impacted by cost considerations.

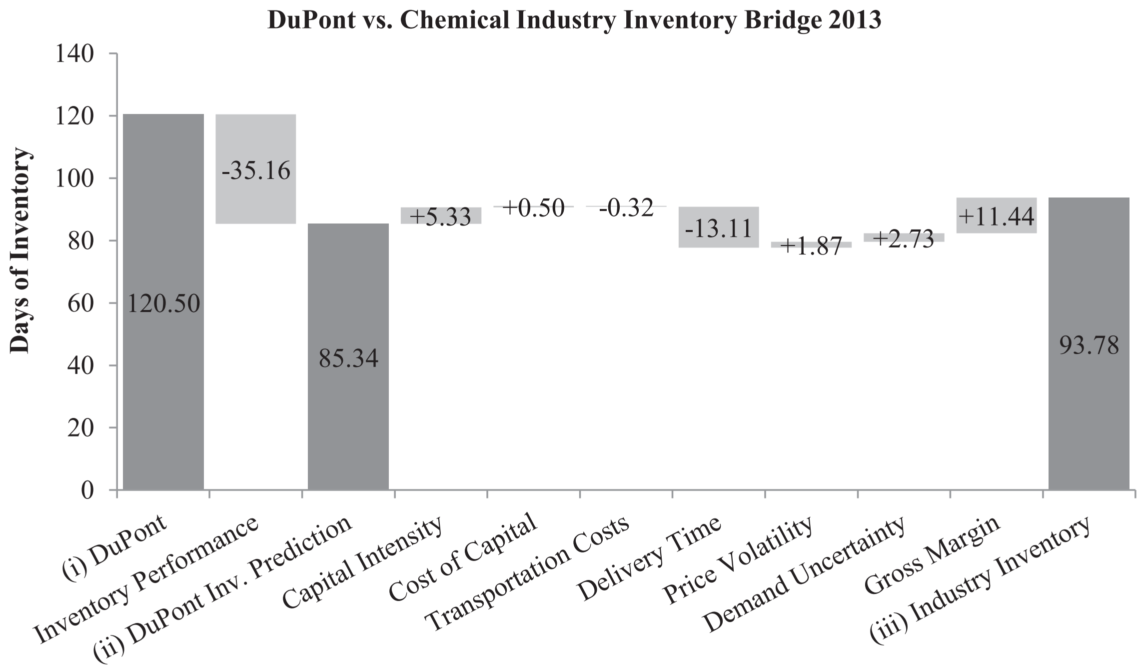
Figure 7 Inventory Driver Profiles for the Defined Industry Clusters



2.9.2 Within Industry Benchmarking to Improve Inventory Performance

Inventory performance benchmarking within industries allow firms to compare their inventory with direct competitors. Such comparisons can also be used to check supply chain strategy alignment with industry standards or best practices (e.g., by comparing to a best-in-class peer company). Figure 8, an inventory bridge (equivalent to the established EBITDA-Bridge) for the chemicals company DuPont Nemours shows the sources of inventory differences between the company and the Advanced Process Industry cluster. From left to right, Figure 8 shows: (i) DuPont held on average 120.5 days of inventory in 2013, while (ii) the model predicts 85.34 DoI, considering the firm's characteristics. The delta of 35.16 DoI could be due either to inventory drivers not considered in the model or to DuPont holding more inventory than commonly done in the industry. Under (iii) the model makes a prediction of 93.78 DoI for the "Chemicals & Allied Products" industry which is adjusted for the introduced control variables (compared to DuPont) such as firm size and number of employees which are hardly changeable in the short-term. The difference between (ii) and (iii) is broken down according to inventory drivers. We note, for example, that DuPont is less driven by delivery time (-13.11 DoI), but puts more focus on gross margin (proxy for target service level: +11.44 DoI) when determining optimal inventory levels compared with the market overall. The following are examples of how DuPont could use this analysis: 1) the delta of -35.16 indicates that DuPont is far from the efficient frontier when it comes to inventory management and that there is potential room for improvement when it comes to inventory management and the trade-off between costs and service level. 2) Given DuPont's gross margin, they hold more inventory than the industry standard. Ceteris paribus, they should hence be able to reduce inventory without reducing service below the industry benchmark. 3) Regarding price volatility DuPont is acting close to the industry average. However, as Table 5 shows, improvements in this area would still have a large impact. 4) Demand uncertainty, on the other hand, shows less potential but might be easier to actually improve on the short run by investing in forecasting.

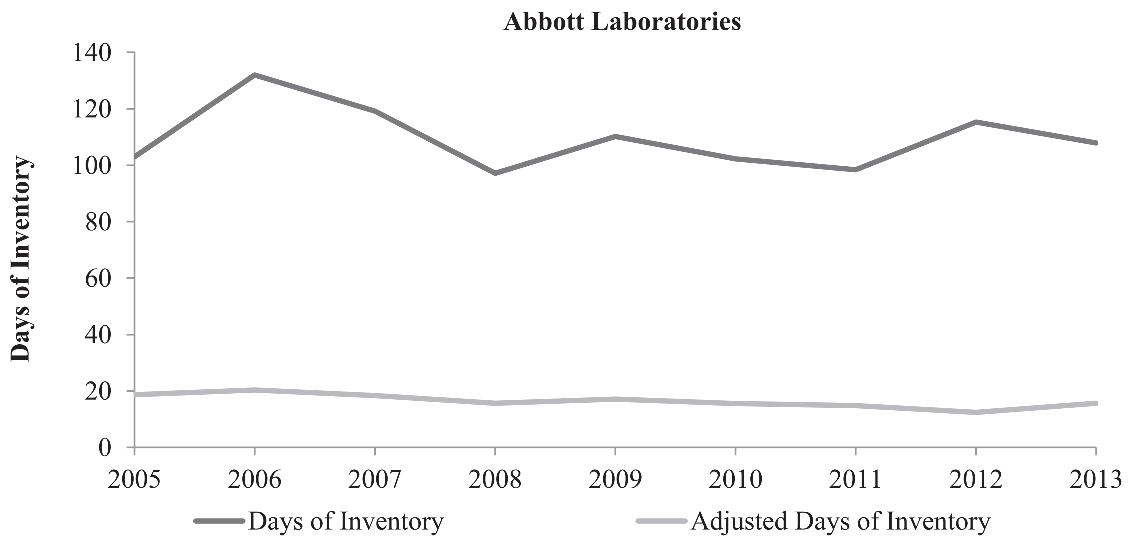
Figure 8 Inventory Bridge Comparing DuPont Nemours with Advanced Process Industries in 2013

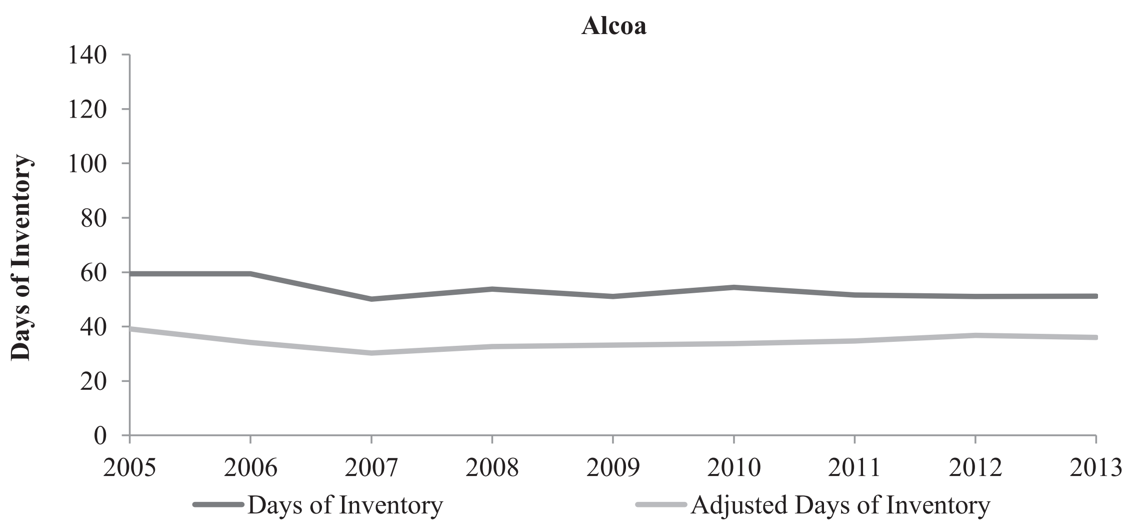


Adjusted days of inventory (ADoI) is a measure that reduces the reported inventory levels by the amount explained by the inventory drivers and can be interpreted as inventory management performance (Gaur et al. 2005). Figure 9 shows by way of example the ADoI development for two major firms Alcoa and Abbott Laboratories, which allows us to draw the following conclusions:

(i) the inventory drivers are responsible for a considerable part of inventory volatility (e.g., Abbott Laboratories); (ii) even though a company has increasing/decreasing inventory levels, this could be due to external factors and its actual inventory performance could be decreasing/increasing (e.g., Abbott Laboratories 2011–2012); and (iii) the unadjusted days of inventory can give an incorrect picture when comparing the inventory performance of two companies.

Figure 9 Adjusted Inventory Levels (AIL) for Alcoa and Abbott Laboratories





2.10 Conclusion & Future Research

This paper develops an empirical inventory model designed for process industries, based on the idea that these industries exhibit a set of characteristics that directly impact inventory management. The model has strong explanatory power for inventory variations and enhances the understanding of inventory management constraints in process industries. Through our analysis, we identify and quantify the levers that managers can pull to optimize inventory levels. We show that capital intensity, capital costs, transportation costs, delivery time, price volatility, demand uncertainty and gross margin directly affect a company's degree of freedom in terms of inventory management. Adjusting inventory performance for these factors can lead to diametrically different conclusions compared to traditional inventory metrics.

Our paper is based on publicly available financial, trading and credit rating data, which naturally implies some limitations. Even though we rely on previously established proxies for the majority of our variables, some variables were developed for this study and need validation. In addition, aspects such as production footprint and portfolio complexity theoretically also impact inventory levels and should be considered going forward. Future research should focus on prescriptive advice for managers on how to develop and implement best practices in inventory management while taking specific process types into account.

Chapter 3

Leveraging Your Supply Chain

Why Process Industries Are Different

3.1 Introduction

Globalization, shifts in demand to new markets and technological advances are dramatically changing the business environment in many industries. These trends imply new possibilities, but also increase the competitive pressure, forcing companies to adapt and alter their way of working. Supply chain management, in its modern guise at the core of many organizations, plays an ever more important role under these circumstances. The supply chain function has to improve cooperation internally between different business functions, such as manufacturing and sales, as well as externally with customers and suppliers. It has become a truly holistic business function, and successful companies have managed to turn it from a cost center into a business driver.

In a large-scale survey that we conducted with senior executives across different business functions from 13 industries, more than four-fifths noted that supply chain management has become "more" or "much more important" over the last five years compared with other functions (see "About the Research"). Some companies have changed the paradigm in their industry and gained a substantial competitive advantage with their supply chain. For instance, Apple's Tim Cook said when he was COO that "inventory is fundamentally evil," with its value declining by 1–2% a week.

From the moment he was hired in 1998, he pulled the company out of manufacturing, closed factories and warehouses and set up relationships with third-party contract manufacturers, all of which helped to reduce inventory from weeks to days (Lashinsky 2008). Procter & Gamble, another supply chain champion, aims for "holistic optimizations" through unprecedented levels of real-time supply chain analytics, which is believed to increase sales by 1–2% and margins by 2–5% (Banker 2015). One of the best known and highly cited examples of supply chain excellence is Zara, the Spanish apparel company. It segmented the product portfolio according to the product's demand characteristics, setting up several supply chains in parallel with distinct levels of costs, time-to-market and flexibility (Ferdows et al. 2004). Dell took a similar approach when transforming its supply chain to "serve new customers in new channels with new types of products." (Simchi-Levi et al. 2013).

There is an ever growing number of frameworks to help managers tackle the optimization of all aspects of supply chain management. Like the above examples, most of these frameworks and best practices are inspired by industries that operate close to the end customer such as consumer goods or automotives, which we refer to as consumer industries. At the other end of the value chain, manufacturing-focused process industries, such as steel making or chemicals, have traditionally focused mainly on logistics rather than integral supply chain management. In fact, in the well-established "Gartner Supply Chain Top 25" ranking – which lists the best companies in terms of supply chain management across industries – process industries do not feature at all in 2015 (or even in recent years).

So why are companies in process industries struggling to identify and implement new supply chain strategies and practices? In the past, most process industries placed emphasis on cost efficient supply chains. Now companies are increasingly reorienting their supply chain to have a stronger service focus (reacting quickly and reliably to customer requirements). Almost all of the companies we surveyed (98%) are currently implementing supply chain related frameworks such as vendor-managed inventory or collaborative planning, forecasting and replenishment. This trend has been accelerated by increasing financial pressure as a result of plunging commodity prices such as oil, mining and steel in 2014/15, which squeezed the profit margins in many process industries. But transformation is not straightforward, since process industries are dealing with completely different constraints and planning cycles than consumer industries.

Understandably, not every supply chain management strategy is applicable or appropriate for every company or industry. For instance, consumer electronics and apparel companies such as HP and Nike use off-shoring of their manufacturing activities to respond to increasing price pressure. Yet mining firms in the iron ore business – also experiencing low prices and cost pressure – cannot apply the same principle. Likewise, leading French beauty products company L'Oréal addressed excessive demand volatility by collaborating closely with its customers and even directly managing their inventory. It succeeded in improving the demand forecasting accuracy by eight percentage points from 2010 to 2014 and its overall supply service level by about 3%. In contrast Borealis, a major European chemicals company, has to pursue an alternative approach as it sells a significant share of its products on the spot market to anonymous buyers. So the question remains: how can you excel with your supply chain in process industries?

There is broad agreement that excellent supply chain management starts with an aligned supply chain strategy, which can have a positive impact on company performance (Fisher 1997; Lee 2002; Lee 2004). This means that the supply chain is set up to support the company's commercial strategy while taking internal and external constraints into account (Cordón et al. 2013). To stay aligned in ever more dynamic business environments, companies have to constantly adapt and rethink their supply chain. Marshall L. Fisher suggested that companies should define their supply chain depending on certain product and demand characteristics. Functional products require a cost efficient supply chain, whereas innovative products are better served by a responsive and flexible supply chain (Fisher 1997).

In order to apply the Fisher matrix to process industries, as opposed to consumer industries that it largely relates to, the supply chain strategies have to be examined in greater detail. This is due to the fact that cost efficient supply chains can look different depending on the industry. For example, an apparel company (consumer industry) we spoke to about the strategic priorities of its supply chain revealed that it focused on reducing obsolescence costs because of its short product life cycles. In contrast, a cement producer (process industry) mainly talked about batch sizes, asset utilization and optimal routing. Both supply chains strive for efficiency, even though their approaches are entirely different. The same applies to responsive supply chains: Companies in consumer-focused markets such as consumer goods will concentrate their efforts on directly collaborating with their clients to define required minimal batch sizes or delivery times. However, in contrast, companies in process industries such as oil and gas exploration are more likely to try to increase their reactivity internally to capture positive price movements.

Previous research has documented the importance of supply chain alignment, but with a strong focus on consumer industries (Narayanan and Raman 2004; Corbett et al. 1999). We aim to redress the balance by describing specific supply chain strategies for process industries such as chemicals, mining and steel making. We do this by identifying four market archetypes according to the strategic focus (cost vs. sales) of a company's supply chain and the pricing power in the industry. We then describe typical supply chain management strategies for the four identified market archetypes and find that there are two conditions for excellent supply chain management in process industries: alignment with the market archetype and accurate demand forecasting. Finally, we suggest two practical implementation actions that companies can take to optimize their supply chains.

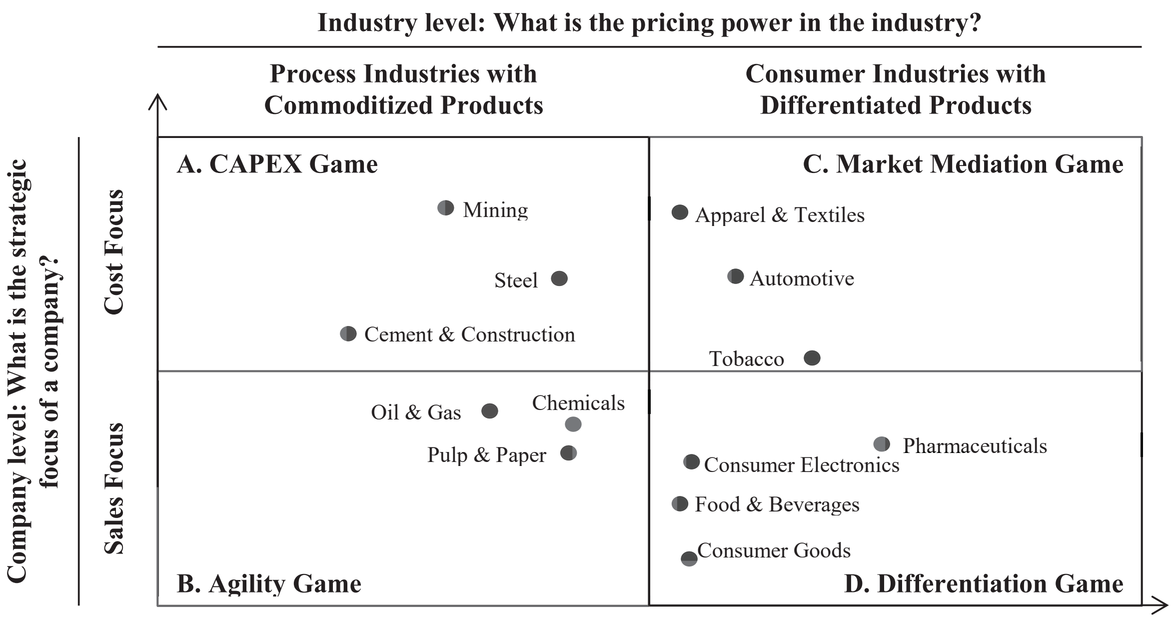
3.2 Literature Review: Supply Chain Management Can Be Your Competitive Edge

There is consensus across academic and managerial literature that the alignment of the supply chain with the firm’s business model has a positive impact on firm performance (Wagner et al. 2012; Selldin and Olhager 2007). This includes taking product, market and industry characteristics into account when defining the supply chain strategy. Fisher (1997) described how the optimum setup of a firm’s supply chain is impacted by product and demand characteristics. On the one hand there are functional products with predictable demand, long product life-cycles and relatively low contribution margins which should be supplied through efficient chains. On the other hand there are innovative products with lower forecasting accuracy and shorter product life-cycles, but higher margins which should be matched with a responsive supply chain. Lee (2002) extended this approach with supply characteristics, distinguishing between stable, flexible and reliable supply chains on one side and evolving, uncertain and vulnerable ones on the other side. In another article Lee (2004) named alignment, besides agility and adaptability as the key success factor for excellent supply chain management. But alignment does not stop at firm-level, Narayanan and Raman (2004) described how supply chains only work optimally when the incentives of all partners along the supply chain are aligned. Corbett et al. (1999) describe the characteristics, such as free exchange of information or coordinated decision making, of truly successful partnerships which emerge in competitive advantages. Supply chain strategies are as well impacted by macro-economic measures as illustrated by Simchi-Levi et al. (2012) who show how oil prices and labor costs were decisive factors for the off-shoring wave which manufacturing intensive industries experienced since the mid-1990s. Simchi-Levi (2010) identified supply chain flexibility and segmentation as key points companies should aspire through supply chain transformation to face today’s challenges which include global supply chains’ long lead-times, shifting customer expectations and increasing labor costs in developing countries. But changing business environments force companies to constantly adapt and re-adapt its operations and currently the inverse trend can be observed. Supply chain disruptions, rising labor costs etc. changed the paradigm and many firms relocate their manufacturing activities back home closer to their customers. Taken together, previous literature has documented the importance of supply chain alignment but with a strong focus on downstream industries. This research intends to close this gap by exploring supply chain alignment in process industries.

3.3 Theory: Market Archetypes Shape the Supply Chain Strategy

We carried out 24 in-depth interviews with senior supply chain managers in consumer and process industries to identify what determines their supply chain priorities. The interviews revealed a broad number of internal and external factors: supply and demand characteristics of the market, breadth of the product portfolio, customer and supplier requirements, and taxes and regulations, to name but a few. Despite the vast number of influencing factors, we found that two predominant characteristics shape and set high-level supply chain strategy: *pricing power* (industry level) and *strategic focus* (company level).

Figure 10 The Four Identified Market Archetypes



In a next step, we conducted a survey with 477 senior supply chain executives across 13 industries and asked them to estimate their industry's position along these two dimensions. We then plotted the average for each industry, categorized according to four market archetypes – A. CAPEX Game, B. Agility Game, C. Market Mediation Game, D. Differentiation game – which we developed in cooperation with the interview partners. As Figure 10 neatly illustrates, from a strategic supply chain perspective, process industries generally correspond to commoditized products, whereas consumer industries have differentiated products.

There are examples of sub-categories, e.g., specialty chemicals have a generally rather differentiated product portfolio, where this rule does not apply. Pharmaceuticals, although often considered a process industry, are closer to consumer industries from a supply chain strategy point of view because of their high degree of product differentiation. The potentially surprising cost focus of the automotives industry might be explained by the numerous small supplier companies.

3.3.1 Industry level: What is the pricing power of a company in the industry?

Michael Porter described two generic, distinct strategies for gaining a sustainable competitive edge: cost leadership and differentiation (Porter 2008). The degree of product differentiation in an industry directly impacts the pricing mechanism and determines the pricing power companies can wield. A company with stronger customer focus and more pricing power is likely to have a closer relationship and a deeper understanding of its customer base. The closer these interactions, the more likely it is that there will be joint efforts to optimize the supply chain, not only on an individual company level but also along the value chain. In consumer industries, companies tend to run supply chains that are tightly embedded in their value chain. Consumer goods companies such as L'Oréal work closely with their key accounts whose sales promotions are directly fed into the consumer goods companies' own demand forecasting. For process industry goods, which are often commoditized, the situation is different. Customer interactions are more transactional, and optimizations will predominantly be focused internally. Syngenta, a leading agrochemical company, stated that distinct degrees of product commoditization are the main reason it runs several parallel supply chains with different underlying strategies to cover its portfolio.

On an industry level, the degree of product differentiation is the predominant characteristic impacting the supply chain and distinguishing between individual and supply chain wide optimizations.

3.3.2 Company level: What is the strategic focus of a company's supply chain?

A company can consider supply chain management as a business driver or a cost center, but this is not set in stone and can change depending on the business context. As a business driver (sales focus), the supply chain will be used to increase the company's top line, while as a cost center (cost focus), it will be designed to reduce expenditure. The main differentiator influencing a company in the process industries to choose one approach over the other is the contribution margin (the selling price per unit minus the variable costs per unit). In process industries, companies are generally price takers, with their contribution margin depending uniquely on their specific position on the cost curve (common method of ranking companies in an industry based on production and transportation costs, indicating their variable profit margin). Companies with high margins will increase average sales prices by capturing price swings based upon a fast supply chain; in contrast, producers with low margins will focus on lowering their cost base through economies of scale and locating their facilities strategically. As Marius Kloppers, former CEO of the world's biggest mining company BHP Billiton, said: "…during the commodity super cycle in the 2000s [a period of high commodity prices and generally high margins], most miners took a 'volume over cost' approach…" This means producers focused on increasing sales volumes rather than improving profit margins. In consumer

> *"We are right at the bottom [of the cost curve], in the lowest quartile. That is incredibly important. That means no matter what happens in the business, we will be profitable."*
>
> ***Sam Walsh, CEO Rio Tinto***

industries, where products and product prices are differentiated, companies can act on different axes. They can either reduce costs related to obsolescence and lost sales through better demand planning, or they can strive to push volumes through customer-tailored offerings.

On a company level in process industries, the contribution margin is the predominant characteristic impacting the supply chain and distinguishing between a cost and a sales focus.

3.4 Methodology

The insights presented in this article are part of a research collaboration between the École Polytechnique Fédérale de Lausanne (EPFL) and IMD business school. It was generously co-funded by these two institutions, as well as the Swiss National Fund (SNF) and the consultancy McKinsey & Company. The study included an extensive review of academic and managerial literature in the fields of supply chain and operations management in process industries, a series of 24 in-depth interviews with supply chain managers across 13 industries, and survey data. The contact list for the survey was created by combining three contact databases to guarantee non-biasness. The whole survey process, from development to analysis, was conducted based on the Dillman method guidelines (Dillman 2000). The questionnaire was e-mailed to 2,397 executives, of whom 477 responded, giving a response rate of 19.9%. Because of the strategic nature of our topic, we mainly targeted senior executives with the necessary experience and overview: 68.9% of respondents held positions of vice-president or above working at corporate, rather than division, level. The industries represented are apparel & textiles (4%), automotive (9%), cement & construction materials (11%), chemicals (13%), consumer electronics (11%), consumer goods (9%), food & beverages (14%), mining (4%), oil & gas (5%), pharmaceuticals & biomedical (10%), pulp & paper (4%), steel & primary metal (4%) and tobacco (3%). The respondents cover all regions, with 56% from Europe, 23% from the Americas and the remaining 21% from Africa and Asia & Pacific. The respondents included both publicly listed companies (85%) and private companies. The average annual sales for 2014 were USD 0.9 billion and ranged from USD 0.4 million up to USD 66 billion, representing the whole range of commercial organizations.

3.5 Analysis

3.5.1 Supply Chain Strategies to Address the Four Identified Market Archetypes

From our research, we gained insights into what successful companies in both consumer and process industries are doing to ensure superior supply chain performance. Below we summarize key considerations for each market archetype, as well as provide some examples from executives that we interviewed.

A. CAPEX Game

In process industries at low margin levels, companies will seek to capture economies of scale in terms of production and supply chain management. This can be achieved through big batch sizes, which allow to pool quantities and to run manufacturing at constantly high utilization rates. At a conference, Sam Walsh, chief executive at the time of Rio Tinto's iron ore business, phrased it thus: "If we have excess capacity we are wasting investment." According to executives at LafargeHolcim, strategically choosing facility locations is also crucial. This enables companies to further lower variable costs by optimizing routing and transportation costs.

B. Agility Game

In process industries at high margin levels, companies will seek to increase average sales prices through a highly responsive supply chain in order to capture favorable price swings. Price volatility has reached record levels in several commodity markets in recent years. This is a major threat for many companies and is often named as the main future risk. But some companies in process industries, such as the commodity traders Noble Group and Trafigura, have adapted their business model to price volatility by increasing their responsiveness and reducing their time to market. There are different approaches to responding to volatility, including increasing production flexibility, reducing lead times, building up speculation inventory and changing transportation modes. The fertilizer industry is an interesting case, in which low manufacturing flexibility meets high demand volatility. Yara, the major Norwegian fertilizer producer, explained that it smooths demand swings due to increasing seasonal volatility by flexibly allocating volumes across an international footprint.

C. Market Mediation Game

Consumer industries such as tobacco, automotive and apparel & textiles, that experience particularly high market mediation costs (costs related to lost sales and product obsolescence), put a specific focus on improving demand forecasting with their average achieved accuracy being about 6% higher than their peers. Philip Morris International (PMI) achieves forecasting accuracy of 85% on SKU levels (compared to the 68% average for consumer industries) through forward integration, by incorporating point-of-sale data into its demand planning and using vendor-managed inventory programs. Many companies in the apparel industry have chosen a different approach to reducing market mediation costs – they have shortened their time to market (e.g., by near-shoring and keeping operations in-house) and can rely on more precise, short-time forecasting horizons.

D. Differentiation Game

Consumer industries with a particularly strong focus on customer interaction such as consumer electronics, consumer goods and food & beverages place special emphasis on supply chain service and tailoring their offering to their clients' needs (e.g., smaller batch sizes, shorter delivery time) to push sales volumes supported by their supply chain. Their supply reliability is on average about four percentage points higher and their average delivery time about two days shorter than their consumer industry peers. Many of the companies we surveyed in these sectors started running key account management programs to collaborate closely with their most important customers. L'Oréal for instance, initiated a collaboration initiative to "…better manage supply networks and optimizing inventory, cost and service."

3.5.2 Conditions for Supply Chain Excellence in Process Industries

Many process industries are currently taking a more holistic approach and upgrading their supply chain function to reposition it at the very core of the organization, operationalizing input from marketing, finance, manufacturing and logistics (Slone et al. 2007). Although today there is a lot of emphasis on dynamic supply chain management to keep up with the ever-changing global environment, focus and simplicity are also important, particularly for companies in process industries. We found that those with the most effective supply chains concentrate on leveraging their own functional strengths coupled with meeting the emerging demands of their markets.

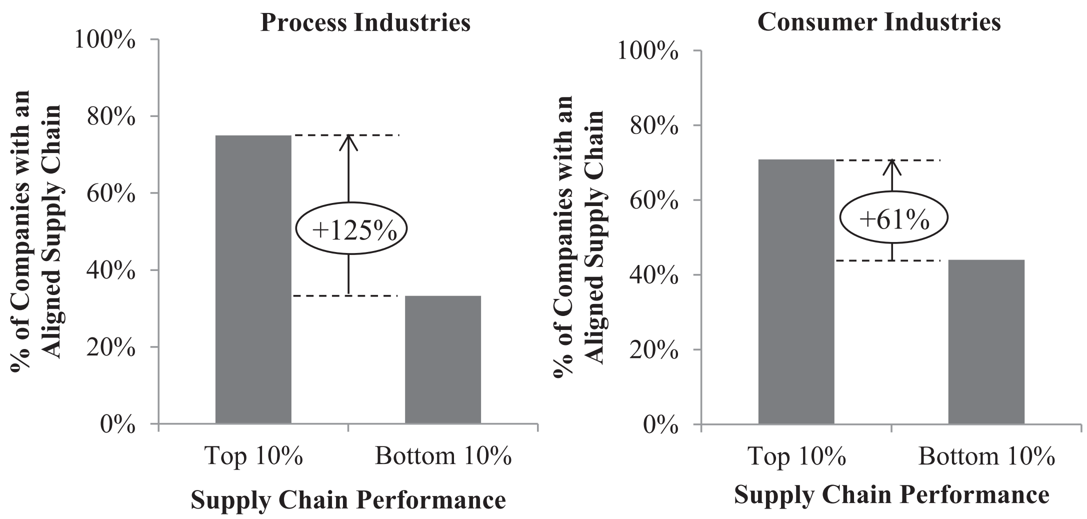
Our interview partners described how they initiated these efforts by making strategic assessments of their current and desired supply chain setup. But defining supply chain strategy is only the beginning. Analyzing successful supply chains, we found that their underlying strategy and performance showed that great supply chains in process industries have two points in common: their strategy is aligned with their market archetype and the supply chain is enabled by good demand forecasting capabilities.

Rule #1: The Road to Supply Chain Excellence Starts with Strategic Alignment

Companies in process industries that align and adapt their supply chain to their market archetype are more likely to achieve superior supply chain performance (Figure 11).

We tested the impact of supply chain alignment on supply chain performance based on our survey. Respondents estimated the importance of eight market characteristics (e.g., demand uncertainty) on their supply chain strategy based upon percentage of importance. The supply chain of a company was considered to be aligned if at least four of these market characteristics were within a standard deviation of the market archetypes average. For example, a company in the cement industry would be compared to the A. CAPEX Game market archetype. This alignment was then linked to supply chain performance, which in this context was considered holistically, taking into account manufacturing (overall equipment effectiveness (OEE) rate, transportation costs, stock holding costs), demand planning (forecasting accuracy, portfolio management), market understanding (price forecasting, market monitoring) and service level (delivery time, supply reliability). Figure 11 indicates that a company with a supply chain strategy which is aligned with the market archetype has a 125% higher likelihood for superior supply chain performance (higher service level at lower cost). The effect of alignment on performance is considerably stronger for process than for consumer industries. We assume this is because of the relative importance of supply chain performance for the overall customer experience. In process industries, where product and supply conditions are standardized and easily comparable, factors such as on-time delivery are even more crucial than in most consumer industries, where many other factors such as after-sales service also play a role.

Figure 11 Relationship between Supply Chain Alignment and Supply Chain Performance



Currently only about one-third of process industry companies in our survey sample are aligned, which is about 40% lower than those in consumer industries. This indicates that the improvement potential is substantial. Indeed, nearly 80% of surveyed firms are now reinforcing capabilities in areas where they have the most accentuated misalignments. For example, an African cement producer increased average delivery times, making it possible to increase batch sizes and reduce transportation costs while improving the supply chain reliability level.

Rule #1: Supply Chain Alignment Leads to Greater Supply Chain Performance

Companies with a supply chain strategy that is aligned with their market archetype have generally better performing supply chains with better service levels at lower costs. This positive effect can be observed across all process industries for cost efficient (A. CAPEX Game) and responsive (B. Agility Game) supply chains.

But how can a company in a process industry align the supply chain in practice, when product portfolios are often broad and have distinct requirements? Alongside a broad range of tasks to be fulfilled, supply chain management encompasses diverse business objectives. These include cost and service level targets which – although not mutually exclusive (McKinsey & Co. 2008) – are after all inherently competing objectives. There are companies excelling along both lines, but they also have a clear strategic focus on either sales or costs without neglecting the other. Companies should regularly reassess their service levels and limit themselves to the objectives that truly add value rather than trying to excel in all dimensions. Yara regularly surveys its customer base to redefine its supply chain service levels. The diversity of its product portfolio and its clients' requirements led the company to run distinct supply chains in parallel (e.g., using different transportation modes).

Implementation of Rule #1:
Supply Chain Alignment Has to Happen on a Granular Level

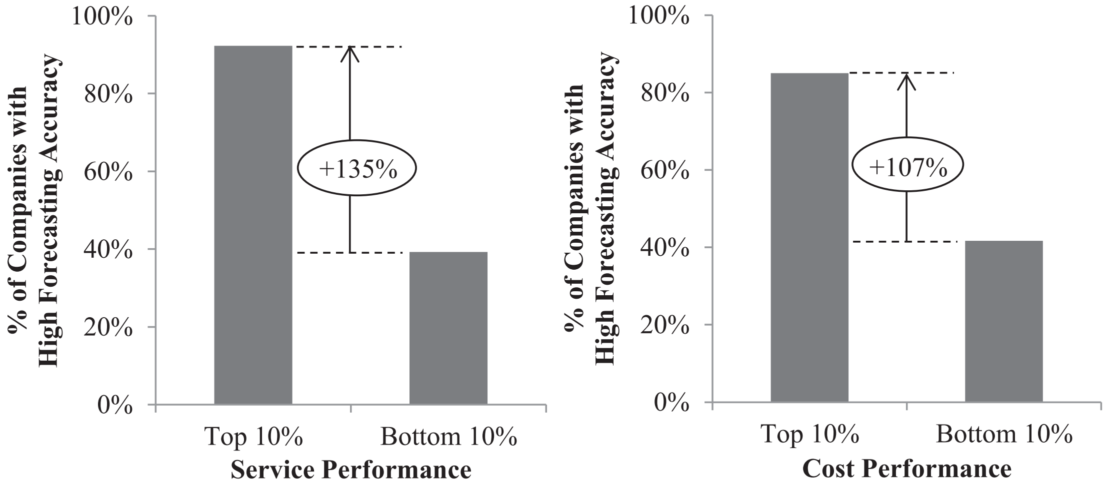
Companies carrying a broad product portfolio and serving a diverse customer base have to align their supply chain by product line and customer segment. Companies in specialty chemicals and pulp & paper are taking a leading role in this regard, but overall, only 32% of the surveyed companies in process industries are implementing programs to segment their supply chain service levels in cooperation with their clients. About 80% of these companies achieve superior supply chain performance.

Rule #2: Demand Forecasting is the Basis of Great Supply Chain Management

According to Richard Markoff, corporate supply chain standards & audits director at L'Oréal, "Nothing is more important in supply chain management than demand forecasting." Our research shows that in process industries, too, demand forecasting acts like a rising tide that lifts all the boats and improves the supply chain performance (Figure 12). The effects of demand planning on the supply chain are broad: (i) stock-outs are reduced and delivery times are shortened because of more accurate predictions, (ii) safety stock levels can be reduced because of lower demand uncertainty, and (iii) production and transportation costs are lowered because of increased and smoothened manufacturing utilization. Figure 12 indicates the likelihood of great supply chain performance in terms of service and cost depending on forecasting accuracy.

Figure 12 Relationship between Demand Forecasting, Service Level and Costs in Process Industries

Note: Demand forecasting accuracy is considered high above 69%, corresponding to the average in process industries



> ***Rule #2: Demand Forecasting leads to Supply Chain Excellence***
>
> *Demand forecasting is like a silver bullet in process industries: Companies with superior demand forecasting capabilities have better supply chains with higher service levels at lower cost. This holds true for both cost efficient (A. CAPEX Game) and responsive (B. Agility Game) supply chains.*

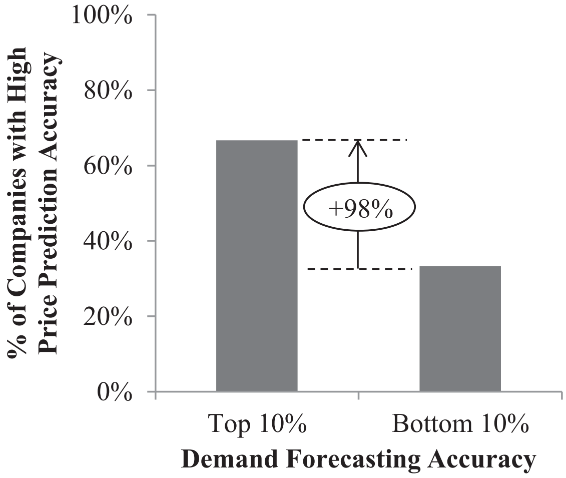
Although the positive impact of improved demand forecasting is undeniable, it is difficult to achieve. This is especially true in process industries where lead times and required forecasting horizons are generally long. A senior operations executive of the multi-billion dollar specialty chemicals company Clariant International stated, "…in the current market environment where demand is global and with high price volatility, reaching demand planning accuracy above 70% is not feasible for us." In order to improve demand forecasting accuracy, supply chain management researchers have provided various frameworks, which are generally based on either pooling demand or reducing the length of the necessary forecasting horizon. Only some of the principles commonly applied in consumer industries can effectively be transferred to process industries. For instance, process industries such as steel making and mining manufacture commodities in continuous flow production. Therefore, principles such as mass customization and postponement (i.e., delaying the moment at which a product becomes customer-specific) are not applicable. Another concept, found in the apparel industry, is to constantly rotate the product portfolio and rely on short forecasting horizons. But process industries generally have long product life cycles and a high share of product specific assets and therefore cannot simply roll over their portfolio. An example of successfully improving demand forecasting in process industries comes from the pulp & paper industry. By reducing lead times as a result of more flexible production assets (e.g., continuous mixers) and implementing quick response manufacturing, companies can rely on more accurate short-term demand forecasts. Another example is portfolio rationalization, which is used by about one in five process industry companies in our sample. The principle is the same as for centralized stock – demand pooling leads to lower variance (on an aggregated demand level) and thus higher forecasting accuracy. However, the most powerful tool we found for companies in process industries to effectively increase their demand planning accuracy was related to monitoring the market and improving their capability to predict the price development of both raw materials and output materials (Figure 13). For many commodities, spot markets provide a second option for companies to sell their products besides contracted sales. Companies that sell or procure heavily on spot markets often build internal trading units that follow the markets closely and enhance their understanding of the market dynamics. Companies in our survey were asked about their capability to predict price developments for the coming six months, both for the products they procured and for the products that they sold. We found this, amongst all the commonly applied methods, to be the

> *"…in the current market environment with high price volatility and global demand, reaching a demand planning accuracy above 70% is not feasible for us."*
>
> ***SVP Operations, Clariant International***

strongest lever to improve demand forecasting accuracy. In consumer industries the same positive effect can be observed, but its impact is considerably weaker.

Figure 13 Relationship between Demand Forecasting and Price Prediction in Process Industries

Note: Price prediction accuracy is considered high above 61%, corresponding to the average in process industries



Discussions with managers revealed that the price building mechanism in commodity markets, such as oil, with its unique market price, is the reason that price prediction is a particularly powerful lever for improving demand forecasting in process industries. The link between supply, demand and pricing is especially direct in process industries, and competitors' actions have a direct impact in a market in which companies are price takers. Companies that monitor and try to understand the market and its competitors – with the objective of anticipating price movements – inherently gain insights into the demand/supply balance. This ultimately leads to better sales forecasting and more effective supply chain management.

Implementation of Rule #2:

Price Prediction through Market Monitoring Increases Planning Accuracy

The ability to predict prices by closely monitoring markets proved to be the most effective way to increase demand forecasting accuracy in process industries, which in turn leads to superior supply chain management performance.

3.6 Discussion & Conclusion: The Supply Chain Management Transformation in Process Industries Is Underway

Supply chain management in process industries still lags behind consumer industries when it comes to alignment and best practices. However, companies in process industries have recognized that the supply chain can be a true competitive edge and are upgrading their capabilities at full speed and investing the necessary resources to do so. For example, Saudi manufacturing company SABIC mentioned to us that it is transforming its historical logistics unit into a holistic supply chain management function operating at the core of the company. BASF, the German chemicals company, has considerably scaled up its talent pool in supply chain management to support the transformation towards a supply chain segmented by customer and product group. Similarly, a senior manager from Syngenta mentioned that "…while in the past most people in supply chain management were generalists transferred from other business departments, today we hire supply chain managers with degrees from the best business schools specifically for these positions."

Based on our findings, about 80% of process industry companies that try to achieve superior supply chain performance by taking a granular approach to product and customer segmentation (Rule #1) are successful. At nearly 90%, the success rate is even higher for the ones following Rule #2 and monitoring market developments. And even though they cannot apply all of the same frameworks as consumer industries, these numbers show that the stakes are high and there is no reason why process industry companies cannot compete strongly in the supply chain excellence rankings.

Chapter 4

Cyclical Investments in Commodity Markets: Short-Term Gain vs. Long-Term Pain

4.1 Introduction & Contribution

In the space of just four years, the top 40 mining companies increased their capital expenditure (CAPEX) from less than USD 70bn in 2009 to more than USD 130bn in 2013 (PricewaterhouseCoopers 2015). These investments in fixed assets are particularly high in manufacturing-intensive and commoditized process industries. They represent 31% of sales in the oil & gas and 40% in the mining industry – significantly higher than, for instance, in consumer electronics (9%) or the automotive industry (19%).[9]

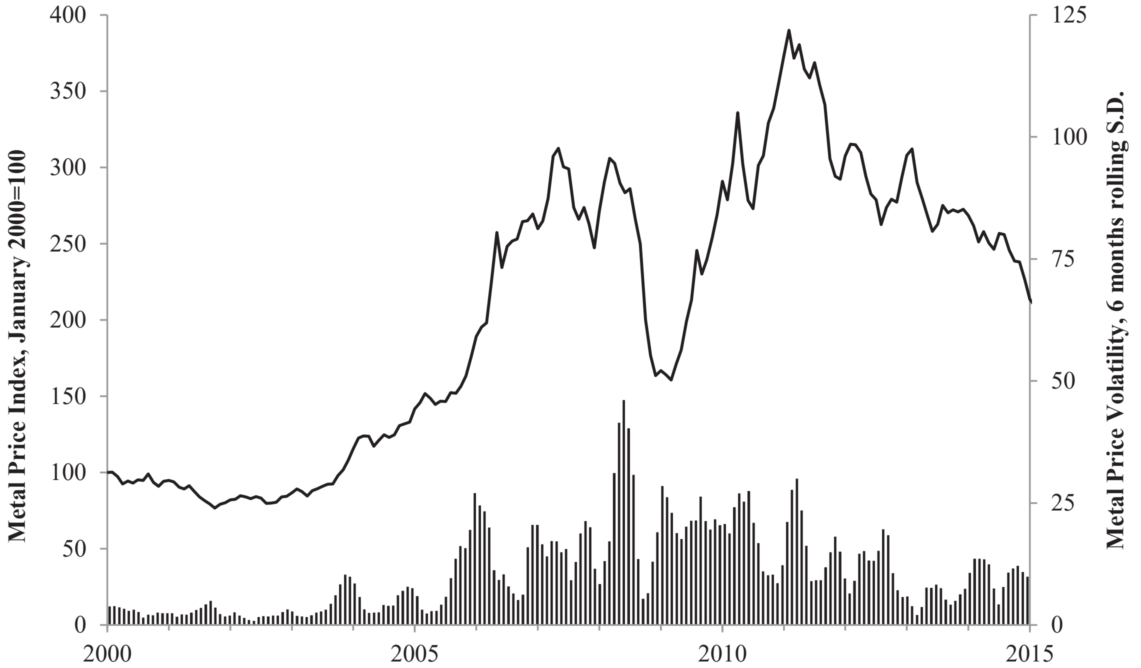
These high fixed costs combined with, by definition, little pricing power make companies' profitability highly sensitive to volatile market prices (Figure 14) and they partly explain why CAPEX by the aforementioned top 40 miners was reduced by 20% as recently as 2014. Slashing CAPEX takes financial pressure off companies' distressed balance sheets. Despite the positive effects in the short term, cutting CAPEX is a double-edged sword. In commodity markets, where products are undifferentiated and competition on price is fierce, reducing investments in manufacturing-related assets impacts a firm's longer-term strategic competitiveness. This concern

[9] COMPUSTAT North American public financial accounting data for 2000–2015.

was expressed by a senior investment manager at Aberdeen Asset Management in reaction to Shell’s announcement that it would reduce CAPEX: “We wouldn’t be surprised to see CAPEX guidance lowered again. However, we want the company to continue to focus on driving long-term growth” (Reuters 2016). Companies face a crucial trade-off when balancing these short-term and long-term interests.

Figure 14 Metal Index Price and Volatility 2000–2015

Source: IMF, Metal Price Index includes Copper, Aluminum, Iron Ore, Tin, Nickel, Zinc, Lead and Uranium Price Indices



Companies are experiencing cash flow swings at the end of a commodity price cycle, as a result of volatile and declining prices. Research has shown that company investments are sensitive to such swings (Hubbard et al. 1993). In turn, these investments impact the company’s manufacturing flexibility (Allen and Pantzalis 1996) and capacity expansions (Anupindi and Jiang 2008). These effects have not been studied jointly. In order to determine the combined short- and long-term effects of CAPEX adjustments on manufacturing operations, their interdependence needs to be studied.

This paper aims to fill this gap by empirically studying (i) how companies in commodity markets adapt their investments in fixed assets depending on market prices, and how these investment adjustments affect (ii) their manufacturing flexibility in the short term and (iii) their capacity expansion in the long term. We then link these findings to stock price performance. We develop empirical models using financial accounting, spot market price and stock market data for the mining and oil & gas sectors for the period from 2000 to 2015. The paper makes a two-fold contribution. First, it adds to the operations management literature by examining the short- and long-term impact of market developments on investment decisions and operational aspects such as manufacturing flexibility and capacity expansion. This holistic consideration is complementary to the established literature, which primarily explains single relationships. We find that CAPEX follows market prices and is inversely related to price volatility. These variables explain 69.0% of *within-firm* and 80.4% of *total* variation of investments in fixed assets. These values are remarkable, since the model covers a turbulent period with constantly changing price dynamics. We show that CAPEX drives up utilization rates and negatively correlates with short-term volume flexibility and positively correlates with long-term production and capacity growth. Second, we give managers insights into the implications of their decisions over the complete market cycle (rather than focusing solely on a downturn or an upturn). If we combine the short-term effect that CAPEX adjustments have on manufacturing volume flexibility with the long-term impact on capacity growth, we see that CAPEX has an important impact on stock market returns and, in the long term, the impact on capacity overshadows the one on manufacturing flexibility.

In the remainder of this paper, Section 2 reviews the literature and Section 3 develops the theory and hypotheses. Section 4 illustrates the method, including data, variables and statistical specifications. Section 5 presents the empirical results and Section 6 consists of additional robustness tests. Section 7 presents post-hoc analysis, Section 8 provides discussion and managerial insights and Section 9 draws conclusions and suggests avenues for future research.

4.2 Literature Review

Three streams of literature are particularly relevant for our study. First, we base our work on the existing body of literature examining the determinants of investment decisions at the firm level. Second, this research builds on previous work on the value of manufacturing flexibility. Third, we draw on the literature stream related to long-term capacity planning. Even though these three aspects are extensively studied in the finance and operations management literature, the holistic operational impact of investment decisions in the short and long term is not yet well understood.

4.2.1 Price & Asset Development

The development of manufacturing assets in process industries requires high investments and cash outflows, which have to be financed from either external or internal sources. The two are interdependent; Whited (1992) shows that constraints in obtaining debt favor the use of internal financing. Hoshi et al. (1991) find that strong ties to external finance institutes reduce the importance of internal liquidity. Gilchrist and Himmelberg (1995) raise the concern that cash flows, like liquidity, can also be an indicator of the existence of an accelerator effect (positive impact of GDP growth on private fixed investments) or of information about future investment opportunities. In this work, we focus on internally generated cash flows as Mayer (1990) empirically show that they are generally the dominant source of finance for investments. Jensen (1986) indicates that the dominant role of internal financing might not be the result of limited access to external financing, but suggests rather that this reflects managers' decisions to ignore market valuation signals in favor of overinvestment in growth. These internally financed investments are particularly sensitive to cash flow volatility and financial liquidity, as modeled for many different assumptions (Fazzari and Athey 1987; Fazzari, et al. 1988a, 1988b; Hoshi et al. 1990; Hubbard et al. 1993; Almeida et al. 2004). For instance, Almeida and Campello (2007) show that there is a multiplier effect of tangible assets and investments, which increases the investment–cash flow sensitivity and particularly exposes the process industries under consideration. Cleary (1999) challenges this finding with his broad scale empirical study, in which he provided evidence that the investments of the least financially constrained firms are the most sensitive to cash flow volatility. We contribute to this stream of literature by introducing an operational aspect, as we focus on the investments in fixed assets required in manufacturing industries, whereas previous finance literature has mainly focused on firms' financial liquidity constraints and access to external financing.

4.2.2 Manufacturing Flexibility

Manufacturing flexibility describes "the ability to change or react to environmental uncertainty with little penalty in time, effort, cost or performance" and is vitally important for companies in times of greater volatility and higher competitive pressure (Upton 1994). It has two apects – range and time. The former describes the variations a system offers along dimensions such as volume, product type and material handling (Koste and Malhotra 1999); the latter measures the time until a system attains a new stage. The theoretical basis was laid down by Gerwin (1993), who developed a conceptual framework for operational flexibility. He combined sources of uncertainty such as demand, machine downtime and life-cycle duration with strategic objectives. This theoretical work was further driven by De Toni and Tonchia (1998), who structured the topic of manufacturing according to six different aspects: (i) the definition of flexibility, (ii) the request for flexibility, (iii) a classification according to dimensions of flexibility, (iv) the measurement of flexibility, (v) the choices for flexibility and (vi) the interpretation of flexibility. In the context of our research, which examines process industries and commodity markets, not all sources of uncertainty and dimensions of flexibility apply or are equally important. Goyal and Netessine (2007) find that volume flexibility is particularly valuable in cases of high demand uncertainty, low demand correlation over time and low total market size. We therefore want to focus on variations in market prices and a firm's ability to ramp production volumes in a flexible way up or down flexibly. But flexibility comes at a cost (Suarez et al. 1996; Van Mieghem 1998), particularly in relation to compared to dedicated equipment (Bengtsson 2001), therefore measuring its magnitude and value is crucially important (Gupta and Goyal 1989; Ramasesh and Jayakumar 1991; Dixon 1992; Gupta 1993; Ettlie and

Penner-Hahn 1994; Koste et al. 2004). The ability of commodity markets to react to often unpredictable price swings is fundamentally different to traditional cost reduction strategies (De Meyer et al. 1989). Fiegenbaum and Karnani (1991) confirm this finding by presenting empirical evidence across 83 industries illustrating the competitive advantage that manufacturing flexibility can bring. The literature presents two distinct approaches to quantifying the value of flexibility, which can be accomplished either by looking at the impact flexibility has on a firm's market valuation or by testing the amount of avoided costs or marginal performance (Garavelli 2003). Allen and Pantzalis (1996) quantify the value of the capability to adjust production decisions in response to exogenous perturbations by testing its impact on a firm's market value and find a positive and significant relationship. Tang and Tikoo (1999) examine the same by relating stock returns to changes in earnings (the so-called earnings response coefficient). They find a net value impact of flexibility, although it can be positive or negative depending on the company's footprint. Graves and Tomlin (2003) examine the benefits of process flexibility in supply chains and how it prevents inefficiencies and improves the likelihood of meeting demand. Vokurka and O'Leary-Kelly (2000) provide a comprehensive review of the empirical research on manufacturing flexibility. We contribute to the stream of empirical research by providing a proxy for manufacturing volume flexibility and modeling the dynamics of the increasingly important sales and operations planning (S&OP) process.

4.2.3 Capacity Expansion

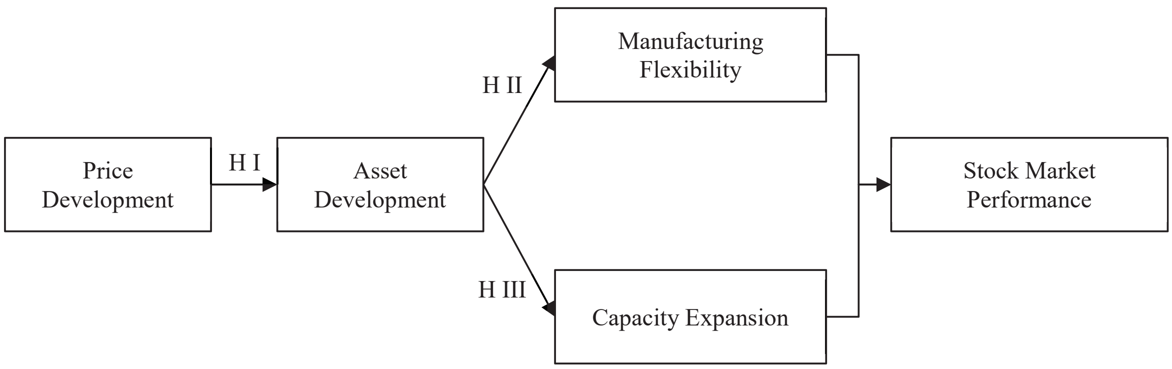
Capacity planning is a crucial determinant for the growth of companies in manufacturing industries (Zijm and Buitenhek 1996) and has a significant impact on their market valuation (Cooper et al. 2008). It is of particular and strategic importance for process industries (Guide Jr. et al. 1997) because: (i) new investments require considerable resources, and payback times are long; (ii) manufacturing equipment has low scrap value; and (iii) important economies of scale can be achieved (Paraskevopoulos et al. 1991). Geng and Jiang (2009) show this for the semiconductor manufacturing industry by reviewing existing methods of capacity planning (e.g., the static capacity model and the neighborhood search method) and illustrating the industry-specific difficulties such as long lead times and high capacity increment costs. The long payback times for manufacturing equipment in process industries make these investments risky, particularly in times of high demand uncertainty (Paraskevopoulos et al. 1991). Goyal and Netessine (2007) model the relationship between investments in technology and capacity under demand uncertainty. They show that the cost of capacity for a competitor is negatively associated with a firm's willingness to pay for volume flexibility. Anupindi and Jiang (2008) show that flexible companies are more profitable and can invest more in capacity expansion. In a similar way, Van Miegham and Dada (1999) consider a case with sequential decisions on capacity, production and pricing, and illustrate optimum investment strategies under different scenarios of competition, uncertainty and the timing of operational decisions. Surprisingly, they find that more postponement (pricing and/or production) makes the optimal capacity more sensitive to uncertainty. We contribute to the mainly modeling based literature with this empirical work on capacity planning and asset development by looking at an industry setup in which demand and prices are exogenous, contrary to most of the established literature, which models two-stage cases in which companies first make a decision on capacity, followed by one on pricing.

4.3 Theory & Hypothesis

Commodity markets are interesting case examples for research in operations management, since pricing dynamics are directly dependent on the supply-demand balance, and manufacturing plays a particularly central role. Products are, by definition, undifferentiated and the unique market price is defined by the cash cost of the marginal producer. Where competition is global, there are transparent reference prices for many industrial and precious metals (e.g., the London Metal Exchange), for oil (e.g., Brent, WTI) and for gas (e.g., Henry Hub Futures Contract). For other commodities, such references also exist, but competition is not global. For cement, for instance, transportation costs are very high compared with production costs, therefore more local markets exist. The same holds true for fertilizer chemicals and storage costs. Marketing activities do not play a major role in commodity sectors and a company's profitability depends directly on operational efficiency and production costs. Companies have no or little pricing power, and the impact of prices on generated cash flows is particularly direct. This paper aims to answer the following research questions (Figure 15):

- What is the impact of market price on the asset development of firms in process industries?
- What is the impact of asset development (i.e. capital expenditures) on manufacturing flexibility in process industries?
- What is the impact of asset development (i.e. capital expenditures) on capacity expansion in process industries?
- What is the combined impact of these manufacturing aspects on the stock market performance of firms in process industries?

Figure 15 Hypotheses – Impact of Market Prices on Investment Volume and Operations



Process industries, by definition, require manufacturing assets and this implies important cash outflows. Combining these cash outflows with the abovementioned cash flow sensitivity explains why we developed three hypotheses (Figure 15) to examine the impact of dynamic markets on rather inflexible operations: (i) how do price volatility and price trends impact investments in fixed assets and how do these investment decisions affect (ii) short-term manufacturing flexibility and (iii) long-term capacity expansion.

4.3.1 Hypothesis I – Price & Asset Development

Investments in the development and maintenance of fixed assets represent the main competitive edge for firms in industries with undifferentiated products. These CAPEX are not only a core competency of firms in commodity markets, but they are also particularly high compared to other industries and represent a major cash outflow that has to be financed. These investments are primarily financed from internal sources (Mayer 1990). The cash flow generated depends directly on market prices. Lamont (1997) shows that petrol companies largely decreased their CAPEX in response to the 1986 drop in oil prices because of reduced cash inflows (independent of the amount of investment opportunities). *Therefore the existing literature suggests that CAPEX depends on market price trends.*

Hypothesis Ia: *CAPEX is positively correlated with long-term price trends*

Dixit and Pindyck (1994) argue that investments are associated with projected future cash flow volumes and Modigliani and Weingartner (1958) show that anticipated sales positively impact investment volumes. Investments are sensitive to the availability of internal funding (Gilchrist and Himmelberg 1995; Cleary 1999). *In conclusion, the more volatile prices, the more volatile (and uncertain) are cash inflows, which negatively impacts CAPEX.*

Hypothesis Ib: *CAPEX is negatively correlated with demand uncertainty*

4.3.2 Hypothesis II – Manufacturing Flexibility

Manufacturing flexibility is particularly valuable in process industries with long lead times and high demand uncertainty (Milner and Kouvelis 2002; Goyal and Netessine 2011). The importance of short-term volume adjustments increases with higher price volatility in the market (Bessembinder and Seguin 1993), which is currently the case in many commodity markets. Therefore in the 1980s, companies started using the so-called sales and operations planning (S&OP) mechanism, a cross-functional process to guarantee a "…medium to long-term stable production plan" (Coldrick et al.

2003). In recent years, the purpose has shifted more toward a "…dynamic business performance process." The objective is to make production and sales refinements (Grimson and Pyke 2007) and quickly react to changing market and operational conditions (Olhager et al. 2001). The liquid spot markets that exist for many commodities make the S&OP process particularly valuable, since they permit firms to flexibly adjust sales volumes (Seifert et al. 2004) and capture favorable price peaks. S&OP is often the direct responsibility of the CEO, consists of regular meetings generally including sales, operations and finance, and decides on production, inventory and sales adaptions from the forecasts for the upcoming period (Stahl 1995; Lapide 2004a, 2004b). These variables are interdependent (Olhager et al. 2001; Goyal and Netessine 2007) and based on external (e.g., market price, supply-demand balance) and internal factors (e.g., contracted sales, idle production capacity). Manufacturing-related fixed assets require significant investments, which put financial pressure on the company and incentivize constantly high utilization rates (Pil and Holweg 2004). *Therefore CAPEX acts as a production driver.*

Hypothesis IIa: *Short-term production is positively correlated with CAPEX*

This fixed cost pressure limits a company's freedom to adapt supply volumes flexibly in the short term thus *CAPEX is a determinant of manufacturing volume flexibility.*

Hypothesis IIb: *Manufacturing flexibility is negatively correlated with CAPEX*

4.3.3 Hypothesis III – Capacity Expansion

Capacity planning in manufacturing industries involves deciding on the amount, type and timing of capacity adjustments (Hayes and Wheelwright 1984) and can be described as a sizing problem (Olhager et al. 2001). Capacity adjustments – how much capacity to add or reduce – are particularly important in the process industries operating in commodity markets, since they are characterized by undifferentiated products and high fixed costs. Price competition is fierce and economies of scale are essential. Therefore investments in fixed assets translate, to a great extent, into additional capacity and production in commodity markets while in consumer industries these investments can be spent on higher quality production. Capacity increases are discrete and happen stepwise (Olhager et al. 2001), and this is particularly true in the two industries considered – mining and oil & gas. In these industries, projects exploring new resources are in many cases in remote locations and require complex and extensive infrastructure investments (World Economic Forum 2014). They are therefore not only particularly costly but also require long development periods. *The implementation time for capacity expansion projects in commodity markets is particularly long.*

Hypothesis III: *Long-term capacity growth is positively correlated with past CAPEX*

4.4 Variables & Data Sources

This section presents the database, the operationalization of the variables and the specifications of the statistical models.

4.4.1 Data Sources

The hypotheses were developed for process industries operating in commodity markets. In order to test hypothesis I, we need detailed information on prices, which is known for commodities with a unique market price, but not systematically reported in other industries. Hypotheses II and III require significant investments in fixed assets, which is the case in manufacturing-intensive process industries. In consumer industries, these investments are lower and the formulated effects are overshadowed by other activities such as marketing. We therefore include in our research the mining industry and the oil & gas industry (Table 8), since both fulfill these two requirements. Other process industries such as chemicals, pharmaceuticals, steel making and cement do not share all of the required conditions, since the first two are (at least in important subsectors) not fully commoditized and the last two are more locally organized (and thus do not provide the same uniformity of global market prices).

Table 8 Database of Mining and Oil & Gas Industries and Subsectors by SIC Code

Mining Industry	SIC	Exemplary Firms	# Firms	# Obs
Metal Mining	10	Barrick Gold Corp., Freeport-McMoran Inc., Anglo American PLC, Rio Tinto	395	6,999
Bituminous Coal and Lignite Mining	12	Yanzhou Coal Mining Co. Ltd., Consol Energy Inc., Peabody Energy Corp.	42	812
Mining and Quarrying of Nonmetallic Minerals, except Fuels	14	Martin Marietta Materials, Compass Minerals Intl. Inc., Athabasca Minerals Inc.	43	1,055
Oil and Gas Extraction	13	Baker Hughes Inc., Weatherford Intl Plc, Halliburton Co., ConocoPhillips, Schlumberger Ltd.	955	21,306
Petroleum Refining and Related Industries	29	Hess Corp., BP Plc, Chevron Corp., Exxon Mobil, Husky Energy Inc., Suncor Energy Inc.	98	2,542

The database was created by sourcing and matching data from Compustat North America (quarterly and annual financial accounting data), Bloomberg (stock market) and the International Monetary Fund (historical monthly spot price data). Table 9 provides the descriptive statistics for 2000–2015; the data for 1997–1999 was collected to calculate sales forecasts for the first year. We excluded companies with missing or negative values for cost of goods sold (COGS), CAPEX, inventory and sales.

Table 9 Descriptive Statistics for the Mining and Oil & Gas Industries for 2000–2015

Variable	Unit	Mining			Oil & Gas		
		Mean	S.D.	# Obs	Mean	S.D.	# Obs
Sales	$ M	473.0	2,485	8,866	1,794.1	9,410.1	23,848
Sales Forecast	$ M	475.2	2,542.3	8,866	1,779.6	9,426.8	23,848
Production	$ M	306.2	1,543.7	8,866	1,403.0	7,890.0	23,848
Inventory	$ M	170.7	623.3	8,866	419.6	2,442.5	23,848
Target Inventory	$ M	163.6	602.1	8,866	415.7	2,395.8	23,848
CAPEX	$ M	190.7	973.5	8,866	559.9	2,433.6	23,848
Gross Margin	%	5.11	116.4	8,866	21.4	163.4	23,848
Demand Uncertainty	%	45.5	118.6	8,866	34.0	51.5	23,848
Price Trend	%	-0.2	7.5	8,866	5.6	22.4	23,848
Lead Time	Days	192.4	1,414.6	8,866	312.5	627.8	23,848

4.4.2 Variable Definitions

Wherever possible, we operationalized the variables used as established in the literature. The indices *i, t* and *n* are the firm, yearly and quarterly indices, respectively. Production is measured, as is commonly done (Bray and Mendelson 2012), by adapting the COGS with the delta of inventory at the end and beginning of the period.

$$Production_{itn} = COGS_{itn} + Inventory_{itn} - Inventory_{i,t,n-1}$$

Inventory is measured as average inventory at the end and beginning of the quarter.

$$Inventory_{itn} = \frac{Inventory_{itn} + Inventory_{i,t,n-1}}{2}$$

Sales are represented as reported in the income statements. Demand uncertainty is measured as the relative difference between the sales forecast and actual sales. As firms do not systematically report their sales forecast, the Holt forecasting (Holt 2004) method is used to create sales forecast figures based on previous sales performance (e.g., Gaur et al. 2005; Jain et al. 2013).

$$DemandUncertainty_{itn} = \frac{SalesForecast_{itn} - Sales_{itn}}{Sales_{itn}} = \frac{(a_{itn} + b_{itn}) - Sales_{itn}}{Sales_{itn}}$$

Where $a_{itn} = \alpha * Sales_{i,t,n-1} + (1-\alpha)(a_{i,t,n-1} + b_{i,t,n-1})$ and $b_{itn} = \beta\left(a_{itn} - a_{i,t,n-1}\right) + (1-\beta)$ and α and β are coefficients between 0 and 1. The optimum value for the coefficients, where the mean square error (MSE) is minimized, were obtained for (α=0.5; β=0.5).

The price trend variable is calculated as the difference between the current price and the closing price two quarters before.

$$PriceTrend_{itn} = \frac{Price_{itn} - Price_{i,t,n-2}}{Price_{i,t,n-2}}$$

Capital intensity is measured based on expenditures for fixed assets on an annual basis, since the typical CAPEX planning cycle generally comprises the entire fiscal year. Companies do not publish lead time information, but Roumiantsev and Netessine (2007b) developed a proxy based on accounts payable. A detailed discussion can be found in their paper; the basic idea is that “financial transactions should be correlated with times of shipment and delivery of inputs and therefore should be correlated with the lag a company has to respond…” (Roumiantsev and Netessine 2007b, p. 16). Therefore we use days of accounts payable outstanding.

$$LeadTime_{itn} = DaysPayablesOutstanding_{itn} = \frac{365}{(4 * \frac{COGS_{itn}}{AccountsPayables_{itn}})}$$

The gross margin (GM) is defined as established.

$$GrossMargin_{itn} = \frac{Sales_{itn} - COGS_{itn}}{Sales_{itn}}$$

Firms set inventory targets and they try to close deviations from this level (Irvine 1981). Since companies do not systematically reveal these objectives, we use the average inventory measure among peer companies outlined by Chen et al. (2007). Therefore we calculate the delta target inventory as the difference between the average inventories among firms with the same SIC code and the current inventory level of the firm.

$$\Delta TargetInventory_{itn} = TargetInventory_{it} - Inventory_{itn} = \frac{1}{m}\sum_{m}^{SIC}\left(\frac{Inventory_{itm}}{COGS_{itm}}\right) - \frac{Inventory_{itn}}{COGS_{itn}}$$

Manufacturing flexibility in this work describes volume flexibility (Goyal and Netessine 2007), a firm's ability to adapt production volumes at short notice as a reaction to external perturbations (Allen and Pantzalis 1996). The literature does not offer an empirical measure for volume flexibility, a gap we aim to fill as follows. If a company decides in the S&OP process to increase/decrease sales volumes because of higher/lower than expected market prices, this sales volume difference compared to forecasts has to be allocated. For instance, if the Australian mining company Rio Tinto, decides to increase the sales volume of aluminum for the upcoming quarter by 40kT, it has to decide which share comes from production (higher utilization) and which from inventory. Manufacturing flexibility indicates the degree to which such sales adjustments are handled by production adjustments and is calculated as the difference between the sales adjustment (Delta_Sales) and the inventory adjustment (Delta_Inventory). For illustrative purposes, let us assume the following scenario:

- Delta_Sales: Sales volume increased from forecast of 800kT to 840kT.
- Manufacturing Flexibility: Production volume increased from the planned 780kT to 810kT.
- Delta_Inventory: Sold inventory increased from the planned 20kT to 30kT, reducing the inventory level from 100kT to 70kT instead of the planned level of 80kT.

The sales adjustment (Delta_Sales) is calculated simply as the difference between actual sales and forecasted sales. The inventory adjustment (Delta_Inventory) is proxied by the difference between actual inventory sales and planned inventory sales. However, companies do not systematically publish the figures for planned inventory sales. Yet they generally have inventory level targets, and we assume these targets have been met over the previous four quarters. Therefore we calculate the planned inventory sales as the difference between the current inventory level and the average inventory level of the previous four quarters.

$$\begin{aligned} ManufacturingFlexibility_{itn} &= \Delta Sales_{itn} + PlannedInventoryChange_{itn} - ActualInventoryChange_{itn} \\ &= (Sales_{itn} - SalesForecast_{itn}) + (AverageInventory_{itn} - Inventory_{i,t,n-1}) \\ &\quad - \left(Inventory_{itn} - Inventory_{i,t,n-1}\right) \end{aligned}$$

We also tested the scale-dependent variables – production (PROD), capital intensity (CAP), sales (SALES) and inventory (INV) – as intensities by dividing them by the market value of equity (Jain et al. 2013), which confirmed the found insights. We control for potential spurious econometric interferences (Barth and Clinch 2009).

4.5 Methodology

In order to test the hypotheses, we develop empirical models in accordance with the established finance and operations management literature: a dynamic panel model to examine the impact of market prices on CAPEX volumes (H Ia; H Ib), a simultaneous equation model (SEM) to reflect the impact of CAPEX on production (H IIa), a dynamic panel model to examine the relationship between CAPEX and manufacturing flexibility (H IIb), and a panel vector autoregressive model (VAR) to identify implementation times of investments (H III). The models are in log-multiplicative form, as in comparable operations management research (Gaur et al. 2005; Roumiantsev and Netessine 2007). All models include firm-specific terms (A_i, B_i, C_i, D_i, E_i) controlling for unobserved firm-specific characteristics, yearly/quarterly dummies (a_t b_t, c_t, d_t, e_t) accounting for time-dependent macro effects, and idiosyncratic firm-time-specific error terms ($\alpha_{itn}, \beta_{itn}, \gamma_{itn}, \delta_{itn}, \varepsilon_{itn}$).

4.5.1 Dynamic Panel Model – H I – Price & Asset Development

The CAPEX planning process to decide on investment volumes follows the fiscal year cycle, since CAPEX is a crucial cost item in financial planning. The magnitude of investments in commodity markets is impacted by market prices, particularly price volatility and price trends. CAPEX covers investments in new capacity and the maintenance of the current fixed asset base. Therefore, current investments are directly linked to former investments and we include CAPEX of the previous year. A classic fixed effects estimator would be biased, as shown by Nickell (1981), so instead we implement the Arellano-Bond estimator (Arellano and Bond 1991) with robust standard errors and adapted for dynamic panel data with "small T, large N" panels. The CAPEX planning is modeled as follows:

$$log\,CAPEX_{it} = A_i + \alpha_1\,log\,PriceTrend + \alpha_2 logDemandUncertainty_{it} + \alpha_3 logCAP_{i,t-1} + \alpha_4 logSales_{it} + \ a_t + \alpha_{it}$$

4.5.2 SEM & Dynamic Panel Model – H II – Manufacturing Flexibility

The S&OP process determines adaptations from forecasts of sales, inventory and production for the upcoming sales period. They depend directly on one another: the higher the planned sales, the more the company has to produce and/or sell of its inventory. Sales are constrained by idle production capacity and inventory. Additional production is a potential substitute for inventory and is directly related to sales levels. The simultaneous interdependence of these dependent variables can lead to inconsistent estimates. We control for this by setting up the following simultaneous equation model – as done before in operations management literature (Kesavan et al. 2010; Jain et al. 2013) – for the three dependent variables production, inventory and sales:

$$\begin{aligned} log\,Production_{itn} = {} & B_i + \beta_1 logInventory_{itn} + \beta_2 logSales_{itn} + \beta_3\,log\,Production_{i,t,n-1} + \beta_4 logCAPEX_{it} \\ & + \beta_5 logLeadTime_{itn} + b_t + \beta_{itn} \end{aligned}$$

$$\begin{aligned} logInventory_{itn} = {} & C_i + \gamma_1 logProduction_{itn} + \gamma_2 logSales_{itn} + \gamma_3 logInventory_{i,t,n-1} + \gamma_4 logTargetInventory_{itn} \\ & + \gamma_5 logGrossMargin_{itn} + \gamma_6 logDemandUncertainty_{itn} + d_t + \delta_{itn} \end{aligned}$$

$$logSales_{itn} = D_i + \delta_1 logProduction_{itn} + \delta_2 logInventory_{itn} + \delta_3 logSales_{i,t,n-1} + \delta_4 logGrossMargin_{itn} + d_t + \delta_{itn}$$

The current performance of the dependent variables depends on former performance, the so-called halo effect, and is modeled with the introduction of the lagged dependent variables (Brown and Perry 1994), which satisfy the conditions for instruments (Kesavan et al. 2010). Besides the interactions of the dependent variables, each equation is completed by a number of exogenous terms and control variables. Capital expenditures on fixed assets are particularly high in process industries and account for a high share of fixed costs. They are amortized by producing large volumes at constantly high utilization rates. Therefore CAPEX is positively correlated with production (Gaur et al. 2005). Sales refer to the sum of production and sold inventory. The same holds true for the sales delta defined in the S&OP – it either has to be produced or come from stock. The extent to which a company can handle additional sales defined in the short-term S&OP with increased production depends inversely on the lead time. Supply chain managers pursue inventory targets, amongst others. The more the current level deviates from this target, the more they are incentivized to correct (sell or hold back) the inventory level toward achieving the target. The literature has established the positive effect of the gross margin and demand uncertainty on inventory (Gaur et al. 2005) and of the gross margin on sales (Kesavan et al. 2010). We implement a fixed-effects model to test how CAPEX affects not only short-term production volumes but also manufacturing volume flexibility.

$$logManufacturingFlexibility_{itn} = E_i + \varepsilon_1 logCAPEX_{itn} + e_t + \varepsilon_{itn}$$

4.5.3 Panel Vector Autoregressive Model – H III – Capacity Expansion

There is a time lag between the moment the cash outflow for a project is accounted for and the moment the corresponding production capacity becomes operational. Companies generally invest every year in a portfolio of projects for the maintenance and expansion of fixed assets. These investments translate into production capacity after varying time periods, depending on the type and size of the project. Therefore current production potentially depends on various lagged investments. In order to determine the dynamic intertemporal relationship between investments in manufacturing assets and production, an autoregressive model was applied to our panel dataset, as done before in operations management and finance literature (e.g., Love and Zicchino 2006; Eroglu and Hofer

2011). We applied a least square dummy variable (LSDV) estimator, which fits both variables, to lags of itself and the other variable (Bun and Kiviet 2006). The LSDV estimator can be more efficient (Kiviet 1995) than the Generalized Method of Moments (GMM) estimator (Arellano and Bond 1991), which can be generalized for models with higher-order lags (Kiviet and Phillips 1994). We used the annual growth in production and CAPEX as dependent and independent variable, respectively. Love and Zicchino (2006) use a similar model to examine the relationship between companies' financial conditions and investment. CAPEX includes one-off exploration and development costs incurred in the lifetime of a new production site (Mining: PricewaterhouseCoopers 2007; Oil & Gas: PricewaterhouseCoopers 2011). The number of time lags included in our model depends on the project type. Having reviewed the documentation of several greenfield projects across commodities, we find that capacity planning periods generally last up to six years (Olhager et al. 2001; Hartman and Mutmansky 2002).

$$\frac{Production_{it} - Production_{i,t-1}}{Production_{i,t-1}} = F_i + \sum_{g=1}^{6} \zeta_f * \frac{CAPEX_{i,t-g} - CAPEX_{i,t-g-1}}{CAPEX_{i,t-g-1}} + f_t + \zeta_{it}$$

4.6 Analysis

4.6.1 Analysis H I – Price & Asset Development

The coefficients for the price trend (Mining: α_1= 0.272; Oil & Gas: α_1= 0.164) and demand uncertainty (Mining: α_2= -0.0877; Oil & Gas: α_2= -0.0891) are significant and in the predicted direction (Table 10), confirming our hypotheses H Ia and H Ib and aligned with most of the established finance literature. As predicted, companies increase their investments in fixed assets in times when prices have risen over the previous two quarters (price trend variables). The reason for this positive association might be that companies have earned higher cash inflows and therefore have more resources available and/or that they expect prices to increase further and will therefore continue to invest to capture higher earnings in future. Commodity price variations can be separated into long-term dynamics and short-term variations (Schwartz and Smith 2000). While the former (here called price trend) is positively correlated with CAPEX, demand uncertainty increases the risks associated with investments and therefore negatively correlates with CAPEX. This means that companies are reluctant to spend, since the projected future returns on investments have to be discounted by higher risks.

Table 10 Dynamic Panel Model – H I – Price Development Impact on CAPEX – Estimates

CAPEX	Mining	Oil & Gas
Price Trend	0.272**	0.164***
	(0.106)	(0.0212)
Demand Uncertainty	-0.0877*	-0.0891**
	(0.0391)	(0.0319)
Lagged CAPEX	0.643***	0.651***
	(0.0404)	(0.0265)
Sales	0.0655**	0.00864
	(0.0209)	(0.0186)
N observations	8,866	23,848
N firms	480	1,053

Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

4.6.2 Analysis H II – Manufacturing Flexibility

An extract of the results of the SEM that models the S&OP dynamics and indicates the enhancing impact CAPEX has on short-term production volumes can be found in Table 11 (the complete table with the SEM estimates can be found in the appendix; Table 19). We note that CAPEX is indeed a highly significant production driver (Mining: β_4= 0.0722; Oil & Gas: β_4= 0.151) for both industries under consideration, as stated in hypothesis H IIa. This confirms that cash outflows for CAPEX impact the daily operations of firms in these sectors and incentivize them to sweat their assets and constantly produce at high utilization rates. This limits their room for maneuver to adapt production volumes without slashing spending on fixed assets. The explicative power of the SEM model is very high with strong overall R^2 values.

Table 11 Simultaneous Equation Model – H IIa – CAPEX Impact on Production – Estimates

Production	Mining	Oil & Gas
CAPEX	0.0722***	0.151***
	(0.00551)	(0.0206)
Year Dummies	Yes	Yes
N observations	7,312	17,405
N firms	436	994
Overall R^2	97.43%	99.10%

Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The driving effect CAPEX has on production levels is directly linked to its effect on manufacturing volume flexibility.

Table 12 Dynamic Panel Model – H IIb – CAPEX Impact on Manufacturing Flexibility – Estimates

Manufacturing Flexibility	Mining	Oil & Gas
CAPEX	-0.0835***	-0.0555***
	(0.0121)	(0.00825)
Lagged Manufacturing Flexibility	0.297***	0.351***
	(0.0275)	(0.0233)
N observations	8,866	23,848
N firms	480	1’053

Standard errors in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Since companies are incentivized to boost production and increase capacity utilization with increasing investment volumes, this intuitively reduces their willingness and ability to flexibly decrease and increase production levels. In line with H IIb, this explains the negative impact CAPEX has on manufacturing flexibility (Table 12; Mining: ε_1= -0.0835; Oil & Gas: ε_1= -0.0555) and why companies do not reduce production even in times of structural oversupply.

4.6.3 Analysis H III – Capacity Expansion

The estimates of the panel vector autoregressive model are shown in Table 13, which indicates that a relative increase in CAPEX impacts the long-term future production capacity growth, confirming the third hypothesis. The significant impact of investments dating back six years indicates the long planning and implementation horizon of these industries (Mining: $\zeta_{1=}$ 0.0802 to $\zeta_{6=}$ 0.164; Oil & Gas: $\zeta_{1=}$ 0.398 to $\zeta_{6=}$ 0.472), particularly compared to volatile market prices. In the mining industry we observe peaks of impact after years three and six, which could indicate that they have fewer, but bigger, projects. In the oil & gas industry, the impact is more smoothly spread out, particularly over years two to five (i.e. $\zeta_2, \zeta_3, \zeta_4, \zeta_5$). We applied the Granger causality tests (Granger 1969) on the VAR estimates. The null hypothesis that the six lagged terms of CAPEX growth do not forecast production growth is rejected at significance level p-value < 0.001.

Table 13 Panel VAR – H III – CAPEX Growth Impact on Production Growth – Estimates

	Response of Production Growth	
Response to	**Mining**	**Oil & Gas**
CAPEX Growth 1-Year Lagged	0.0802***	0.398***
	(0.0154)	(0.0763)
CAPEX Growth 2-Year Lagged	0.0515**	0.846***
	(0.0180)	(0.0784)
CAPEX Growth 3-Year Lagged	0.168***	1.048***
	(0.0220)	(0.104)
CAPEX Growth 4-Year Lagged	0.0740***	1.161***
	(0.0211)	(0.0898)
CAPEX Growth 5-Year Lagged	0.0303	0.820***
	(0.0228)	(0.129)
CAPEX Growth 6-Year Lagged	0.164***	0.472***
	(0.0199)	(0.122)
N observations	705	945
N firms	141	189
Overall R2	72.27%	73.81%

Standard errors in parentheses * p < 0.05, ** p < 0.01, *** p < 0.001

4.7 Robustness Tests

We test the robustness of the presented models and results by altering the econometric models. Across the vast series of robustness tests, we continue to find very strong results, which further support our results and confirm our hypotheses. We used the Arellano-Bond estimator to model the impact of market prices on CAPEX volumes while accounting for the dynamic nature of the model. We also applied the Anderson-Hsiao estimator and an individual fixed-effects model including lagged CAPEX (Table 14), which confirmed our results for both industries and the robustness of the results.

Table 14 Robustness Tests – H I – Price and Asset Development – Alternative Estimators

	Regressand	Regressors		Model
		Price Trend	Demand Uncertainty	
Mining		Original Dynamic Panel Model		
Mining	**CAPEX**	0.272**	-0.0877*	Arellano-Bond Estimator
Mining		Alternative Models		
Mining	**CAPEX**	0.310***	-0.0959***	Anderson-Hsiao Estimator
Mining	**CAPEX**	0.384***	-0.0576***	Fixed-Effects Estimator
Oil & Gas		Original Fixed Effects Model		
Oil & Gas	**CAPEX**	0.164***	-0.0891**	Arellano-Bond Estimator
Oil & Gas		Alternative Models		
Oil & Gas	**CAPEX**	0.244***	-0.0983***	Anderson-Hsiao Estimator
Oil & Gas	**CAPEX**	0.150***	-0.0474***	Fixed-Effects Estimator

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

In a similar manner, we applied different estimators (two-stage least square, OLS, single equation fixed effects, single equation random effects) to model the dynamics of the S&OP process (extract of the table: Table 15; complete table with all estimates: appendix; Table 20). The coefficients of the last three are significantly different (Mining: $\beta_{4,OLS}$= 0.0252, $\beta_{4,FE}$= 0.0415, $\beta_{4,RE}$= 0.0487; Oil & Gas: $\beta_{4,OLS}$= 0.0261, $\beta_{4,FE}$= 0.0716, $\beta_{4,RE}$= 0.0642) from the ones found with the base model (simultaneous equation model, three-stage least square; Mining: β_4= 0.0722; Oil & Gas: β_4= 0.151) as shown by the Hausman test. This implies they are inconsistent because of the simultaneity of the equations. Compared to the 2SLS, the 3SLS corrects for the fact that the error terms are correlated.

Table 15 Robustness Tests – H IIa – Manufacturing Flexibility – Alternative Estimators

Production	Mining	Oil & Gas	Model
CAPEX	0.0722***	0.151***	Original 3SLS SEM model
CAPEX	0.0507***	0.190***	2SLS SEM model
CAPEX	0.0252***	0.0261***	OLS SEM model
CAPEX	0.0415***	0.0716***	Single equation FE model
CAPEX	0.0487***	0.0642***	Single equation RE model

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The relationship between CAPEX and short-term manufacturing flexibility was originally tested with the Arellano-Bond estimator. We also applied the Anderson-Hsioao estimator and a single equation fixed-effect model (Table 16) which also showed strongly significant results.

Table 16 Robustness Tests – H IIb – Manufacturing Flexibility – Alternative Estimators

Production Flexibility	Mining	Oil & Gas	Model
CAPEX	-0.0835***	-0.0555***	Original Arellano-Bond Estimator
CAPEX	-0.0802***	-0.0578***	Anderson-Hsiao Estimator
CAPEX	-0.121***	-0.0936***	Fixed-Effects Estimator

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 17 indicates the results for alternative estimators in addition to the panel VAR.

Table 17 Robustness Tests – H III – Capacity Expansion – Alternative Estimators

	Response of	Response to						Description
		1L.ΔCAP	2L.ΔCAP	3L.ΔCAP	4L.ΔCAP	5L.ΔCAP	6L.ΔCAP	
Mining		Original Panel Vector Autoregressive Model						
Mining	ΔPROD	0.0802***	0.0515**	0.168***	0.0740***	0.0303	0.164***	Panel VAR
Mining		Alternative Models						
Mining	ΔPROD	0.0819*	-0.0534	0.229**	1.024*	-0.0802	1.637*	Fixed effects
Mining	ΔPROD	0.117***	-0.0331	0.328***	0.116***	0.0525*	0.105***	Arellano-Bond
Oil & Gas		Original Panel Vector Autoregressive Model						
Oil & Gas	ΔPROD	0.398***	0.846***	1.048***	1.161***	0.820***	0.472***	Panel VAR
Oil & Gas		Alternative Models						
Oil & Gas	ΔPROD	0.485	0.121	0.00315	1.119**	0.593*	-0.466	Fixed effects
Oil & Gas	ΔPROD	0.468***	0.214*	0.0335	1.159***	1.009***	-0.378***	Arellano-Bond

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

4.8 Post-hoc Analysis

Commodity markets for the mining and oil & gas sectors are historically cyclical (Bain 2013). Our results show that the market price development has a direct impact on CAPEX, and that companies' investment behavior follows the cyclicality of the markets. We also illustrate how the spending on fixed assets, on the one hand, negatively impacts short-term manufacturing volume flexibility (since cash outflows are a production driver) and, on the other hand, is positively correlated with long-term production capacity growth. Capacity growth is crucial to secure a company's market position, earn higher profits and further increase investments in capacity (Anupindi and Jiang 2008). In the finance literature, the role of investments is as a predictor of stock returns (Cooper et al. 2008; Gray and Johnson 2011). We believe that the crucial importance of CAPEX in the industries considered and the complex interaction effects between the described operational aspects requires a holistic short- and long-term assessment of the relationship between capital expenditures and stock performance – something that has not been done to date. To close this gap, we implemented a fixed-effects model as used in the corresponding finance literature to test the impact of investments on stock performance (e.g., Cooper et al. 2008). Lamont (2000) shows that investment plans have substantial forecasting power with respect to annual stock returns and contain information not captured by other forecasting variables. He also states the importance of including lagged data of investments in order to study stock returns. Therefore our econometric model specifies:

$$\frac{StockPrice_{it} - StockPrice_{i,t-1}}{StockPrice_{i,t-1}} = G_i + \sum\nolimits_{h=1}^{6} \eta_h * \frac{CAPEX_{i,t-h} - CAPEX_{i,t-h-1}}{CAPEX_{i,t-h-1}} + g_t + \eta_{it}$$

We find that although recent spending reductions boost the market valuation (Mining: η_1= -0.100, η_2= -0.0874, η_3= -0.0513; Oil & Gas: η_1= -0.0495, η_2= -0.0357), the effect in the longer run (Mining: η_4= 0.0125, η_5= 0.0127, η_6= 0.00698; Oil & Gas: η_3= 0.0786, η_6= 7.9e-08) is the opposite (Table 18). The model explains 13.3% for mining and 12.4% for oil & gas of within variances. This indicates that CAPEX management is highly important in such industries, where prices are dictated by the markets and commercial levers are limited. The overall R^2 is 4.03% for mining and 4.48% for oil & gas, which is in line with the values in the established literature (e.g., Gray and Johnson 2011).

Table 18 Response of Stock Price to CAPEX over Time

Stock Price Growth	Mining	Oil & Gas
CAPEX Growth 1-Year Lagged	-0.100**	-0.0495***
	(0.0323)	(0.0101)
CAPEX Growth 2-Year Lagged	-0.0874**	-0.0357*
	(0.0297)	(0.0181)
CAPEX Growth 3-Year Lagged	-0.0513**	0.0786***
	(0.0195)	(0.0111)
CAPEX Growth 4-Year Lagged	0.0125**	0.0479
	(0.00431)	(0.0332)
CAPEX Growth 5-Year Lagged	0.0127***	0.0293
	(0.00364)	(0.0299)
CAPEX Growth 6-Year Lagged	0.00698***	7.90e-08***
	(0.00130)	(9.41e-09)
N observations	377	987
N firms	116	270

Standard errors in parentheses * p < 0.05, ** p < 0.01, *** p < 0.001

4.9 Discussion & Managerial Insights

The role of every manager is to create long-term value for stakeholders. The principle of value creation has stood the test of time, dating back to Alfred Marshall and his notion of the difference between the return on capital and cost of capital (Marshall 1890). In their highly regarded book, Koller et al. (2010) describe two major ingredients for long-term value creation: revenue growth and return on invested capital (ROIC). The combination of the two generates cash flow which, if it exceeds the cost of capital, leads to value creation. Applying this framework to the analysis in this paper explains the U-shaped results, negative in the first two to three years before turning positive which we find in Table 18. Revenue growth can come from either (i) higher average sales prices or (ii) higher production volumes. Cutting capital expenditures potentially affects both: (i) in the short term, companies gain volume flexibility (Table 12), which allows them to strategically position volumes on the market to capture favorable price peaks and potentially increase their average sales price, but (ii) in the long term, production growth (Table 13) is negatively impacted. The ROIC is obtained by multiplying a company's operating margin and capital turnover. Both components are impacted by CAPEX adjustments: the former increases due to lower depreciation and the latter increases due to a lower amount of fixed assets. These effects are, in the long run, at least partly offset by lower revenues. A company's cost of capital is also affected by capital expenditures. For instance, Glencore, the highly leveraged Swiss mining company, put a USD 6bn ceiling on its CAPEX in 2015 in an effort to reduce its debt at a time of falling commodity prices, amid concerns about its ability to limit its interest burden. Furthermore, these concerns negatively affected its credit rating and drove up the cost of accessing external financing.

The role of managers is highly complex, since their decisions affect and are affected by a complex system of interlinked operational and financial variables. This paper has mainly focused on the holistic operational impact of managers' investment decisions. We show that from an operational point of view, long-term steady asset development is beneficial. Practitioners have to combine these guidelines with real-world financial constraints.

4.10 Conclusion & Future Research

This paper establishes empirical evidence for the short- and long-term operational impact of adjustments to investments in manufacturing assets and links this to stock returns. There is an extensive body of literature that looks at the different aspects that impact investment volumes and how these relate to a firm's operational and financial performance. The interaction effects between these variables are complex; therefore individual considerations hardly give the full picture. Instead, we have proposed a more holistic view of how investments in fixed assets affect the short-term volume flexibility and long-term capacity expansion of a company. The literature has already established that, in general, investments in a company's assets are a significant predictor of future stock returns (Cooper et al. 2008; Gray and Johnson 2011). We find, however, that increasing these investments for companies in the mining and oil & gas industries has a negative impact on a firm's stock price in the first two to three years, but that this trend is more than offset for in the ensuing years. We have also shown that in these commodity markets with close to perfect competition, price trends and volatility have a direct impact on firm-level investments, leading companies to "follow" the market. Combining this with the insights above, our results suggest that managers of financially healthy companies should withstand the stock market's short-term pressure to reduce fixed costs and play the long game.

Our insights raise further questions, which could be addressed by future research. First, we look at the average impact these investment decisions have on stock performance. It would be valuable to segment the market by financial indicators and test how these effects are altered or moderated. Second, in our study capital expenditures on manufacturing assets are considered on an aggregate level, whereas public data does not specify the type of investment. It could be interesting to study how investments in upgrading the current asset base have a different effect compared to investments in new equipment. An event study could be a possibility, whereby companies announce the additional production volume, the assets invested and the timeline and check how the stock markets react in the days, months and years after. Third, there might be alternative explanations for investment decisions, such as herd behavior, whose impact can be tested. Fourth, a comparison between process and consumer industries would further validate our findings.

Chapter 5 Conclusion

5.1 Discussion

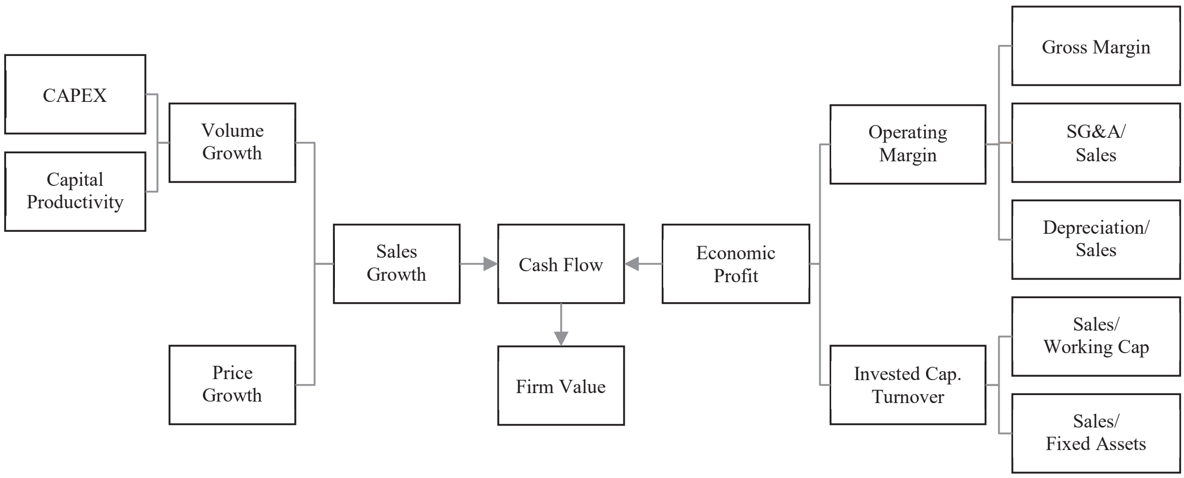
In this dissertation, we have looked at supply chain management in process industries from strategy to implementation while taking industry-specific constraints explicitly into account. The three research chapters (Chapters 2 to 4) draw individual conclusions which feed into one another. Hence this conclusion presents an overarching discussion on insights gained throughout this work and outlines potential future research avenues.

Supply chain management is a well-established business function and research topic. And process industries are long-established business sectors. Yet if the two have been around for so long, why is supply chain management in process industries still an important and interesting topic in today's business context? This is what we set out to explore.

Chapter 2 establishes that supply chain management in process industries follows unique dynamics and requires distinct approaches. However, despite the extensive body of research literature inspired by real-world applications, there is a surprising paucity of research examining how process-industry-specific constraints impact supply chain management. For instance, aspects such as the implications of high fixed costs on a company's ability to react to high commodity price volatility are not discussed. This combination of serving highly dynamic markets with often rather inflexible manufacturing activities opens up a rich and interesting field of unexplored research questions. And currently they are perhaps more relevant than ever, with profit margins being squeezed and prices plunging across many process industries since 2011.

Companies in these often highly commoditized markets do not have all the commercial tools that are available to consumer industries. Naturally, they turn their sights toward optimizing their cost base in order to remain profitable. The stakes are high, since their supply chain related costs are higher than those of their peers in consumer industries. They include transportation, warehousing, direct workforce and inventory capital costs and they represent on average from 10% (pulp & paper) up to 20% (steel and commodity chemicals) of sales in process industries, whereas they only represent 5% (fast-moving consumer goods, automotive) to 8% (high-tech companies) of sales in consumer industries.

Figure 16 Firm Value Driver Tree



In concluding this dissertation, we want to show that supply chain management can give companies an edge in achieving sustainable, long-term firm value. A company's supply chain transformation starts with defining its strategy, which has to be aligned to the business and product context (Fisher 1997). In Chapter 3 we developed two supply chain strategies that are adapted for process industries and lead to higher service levels with lower supply chain related costs: "CAPEX Game" and "Agility Game." The former aims to sweat the manufacturing assets and constantly produce at high utilization rates. In this way, the operating margin is pushed up because of low fixed costs-to-sales ratios (i.e. Depreciation-to-Sales and SG&A-to-Sales). This positive effect is partly (negatively) compensated for by lower average sales prices, since the company has to sell constantly (rather than waiting for higher prices). CAPEX Game is favorable if fixed costs are significant compared to transportation costs and generally for companies with high capital costs. The latter, Agility Game, seeks to transform the supply chain into a business driver and improve the average sales price by capturing short-term price peaks. It is particularly interesting in market environments with high demand uncertainty and where price volatility is high compared to gross margins. For instance Borealis, a major Austrian chemicals company, runs a trading unit that optimizes its asset utilization and boosts its sales based on a very reactive supply chain setup. Whether a company chooses to follow a sales-enhancing or cost-focused supply chain strategy depends on the industry and company context and has to be analyzed.

Against a backdrop of declining prices, yet with significant improvement potential, supply chain management has moved up the agenda of companies in process industries. Yet, transforming the supply chain management function takes time, and financially distressed companies in many cases have to take immediate action by reducing their CAPEX to react to lower cash inflows. We have seen in Chapter 4 that reducing investments in fixed assets is a powerful lever to gain financial and operational relief in the short term, but it is accompanied by a negative effect on a firm's long-term growth perspectives and firm value. CAPEX reductions are made with the objective of rapidly improving profitability, for instance by improving a company's interest coverage ratio and reassuring the markets about its ability to pay the interest on its debt. If we analyze the impact beyond the immediate fixed-cost reductions, we see in the value driver tree (Koller et al. 2010; Figure 16) that reducing CAPEX will, in the short to mid-term, boost economic profit by improving the operating margin (due to lower depreciation) and invested capital turnover (due to lower fixed assets), but will, in the long term, limit the volume growth.

Supply chain management in process industries is more relevant than ever in tough times; it can be the differentiator between a good company and a great company. However, it is not merely an extension of traditional consumer-industry focused supply chain management, but requires distinct approaches in order to truly make a difference. A steel-making or mining company cannot aim to become an icon of supply chain management by copying supply chain management champions from consumer industries such as Procter & Gamble, Apple and L'Oréal. It has to rethink its entire supply chain setup, starting from the strategy all the way through to implementation.

5.2 Future Research Avenues

Besides providing managerial insights, this dissertation lays a theoretical foundation and raises a number of questions which could lead to avenues for future research on supply chain management in process industries.

For example, Chapter 2, which outlines the constraints that process industries experience in terms of supply chain management, relied on secondary data and was based on a number of empirical proxies. These measures make it possible to draw valid conclusions, but they remain approximate. In a next step, the statistical models could be populated with primary data (e.g., a database created based on a survey) and combined with a mathematical model. The former would make it possible to test some of the claims and gain more detailed insights. The latter, a mathematical model describing, for instance, the impact of transportation costs on inventory management would make it possible to develop forward-looking, prescriptive insights.

The conceptual framework in Chapter 3, which was empirically tested, could be further refined with a complementary case study. Our descriptions of "best-in-class" supply chain strategies give a bird's eye-view of the desired supply chain setups, but lack the validation of a real-world, in-depth example. For instance, what are the practical challenges facing a mining company that is striving to achieve an Agility Game approach and sets up an internal commodity trading branch to optimize its asset utilization and average sales price? Such a case study would not only validate our findings but could also potentially reveal further refinements to the framework. We made a distinction between sales-enhancing and cost-focused supply chains in process industries. There are possibly further sub-groups requiring variations of these strategies.

Chapter 4, in a next step, could be extended beyond operational considerations to include further financial aspects such as a company's credit rating and liquidity, which determine its access to and cost of alternative external funding.

We believe that, overall, future research should place particular emphasis on the implementation of supply chain transformations that respond to questions such as: How critical is the implementation time of such a transformation for it to be successful? What resources does such a transformation require and what is the return on investment? What is the optimal organizational setup for leading a supply chain transformation? These studies would build on our managerial insights and add a further level of applicability to the findings for supply chain managers.

References

Abel, A.B., 1985. Inventories, Stock-outs and Production Smoothing. *The Review of Economic Studies* 52, 283–293.

Allen, L., Pantzalis, C., 1996. Valuation of the Operating Flexibility of Multinational Corporations. *Journal of International Business Studies* 633–653.

Almeida, H., Campello, M., 2007. Financial Constraints, Asset Tangibility, and Corporate Investment. *Review of Financial Studies* 20, 1429–1460.

Almeida, H., Campello, M., Weisbach, M.S., 2004. The Cash Flow Sensitivity of Cash. *The Journal of Finance* 59, 1777–1804.

Anupindi, R., Jiang, L., 2008. Capacity Investment under Postponement Strategies, Market Competition, and Demand Uncertainty. *Management Science* 54, 1876–1890.

Arellano, M., Bond, S., 1991. Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations. *The Review of Economic Studies* 58, 277–297.

Arrow, K.J., 1958. Studies in the Mathematical Theory of Inventory and Production. Stanford University Press, Palo Alto.

Asche, F., Gjølberg, O., Völker, T., 2003. Price Relationships in the Petroleum Market: An Analysis of Crude Oil and Refined Product Prices. *Energy Economics* 25, 289–301.

Aviv, Y., 2001. The Effect of Collaborative Forecasting on Supply Chain Performance. *Management Science* 47, 1326–1343.

Bain, C., 2013. Guide to Commodities: Producers, Players and Prices, Markets, Consumers and Trends. John Wiley & Sons, New York.

Balakrishnan, R., Linsmeier, T.J., Venkatachalam, M., 1996. Financial Benefits from JIT Adoption: Effects of Customer Concentration and Cost Structure. *Accounting Review*, 183–205.

Banker, S., 2015. Procter & Gamble's Futuristic Control Tower Environment. *Fortune*, July 1.

Barth, M.E., Clinch, G., 2009. Scale Effects in Capital Markets-Based Accounting Research. *Journal of Business Finance & Accounting* 36, 253–288.

Bengtsson, J., 2001. Manufacturing Flexibility and Real Options: A review. *International Journal of Production Economics* 74, 213–224.

Bessembinder, H., Seguin, P.J., 1993. Price Volatility, Trading Volume, and Market Depth: Evidence from Futures Markets. *Journal of Financial and Quantitative Analysis* 28, 21–39.

Blumenfeld, D.E., Burns, L.D., Diltz, J.D., Daganzo, C.F., 1985. Analyzing Trade-offs between Transportation, Inventory and Production Costs on Freight Networks. *Transportation Research Part B: Methodological* 19, 361–380.

Boston Consulting Group, 2010. Flexibility and Innovation – Today's Imperatives for Steel https://www.bcgperspectives.com/content/articles/metals_mining_sourcing_procurement_flexibility_innovation_todays_imperatives_steel/ (accessed 12.10.13)

Boston Consulting Group, 2012. Expertise & Impact Taking the Long-Term View in Turbulent Times http://www.bcg.com/expertise_impact/publications/PublicationDetails.aspx?id=tcm:12-125031 (accessed 12.6.13).

Bousso, R., 2016. Shell under Pressure to Reduce Spending. *Reuters*, April 8

Bray, R. L., Mendelson, H., 2012. Information transmission and the bullwhip effect: An empirical investigation. *Management Science* 58, 860-875

Brown, B., Perry, S., 1994. Removing the Financial Performance Halo from Fortune's "Most Admired" Companies. *Academy of Management Journal* 37, 1347–1359.

Bun, M.J., Kiviet, J.F., 2006. The Effects of Dynamic Feedbacks on LS and MM Estimator Accuracy in Panel Data Models. *Journal of Econometrics* 132, 409–444.

Burns, L.D., Hall, R.W., Blumenfeld, D.E., Daganzo, C.F., 1985. Distribution Strategies that Minimize Transportation and Inventory Costs. *Operations Research* 33, 469–490.

Caballero, R.J., Farhi, E., Gourinchas, P.-O., 2008. Financial Crash, Commodity Prices and Global Imbalances. National Bureau of Economic Research.

Cachon, G., Terwiesch, C., 2006. Matching Supply with Demand. McGraw-Hill, New York.

Cachon, G.P., Fisher, M., 2000. Supply Chain Inventory Management and the Value of Shared Information. *Management Science* 46, 1032–1048.

Chen, F., Zheng, Y.-S., 1994. Lower Bounds for Multi-Echelon Stochastic Inventory Systems. *Management Science* 40, 1426–1443.

Chen, H., Frank, M.Z., Wu, O.Q., 2005. What Actually Happened to the Inventories of American Companies between 1981 and 2000? *Management Science* 51, 1015–1031.

Chen, H., Frank, M.Z., Wu, O.Q., 2007. US Retail and Wholesale Inventory Performance from 1981 to 2004. *Manufacturing & Service Operations Management* 9, 430–456.

Cleary, S., 1999. The Relationship between Firm Investment and Financial Status. *The Journal of Finance* 54, 673–692.

Coldrick, A., Ling, D., Turner, C., 2003. Evolution of Sales & Operations Planning-From Production Planning to Integrated Decision Making. Strata Bridge.

Cooper, M.J., Gulen, H., Schill, M.J., 2008. Asset Growth and the Cross-Section of Stock Returns. *The Journal of Finance* 63, 1609–1651.

Corbett, C.J., Blackburn, J.D., Van Wassenhove, L.N., 1999. Partnerships to Improve Supply Chains. *MIT Sloan Management Review* 40, 71.

Cordón, C., Hald, K.S., Seifert, R.W., 2013. Strategic Supply Chain Management. Routledge, London.

Damodaran, A., 1999. *Estimating risk parameters*.

https://archive.nyu.edu/bitstream/2451/26789/2/S-CDM-99-02.pdf (accessed 3.7.14)

Damodaran, A., 2009. The Dark Side of Valuation: Valuing Young, Distressed, and Complex Businesses. Financial Times Press, New Jersey.

Damodaran, A., 2010. Applied Corporate Finance. John Wiley & Sons, New York.

Daskin, M.S., Coullard, C.R., Shen, Z.-J.M., 2002. An Inventory-Location Model: Formulation, Solution Algorithm and Computational Results. *Annals of Operations Research* 110, 83–106.

De Meyer, A., Nakane, J., Miller, J.G., Ferdows, K., 1989. Flexibility: The Next Competitive Battle the Manufacturing Futures Survey. *Strategic Management Journal* 10, 135–144.

De Toni, A., Tonchia, S., 1998. Manufacturing Flexibility: A literature Review. *International Journal of Production Research* 36, 1587–1617.

Dennis, D., Meredith, J., 2000a. An Empirical Analysis of Process Industry Transformation Systems. *Management Science* 46, 1085–1099.

Dennis, D.R., Meredith, J., 2000b. An Analysis of Process Industry Production and Inventory Management Systems. *Journal of Operations Management* 18, 683–699.

Dillman, D.A., 2000. Mail and Internet Surveys: The Tailored Design Method. Wiley, New York.

Dixit, A.K., Pindyck, R.S., 1994. Investment under Uncertainty. Princeton University Press, Princeton.

Dixon, J.R., 1992. Measuring Manufacturing Flexibility: An Empirical Investigation. *European Journal of Operational Research* 60, 131–143.

Erkip, N., Hausman, W.H., Nahmias, S., 1990. Optimal Centralized Ordering Policies in Multi-Echelon Inventory Systems with Correlated Demands. *Management Science* 36, 381–392.

Eroglu, C., Hofer, C., 2011. Lean, Leaner, too Lean? The Inventory-Performance Link Revisited. *Journal of Operations Management* 29, 356–369.

Ettlie, J.E., 1998. R&D and Global Manufacturing Performance. *Management Science* 44, 1–11.

Ettlie, J.E., Penner-Hahn, J.D., 1994. Flexibility Ratios and Manufacturing Strategy. *Management Science* 40, 1444–1454.

Fazzari, S.M., Athey, M.J., 1987. Asymmetric Information, Financing Constraints, and Investment. *The Review of Economics and Statistics* 481–487.

Fazzari, S., Hubbard, R.G., Petersen, B., 1988. Investment, Financing Decisions, and Tax Policy. *The American Economic Review* 78, 200–205.

Fazzari, S.M., Hubbard, R.G., Petersen, B.C., Blinder, A.S., Poterba, J.M., 1988. *Financing Constraints and Corporate Investment*. Brookings Papers on Economic Activity, 141–206.

Ferdows, K., Lewis, M.A., Machuca, J.A., 2004. Rapid-Fire fulfillment. *Harvard Business Review* 82, 104–117.

Fiegenbaum, A., Karnani, A., 1991. Output Flexibility—A Competitive Advantage for Small Firms. *Strategic Management Journal* 12, 101–114.

Fisher, M.L., 1997. What is the Right Supply Chain for Your Product? *Harvard Business Review* 75, 105–117.

Fransoo, J.C., Rutten, W.G., 1994. A Typology of Production Control Situations in Process Industries. *International Journal of Operations & Production Management* 14, 47–57.

Garavelli, A.C., 2003. Flexibility Configurations for the Supply Chain Management. *International Journal of Production Economics* 85, 141–153.

Gaur, V., Fisher, M.L., Raman, A., 2005. An Econometric Analysis of Inventory Turnover Performance in Retail Services. *Management Science* 51, 181–194.

Gavirneni, S., Kapuscinski, R., Tayur, S., 1999. Value of Information in Capacitated Supply Chains. *Management Science* 45, 16–24.

Geng, N., Jiang, Z., 2009. A Review on Strategic Capacity Planning for the Semiconductor Manufacturing Industry. *International Journal of Production Research* 47, 3639–3655.

Gerwin, D., 1993. Manufacturing Flexibility: A Strategic Perspective. *Management Science* 39, 395–410.

Ghemawat, P., 2001. Distance Still Matters. *Harvard Business Review* 79, 137–147.

Gilchrist, S., Himmelberg, C.P., 1995. Evidence on the Role of Cash Flow for Investment. *Journal of Monetary Economics* 36, 541–572.

Goyal, M., Netessine, S., 2007. Strategic Technology Choice and Capacity Investment under Demand Uncertainty. *Management Science* 53, 192–207.

Goyal, M., Netessine, S., 2011. Volume Flexibility, Product Flexibility, or Both: The Role of Demand Correlation and Product Substitution. *Manufacturing & Service Operations Management* 13, 180–193.

Granger, C., 1969. Investigating Causal Relations by Econometric Models and Cross-Spectral Methods. *Econometrica: Journal of the Econometric Society* 37, 424–38.

Graves, S.C., 1996. A Multiechelon Inventory Model with Fixed Replenishment Intervals. *Management Science* 42, 1–18.

Graves, S.C., Tomlin, B.T., 2003. Process Flexibility in Supply Chains. *Management Science* 49, 907–919.

Gray, P., Johnson, J., 2011. The Relationship between Asset Growth and the Cross-Section of Stock Returns. *Journal of Banking & Finance* 35, 670–680.

Grimson, J.A., Pyke, D.F., 2007. Sales and Operations Planning: An Exploratory Study and Framework. *The International Journal of Logistics Management* 18, 322–346.

Guide Jr, V.D.R., Srivastava, R., Spencer, M.S., 1997. An Evaluation of Capacity Planning Techniques in a Remanufacturing Environment. *International Journal of Production Research* 35, 67–82.

Gupta, D., 1993. On Measurement and Valuation of Manufacturing Flexibility. *The International Journal of Production Research* 31, 2947–2958.

Gupta, Y.P., Goyal, S., 1989. Flexibility of Manufacturing Systems: Concepts and Measurements. *European Journal of Operational Research* 43, 119–135.

Hamilton, J.D., 2009. Causes and Consequences of the Oil Shock of 2007-08. National Bureau of Economic Research.

Hartman, H.L., Mutmansky, J.M., 2002. Introductory Mining Engineering. John Wiley & Sons, New York

Hausman, J.A., Taylor, W.E., 1981. Panel Data and Unobservable Individual Effects. *Econometrica: Journal of the Econometric Society* 1377–1398.

Hayes, R.H., Wheelwright, S.C., 1984. Restoring our Competitive Edge: Competing through Manufacturing. John Wiley & Sons, New York

Hendricks, K.B., Singhal, V.R., 2003. The Effect of Supply Chain Glitches on Shareholder Wealth. *Journal of Operations Management* 21, 501–522.

Hendricks, K.B., Singhal, V.R., 2005. Association between Supply Chain Glitches and Operating Performance. *Management Science* 51, 695–711.

Hill, M.D., Kelly, G.W., Highfield, M.J., 2010. Net Operating Working Capital Behavior: A First Look. *Financial Management* 39, 783–805.

Holt, C.C., 2004. Forecasting Seasonals and Trends by Exponentially Weighted Moving Averages. *International Journal of Forecasting* 20, 5–10.

Hoshi, T., Kashyap, A., Scharfstein, D., 1990. *The Role of Banks in Reducing the Costs of Financial Distress in Japan*. Journal of Financial Economics 27, 67–88.

Hoshi, T., Kashyap, A., Scharfstein, D., 1991. Corporate Structure, Liquidity, and Investment: Evidence from Japanese Industrial Groups. *The Quarterly Journal of Economics* 33–60.

Hubbard, R.G., Kashyap, A.K., Whited, T.M., 1993. Internal Finance and Firm Investment. National Bureau of Economic Research.

Huson, M., Nanda, D., 1995. The Impact of Just-in-Time Manufacturing on Firm Performance in the US. *Journal of Operations Management* 12, 297–310.

Irvine, F.O., 1981. Retail Inventory Investment and the Cost of Capital. *The American Economic Review* 633–648.

Isaksson, O., Seifert, R., 2015. Quantifying the bullwhip effect using two-echelon data: A cross-industry empirical investigation. *International Journal of Production Economics* 171, 311-320

Jain, N., Girotra, K., Netessine, S., 2013. Managing Global Sourcing: Inventory Performance. *Management Science* 60, 1202–1222.

Jensen, M.C., 1986. Agency Cost of Free Cash Flow, Corporate Finance, and Takeovers. Corporate Finance, and Takeovers. *The American Economic Review* 76.

Kesavan, S., Gaur, V., Raman, A., 2010. Do Inventory and Gross Margin Data Improve Sales Forecasts for U.S. Public Retailers? *Management Science* 56, 1519–1533.

Kiviet, J.F., Phillips, G.D.A., 1994. Bias Assessment and Reduction in Linear Error-Correction Models. *Journal of Econometrics* 63, 215–243.

Kiviet, J.F., 1995. On Bias, Inconsistency, and Efficiency of Various Estimators in Dynamic Panel Data Models. *Journal of Econometrics* 68, 53–78.

Koller, T., Goedhart, M., Wessels, D., 2010. Valuation: Measuring and Managing the Value of Companies. John Wiley & Sons, New York.

Koste, L.L., Malhotra, M.K., 1999. A Theoretical Framework for Analyzing the Dimensions of Manufacturing Flexibility. *Journal of Operations Management* 18, 75–93.

Koste, L.L., Malhotra, M.K., Sharma, S., 2004. Measuring Dimensions of Manufacturing Flexibility. *Journal of Operations Management* 22, 171–196.

Lamont, O., 1997. Cash Flow and Investment: Evidence from Internal Capital Markets. *The Journal of Finance* 52, 83–109.

Lamont, O., 2000. Investment Plans and Stock Returns. *The Journal of Finance* 55, 2719–2745.

Lapide, L., 2004b. Sales and Operations Planning Part I: The process. *The Journal of Business Forecasting* 23, 3.

Lapide, L., 2004a. Sales and Operations Planning Part II: Enabling Technology. *The Journal of Business Forecasting* 23, 18.

Lashinsky, A., 2008. Apple: The Genius Behind Steve. *Fortune*, November 24.

Lee, H.L., Billington, C., 1992. Managing Supply Chain Inventory: Pitfalls and Opportunities. *Sloan Management Review* 33.

Lee, H.L., So, K.C., Tang, C.S., 2000. The Value of Information Sharing in a Two-Level Supply Chain. *Management Science* 46, 626–643.

Lee, H.L., 2002. Aligning Supply Chain Strategies with Product Uncertainties. *California Management Review* 44, 105–119.

Lee, H.L., 2004. The triple-A Supply Chain. *Harvard Business Review* 82, 102–113.

Love, I., Zicchino, L., 2006. Financial Development and Dynamic Investment Behavior: Evidence from Panel VAR. *The Quarterly Review of Economics and Finance* 46, 190–210.

Marshall, A., 1890. Principles of Economics. Mac-Millan, London.

Mason, R.L., Gunst, R.F., Hess, J.L., 2003. Statistical Design and Analysis of Experiments: With Applications to Engineering and Science. John Wiley & Sons, New York.

Mayer, C., 1990. Financial Systems, Corporate Finance, and Economic Development. Asymmetric Information, Corporate Finance, and Investment. University of Chicago Press, pp. 307–332, Chicago.

McKinsey & Company, 2008. The Race for Supply Chain Advantage: Six Practices that Drive Performance. https://www.coursehero.com/file/p702qod/the-race-for-supply-chain-advantage-six-practices-that-drive-performance-our/ (accessed 2.23.15).

Menard, S., 2002. Applied Logistic Regression Analysis. Sage, New York.

Milner, J.M., Kouvelis, P., 2002. On the Complementary Value of Accurate Demand Information and Production and Supplier Flexibility. *Manufacturing & Service Operations Management* 4, 99–113.

Modigliani, F., Weingartner, H.M., 1958. Forecasting Uses of Anticipatory Data on Investment and Sales. *The Quarterly Journal of Economics* 23–54.

Narayanan, V.G., Raman, A., 2004. Aligning Incentives in Supply Chains. *Harvard Business Review* 82, 94–102.

Neter, J., Kutner, M.H., Nachtsheim, C.J., Wasserman, W., 1996. Applied Linear Statistical Models. Irwin, Chicago.

Nickell, S., 1981. Biases in Dynamic Models with Fixed Effects. *Econometrica: Journal of the Econometric Society* 1417–1426.

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, 215–225.

Papageorgiou, L.G., 2009. Supply Chain Optimisation for the Process Industries: Advances and Opportunities. *Computers & Chemical Engineering* 33, 1931–1938.

Paraskevopoulos, D., Karakitsos, E., Rustem, B., 1991. Robust Capacity Planning under Uncertainty. *Management Science* 37, 787–800.

Pil, F.K., Holweg, M., 2004. Linking Product Variety to Order-Fulfillment Strategies. *Interfaces* 34, 394–403.

Porter, M.E., 2008. Competitive advantage: Creating and Sustaining Superior Performance. Simon & Schuster, New York.

PricewaterhouseCoopers, 2007. Financial Reporting in the Mining Industry. https://www.pwc.com/gx/en/energy-utilities-mining/pdf/ifrs-mining.pdf (accessed 6.12.16)

PricewaterhouseCoopers, 2011. Financial Reporting in the Oil and Gas Industry - IFRS https://www.pwc.com/id/en/publications/assets/eumpublications/financial-reporting-in-the-oil-and-gas-industry.pdf (accessed 6.16.16).

PricewaterhouseCoopers & MIT Forum, 2013. Making the Right Risk Decisions to Strengthen Operations Performance.

PricewaterhouseCoopers, 2015. Mine 2015. The Gloves are Off. http://www.pwc.com/gx/en/mining/publications/assets/pwc-e-and-m-mining-report.pdf (accessed 4.25.16).

Rajagopalan, S., Malhotra, A., 2001. Have US Manufacturing Inventories Really Decreased? An Empirical Study. *Manufacturing & Service Operations Management* 3, 14–24.

Ramasesh, R.V., Jayakumar, M.D., 1991. Measurement of Manufacturing Flexibility: A Value Based Approach. *Journal of Operations Management* 10, 446–468.

Reuters, 1016. Shell Under Pressure to Reduce Spending http://www.reuters.com/article/us-shell-capex-idUSKCN0X51Q1 (accessed 4.12.2016)

Roumiantsev, S., Netessine, S., 2005. Should Inventory Policy Be Lean or Responsive? Evidence for US Public Companies. Working Paper, University of Pennsylvania.

Roumiantsev, S., Netessine, S., 2007a. Inventory and its Relationship with Profitability: Evidence for an International Sample of Countries. Available at SSRN 2319862.

Roumiantsev, S., Netessine, S., 2007b. What Can Be Learned from Classical Inventory Models? A Cross-Industry Exploratory Investigation. *Manufacturing & Service Operations Management* 9, 409–429.

Schwartz, E., Smith, J.E., 2000. Short-Term Variations and Long-Term Dynamics in Commodity Prices. *Management Science* 46, 893–911.

Seifert, D., Seifert, R.W., Protopappa-Sieke, M., 2013. A Review of Trade Credit Literature: Opportunities for Research in Operations. *European Journal of Operational Research* 231, 245–256.

Seifert, R.W., Thonemann, U.W., Hausman, W.H., 2004. Optimal Procurement Strategies for Online Spot Markets. *European Journal of Operational Research* 152, 781–799.

Selldin, E., Olhager, J., 2007. Linking Products with Supply Chains: Testing Fisher's Model. *Supply Chain Management: An International Journal* 12, 42–51.

Shah, N., 2005. Process Industry Supply Chains: Advances and Challenges. *Computers & Chemical Engineering* 29, 1225–1236.

Shu, J., Teo, C.-P., Shen, Z.-J.M., 2005. Stochastic Transportation-Inventory Network Design Problem. *Operations Research* 53, 48–60.

Simchi-Levi, D., 2010. Operations Rules: Delivering Customer Value through Flexible Operations. MIT Press, Cambridge.

Simchi-Levi, D., Clayton, A., Raven, B., 2013. When One Size Does Not Fit All. *MIT Sloan Management Review* 54, 15.

Simchi-Levi, D., Peruvankal, J.P., Mulani, N., Read, B., Ferreira, J., 2012. Is It Time to Rethink Your Manufacturing Strategy. *MIT Sloan Management Review* 53, 20–22.

Slack, N., 1983. Flexibility as a Manufacturing Objective. *International Journal of Operations & Production Management* 3, 4–13.

Slack, N., Chambers, S., Johnston, R., 2010. Operations Management. Pearson Education, New Jersey.

Slone, R.E., Mentzer, J.T., Dittmann, J.P., 2007. Are You the Weakest Link in Your Company's Supply Chain? *Harvard Business Review* 85, 116.

Stahl, R.A., 1995. Sales and Operations Planning: A Fundamental That Still Works. *International Conference Proceedings – American Production and Inventory Control Society*, pp. 215–218.

Suarez, F.F., Cusumano, M.A., Fine, C.H., 1996. An Empirical Study of Manufacturing Flexibility in Printed Circuit Board Assembly. *Operations Research* 44, 223–240.

Tang, C.Y., Tikoo, S., 1999. Operational Flexibility and Market Valuation of Earnings. *Strategic Management Journal* 20, 749–761.

Taylor, S.G., 1979. Production and Inventory Management in the Process Industries: A State of the Art Survey. *Production and Inventory Management Journal* 20, 1–16.

Taylor, S.G., Seward, S.M., Bolander, S.F., 1981. Why the Process Industries are Different. *Production and Inventory Management Journal* 22, 9–24.

Terjesen, S., Patel, P.C., Covin, J.G., 2011. Alliance Diversity, Environmental Context and the Value of Manufacturing Capabilities among New High Technology Ventures. *Journal of Operations Management* 29, 105–115.

Thonemann, U.W., Bradley, J.R., 2002. The Effect of Product Variety on Supply-Chain Performance. *European Journal of Operational Research* 143, 548–569.

Upton, D.M., 1994. The Management of Manufacturing Flexibility. *California Management Review* 36, 72–89.

Vachon, S., Klassen, R.D., 2002. An Exploratory Investigation of the Effects of Supply Chain Complexity on Delivery Performance. *Engineering Management, IEEE Transactions* 49, 218–230.

Van Donk, D.P., 2001. Make to stock or make to order: The decoupling point in the food processing industries. *International Journal of Production Economics* 69, 297–306.

Van Donk, D.P., Fransoo, J.C., 2006. Operations Management Research in Process Industries. *Journal of Operations Management* 24, 211–214.

Van Hoek, R.I., 2001. The rediscovery of postponement: A literature review and directions for research. *Journal of Operations Management* 19, 161–184.

Van Mieghem, J.A., 1998. Investment Strategies for Flexible Resources. *Management Science* 44, 1071–1078.

Van Mieghem, J.A., Dada, M., 1999. Price versus Production Postponement: Capacity and Competition. *Management Science* 45, 1639–1649.

Van Rijn, T.M.J., 1993. MRP in Process: The Applicability of MRP-II in the Semi-proscess Industry: Final Report of the VLm Working Group. Van Gorcum, Assen.

Vokurka, R.J., O'Leary-Kelly, S.W., 2000. A Review of Empirical Research on Manufacturing Flexibility. *Journal of Operations Management* 18, 485–501.

Wagner, S.M., Grosse-Ruyken, P.T., Erhun, F., 2012. The Link between Supply Chain Fit and Financial Performance of the Firm. *Journal of Operations Management* 30, 340–353.

Whited, T.M., 1992. Debt, Liquidity Constraints, and Corporate Investment: Evidence from Panel Data. *The Journal of Finance* 47, 1425–1460.

Wooldridge, J., 2015. Introductory Econometrics: A Modern Approach, Nelson Education, Toronto.

World Economic Forum, 2014. New Models for Infrastructure Investment in the Mining and Metals Sector.

Wu, Y.N., Cheng, T.C.E., 2008. The impact of information sharing in a multiple-echelon supply chain. *International Journal of Production Economics* 115, 1-11.

Zijm, W.H.M., Buitenhek, R., 1996. Capacity Planning and Lead Time Management. *International Journal of Production Economics* 46, 165–179.

Appendix

Table 19 Simultaneous Equation Model – H IIa – CAPEX Impact on Production – Estimates

	Variables	Mining			Oil & Gas		
		PROD	**INV**	**SALES**	**PROD**	**INV**	**SALES**
Dependent Variables	PROD		0.186***	0.533***		0.0692***	0.108***
			(0.0145)	(0.00882)		(0.00578)	(0.00499)
	INV	0.230***		0.0743***	0.0574***		-0.00200
		(0.0121)		(0.00501)	(0.00343)		(0.00184)
	SALES	0.194***	-0.122***		0.475***	-0.0530***	
		(0.0201)	(0.0145)		(0.00762)	(0.00537)	
Independent Variables	LT	-0.178***			-0.130***		
		(0.00775)			(0.00301)		
	DU		0.130***			0.00691	
			(0.0115)			(0.00638)	
	GM		0.155***			0.0922***	
			(0.0101)			(0.00846)	
	CAP	0.0722***			0.151***		
		(0.00551)			(0.0206)		
	ΔINV		0.264***			0.296***	
			(0.00482)			(0.00330)	
Lagged Variables	Lag PROD	0.212***			0.314***		
		(0.0101)			(0.00587)		
	Lag INV		0.636***			0.672***	
			(0.00610)			(0.00357)	
	Lag SALES			0.330***			0.692***
				(0.0156)			(0.0102)
	Year Dummies		Yes			Yes	
	N observations		7'312			17'405	
	N firms		436			994	
	Overall R2	97.43%	98.43%	97.60%	99.10%	99.17%	98.73%

Standard errors in parentheses   * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 20 Robustness Tests – H II – Sales & Operations Planning Process – Alternative Estimators

	Regressand	Regressors								Description
		PROD	INV	SALES	LT	DU	GM	CAP	ΔINV	
					Original Simultaneous Equation Model					
Mining	PROD		0.322***	0.202***	-0.141***			0.0487***		
	INV	0.474***		-0.377***		0.0425***	0.228***		0.0794***	3SLS
	SALES	0.336***	0.0293***							
					Alternative Models					
	PROD		0.188***	0.284***	-0.115***			0.0507***		
	INV	0.0956***		-0.0312*		0.0532***	0.0471***		0.102***	2SLS
	SALES	0.340***	0.0451***							
	PROD		0.253***	0.453***	-0.0850***			0.0252***		
	INV	0.253***		-0.170***		0.0508***	0.128***		0.0919***	OLS
	SALES	0.415***	0.0194***							
	PROD		0.235***	0.381***	-0.157***			0.0415***		
	INV	0.379***		-0.193***		0.0589***	0.131***		0.0886***	Single Eq. Fixed Effects
	SALES	0.364***	0.0715***							
	PROD		0.167***	0.421***	-0.124***			0.0487***		
	INV	0.323***		-0.195***		0.0527***	0.133***		0.0936***	Single Eq. Random Effects
	SALES	0.358***	0.0550***							
					Original Simultaneous Equation Model					
Oil & Gas	PROD		0.0714***	0.476***	-0.122***			0.193***		
	INV	0.0432***		-0.0272***		0.0135**	0.0593***		0.122***	3SLS
	SALES	0.119***	-0.00536**							
					Alternative Models					
	PROD		0.0616***	0.484***	-0.119***			0.190***		
	INV	0.0256***		-0.0102*		0.0146**	0.00536		0.126***	2SLS
	SALES	0.118***	-0.00507**							
	PROD		0.0836***	0.544***	-0.118***			0.0261***		
	INV	0.0875***		-0.0638***		0.111*	0.0624***		0.122***	OLS
	SALES	0.260***	-0.0339***							
	PROD		0.0936***	0.411***	-0.250***			0.0716***		
	INV	0.198***		-0.103***		0.0309***	0.0875***		0.199***	Single Eq. Fixed Effects
	SALES	0.251***	0.0148**							
	PROD		0.122***	0.418***	-0.237***			0.0642***		
	INV	0.199***		-0.104***		0.0318***	0.0857***		0.201***	Single Eq. Random Effects
	SALES	0.238***	-0.00392							

Standard errors in parentheses * p < 0.05, ** p < 0.01, *** p < 0.001

Curriculum Vitae - Philipp Moser

Born on June 9th, 1984 in Switzerland

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4057 Basel/Switzerland | Tel. +41 79 477 81 37

Education

2013-2016 EPFL, Lausanne, Switzerland — PhD Candidate

- **Topic** Operations Management in Commodity Markets and Process Industries
- **Advisor** Prof. Dr. R.W. Seifert | Collaboration with industrial partners (Borealis, Holcim, Yara, BASF, DuPont, Dow Chemical, Clariant) | Collaboration with IMD Business School
- **Grants** SNF (Swiss National Fund Excellence Research Grant (CHF 100k+); McKinsey & Co.
- **Coursework** Econometrics, Accounting, Private Equity, Corporate Finance, Operations Mgmt (GPA 6.0/6.0)
- **Summer School** Pompeu Fabra (Barcelona, Spain 2014) on Advanced Econometrics & Statistical Modeling | KAIST University (Daejeon, South Korea 2015) on Finance & Entrepreneurship
- **Supervision** Masterprojects in cooperation with industrial partners (Bayer Pharmaceuticals, Philip Morris Intl.)
- **Conferences** INFORMS San Francisco 2014 | Stockholm Business School 2015 | POMS Orlando 2016
- **Publication I** "When the Chain of Opportunity is the Chain of Supply" (2014) – IMD Business School TC
- **Publication II** "New Markets, New Customers and New Supply Chain Problems" (2016) – IMD Business School TC
- **Publication III** "Inventory Dynamics in Process Industries: An Empirical Investigation" (under review)
- **Publication III** "Leveraging Your Supply Chain – Why Process Industries are Different" (under review)
- **Publication V** "Cyclical Investments in Commodity Markets – Short-Term Gain vs. Long-Term Pain " (working paper)

2005-2010 EPFL, Lausanne, Switzerland — Master of Science

- **Topic** Master Degree Nanotechnology Engineering (GPA 5.4/6.0; Top 5% of class)
- **Coursework** including mainly Physics, Mathematics, Linear Algebra & Statistics

Work Experience

2010-2013 McKinsey & Co., Geneva, Switzerland — Associate Consultant

- **Projects** 10+ Clients in Europe, North America, Asia & Pacific
- **Experience** Corporate Strategy, M&A; Strategic Pricing, Organization, Operations
- **Expertise** Clients in Chemicals, Pharmaceuticals, Mining & Basic Materials, Telecommunications
- **Role** Responsible for Teams/Workshops of up to 10 Clients | Coaching of Junior Consultants
- **Education** Trainings on Finance, Strategy, Operations, Due Diligence, Chemicals, Commodities
- **Offers** Competitive Offers from Boston Consulting Group, Bain, Booz & Co., Roland Berger

2009 Alcan Composites, Altenrhein, Switzerland Internship

- **Abstract** Assistance to Head of Operations | 5 Months
- **Projects** Preparation of presentations | Small-scale Project Management | Analysis of Operational Processes

2008 JEMP Construcciones, Quito, Ecuador Internship

- **Abstract** Assistance to CEO & Founder | 3 Months
- **Projects** Market Study for Corporate Development (Office openings in Peru and Colombia)

2007 Kalysis Group SA, Malaga, Spain Internship

- **Abstract** Engineering Intern | Collaboration with Malaga Transportation Company | 3 Months
- **Projects** Development of a multifunctional card reader for mobile applications

Extracurricular Activities

Entrepreneurship

2014 Investment Fund

- Co-founder of a small Business Angel fund | 2 investments CHF 50k+ | Performance by June 2016 +64%

2014 START Lausanne

- Finalist in Start-up competition for CHF 30k Seed Funding

2010 EPFL Forum

- Committee Member | Responsible for “Start-Up Day” (biggest recruitment fair in Switzerland)|Revenues CHF 600k+

Associations

2016 CDE-MTE Program

- Vice-Representative & Treasurer of PhD Students CDM – MTE Program EPFL for 2 years

2010 STI Microengineering

- Vice-Representative Master Students Microtechnology Section EPFL for 2 years

Languages

German		Native
English	C2	Family in Canada	Master Degree 2 years	PhD 3 years	Work 3 years
French	C2	Bachelor Degree 3 years	Living 10+ years in Lausanne & Geneva
Spanish	B1-B2	Work 7 Months	Travel 6 Months

Computer Knowledge

Excellent skills MS Office (Excel, PowerPoint, Word), Bloomberg, Compustat, Capital IQ

Good skills Visual Basic, C/C++ Language

Interests

Squash, Ski-Touring, Tennis, Swimming, Diving, Travelling, Business Newspapers, Politics