On the Incentives to Shift to Low-Carbon Freight Transport

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On the Incentives to Shift to Low-Carbon Freight Transport

Fredrik Eng Larsson

DOCTORAL THESIS

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The transport sector accounts for approximately 20% of EU-27 greenhouse gas (GHG) emissions, and 27% of U.S. GHG emissions. With the Kyoto Protocol, Sweden and several other nations have agreed to reduce these emissions. Often, solutions that involve consolidating freight and moving it to more carbon-efficient transport technologies are advocated as the most advantageous. For such initiatives the technology already exists, so change is only a matter of implementation. But when aggregate data is examined, very little change for the better is seen.

This thesis explores why this may be the case, with the purpose being to increase the understanding of the incentives to shift to low-carbon freight transport. This is explored in a three-phase research structure where, first, macro-data is analyzed, after which theory is built using two multiple case studies, which serve as input to three mathematical modeling studies of different parts of the operator-service provider/forwarder-shipper chain of actors.

By considering the chain of actors on the freight transport market as a service supply chain, the research in this thesis is able to use methods from, and make contributions to, the sustainable supply chain management literature as well as the literature on transport contracting. With this literature as the point of departure, the studies show that there is a matching problem associated with the implementation of low-carbon transports: with the currently used contracts it is usually not rational for the actors on the market to shift to low-carbon transports, even though the total cost on the market, on aggregate, may be reduced from shifting. Nevertheless, there are situations where shifting is rational for all actors. Creating such situations normally requires implementing long-term contracts. The models in this thesis show how such contracts can be designed. However, the models also show that situations where implementation is rational are very sensitive to changes in external parameters such as demand volatility, making implementation high risk in many cases. Another downside is that the environmental improvement is not always as large as one would expect due to inventory build-up and extra truck transports.

For low-carbon transports to be implemented in large scale, their costs need to be more in line with conventional transports, and contracts that allocate risks and profits better need to be implemented. Not until these issues are better understood, and contracts and regulation implemented, can a large scale shift to low-carbon transports be expected.</td></tr>
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Acknowledgements

Yes! Finally. In what may be remembered as one of the hottest summers in well over a hundred years, I finally finished writing this dissertation about how to curb the ongoing climate change. That's right. Instead of eating ice cream or turning on a fan to meet the heat in our Södermalm apartment, I wrote a book about how to address it.

While this may not make me a man of action, it has nevertheless led to a measurable output: this dissertation. And although the creating of this output may be a lonely and hot task at times, it was not a work made in isolation. Throughout the work I have received invaluable direct and indirect support from many friends and colleagues, and I would therefore like to take this moment to thank them for their support.

First, thank you to my three advisors. Andreas for all the patience in dealing with my ideas about research and in reading and commenting on my manuscripts. Without your structured, detailed, and invaluable feedback this thesis would not be what it is. Sten for constantly "confusing me on a higher level". From the master thesis to the doctoral dissertation I have had the privilege of facing your tough and eye-opening questions, inspiring discussions, and much-needed advice. And Peter for supporting and coaching me over the last two and a half years of this research. Your lightning-fast mind and your patience in helping me move on has been both an inspiration and a great resource, and has had an enormous impact on the research and my own development. Thank you!

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Fredrik Eng Larsson
Stockholm, August 2014

Populärvetenskaplig sammanfattning

Godstransporter står för en betydande andel av koldioxidutsläppen i Sverige, liksom i många andra länder. Inom svenskt näringsliv står godstransporter för ca 15% av koldioxidutsläppen och för transportintensiva företag, inom till exempel handeln, kan godstransporter stå för så mycket som 30% av de totala koldioxidutsläppen. Till skillnad från de flesta andra utsläppskategorier är dessa utsläpp dessutom ökande.

Att minska koldioxidutsläpp och övriga emissioner från godstransporter anses viktigt och attraktivt, dels på grund av dess stora andel av totala utsläpp, men även för att en minskning bedöms vara lönsam både ur ett samhällsekonomiskt perspektiv och för företagen på transportmarknaden. Samhällsekonomiska kostnader från utsläpp uppstår från klimat- och hälsoeffekter som skapar kostnader för samhället på lång sikt. Genom att minska utsläppen kan dessa kostnader minskas. Samtidigt innebär minskade utsläpp också minskade drivmedelskostnader för företagen. Om drivmedelsförbrukningen per ton och km minskas, minskas inte bara utsläppen utan även kostnaden per ton och km. Politiker och forskare framhåller därför ofta att det finns gott om ekonomiska incitament för transportmarknadens aktörer att agera samhällsekonomiskt sunt och skifta till mer koleffektiva godstransporter – d.v.s. transport- och logistiklösningar med lägre koldioxidutsläpp. Framför allt framhålls skiften som inte kräver ny teknik, till exempel skiften från lastbilstransporter till intermodala tåg-lastbilstransporter, eller skiften från direkttransporter i medelstora och halvfulla bilar till samlastade transporter med hög fyllnadsgrad i stora fordon. Sådana skiften leder till minskade samhällskostnader såväl som minskade drivmedelskostnader för företagen. Ofta lyfts goda exempel fram – stora företag som Coop, Volvo, och Walmart har alla gjort förändringar i den riktningen.

Men när aggregerade data undersöks tycks dessa företag tillhöra undantagen. Utsläppen från godstransporter ökar, andelen tågtransporter minskar, och projekt som syftar till ökad samlastning läggs ned. Om det finns ekonomiska incitament, politiskt stöd, och ingen ny teknik krävs – varför ser vi då inget skifte till koleffektiva transporter?

Forskningen i den här avhandlingen undersöker detta genom att analysera hur beteende på mikronivå kan leda till den observerade utvecklingen på makronivå. Mer specifikt fokuserar studierna på att undersöka om och hur kontrakten och affärsmodellerna som används på godstransportmarknaderna skapar incitament – piskor och morötter – för att skifta till koleffektiva transporter. För att undersöka endast dessa effekter skalas andra faktorer, som ofta nämns som barriärer för ett skifte till koleffektiva transporter, bort, t.ex. sämre punktlighet, längre transporttid och osäkerhet kring implementeringskostnad. Genom att anta att sådana faktorer är lika för de olika alternativen är det möjligt att fokusera på hur de rent ekonomiska och marknadsmässiga skillnaderna mellan vanliga och koleffektiva transporter leder till olika kontraktsval, som i sin tur leder till olika incitament för eller emot ett skifte till koleffektiva transporter. Detta undersöks i en tredelad forskningsdesign, i vilken makrodata först analyseras, innan teori byggs genom två flerfallstudier vilkas insikter används som inspiration för tre matematiska modeller som behandlar olika delar av kedjan operatör, speditör och varuägare på godstransportmarknaden.

Forskningsresultaten i denna avhandling pekar på att det i många fall – även när faktorer som punktlighet antas identiska mellan alternativen, *och* de totala kostnaderna är lägre – inte är rationellt för aktörerna på transportmarknaden att skifta till koleffektiva transporter. Det vill säga, med de kontrakt som ofta väljs för att sälja koleffektiva transporter skapas sällan incitament för att köpa dem. Detta gäller även om det är företagsekonomiskt motiverat att skifta i sin helhet, d.v.s. när totalkostnaden för företagen på transportmarknaden blir lägre av att skifta. Problemet beror på ett samspel mellan faktorer. På grund av investeringskostnader och efterfrågeosäkerhet, i kombination med en stor och mindre osäker alternativmarknad för vanliga transporter, är det oftast bara rationellt för operatörsledet att investera i koleffektiva transporter om kostnaderna kan skjutas till speditörsledet. Om detta inte är möjligt sker sällan investering. Om det är möjligt, t.ex. på grund av att speditörsledet är under tryck från sina kunder, gör de högre fasta kostnaderna det rationellt för speditörsledet att söka högre och jämnare beläggning. Detta leder i sin tur till högre kostnader för varuägare på grund av högre lager eller sämre servicenivå – kostnader som inte alltid kan kompenseras av speditörsledet eller vill betalas av varuägare. T.ex. visar studierna att speditörer som köper intermodal kapacitet oftast måste kontraktera hela tågavgångar under lång tid för att nå låg genomsnittskostnad. För att kunna realisera dessa kostnadsfördelar krävs att speditören har hög och jämn beläggning på avgången vilket nås t.ex. genom kapacitetsreservationer från kunder (varuägare), och/eller samlastning av flera kunder. Båda dessa alternativ ökar varuägarnas lagerkostnader, ibland markant, på ett sätt som många gånger inte kan kompenseras genom lägre pris på transporttjänsten utan att leda till förlust för speditören. Detta innebär att även när problem så som punktlighet, transporttider och osäkerhet i implementeringskostnad är lika mellan alternativen, så finns ett inneboende matchningsproblem på transportmarknaden som hindrar skifte till koleffektiva transporter. Det är därmed svårt att tro att koleffektiva transporter någonsin kommer få en stor marknadsandel med befintlig marknads- och kostnadsstruktur.

Dock betyder det inte att det aldrig är lönsamt att skifta till koleffektiva transporter. Det finns många situationer där det är lönsamt och rationellt för alla parter att genomföra ett skifte – något som illustreras i fallstudierna i den här avhandlingen. För att skapa sådana situationer krävs oftast långsiktiga kontrakt, där den aktör som har bäst marknadsinformation gör ett långsiktigt åtagande som minskar risken för den aktör som gör investeringen. T.ex. kan varuägaren göra en flerårig reservation av intermodal transportkapacitet hos en speditör eller direkt hos en kombioperatör. Modellerna i den här avhandlingen visar hur sådana kontrakt kan designas. Emellertid visar modellerna också att situationerna då det är lönsamt att införa kontrakten är få och väldigt känsliga – små förändringar i marknadssituationen (t.ex. förändrad efterfrågan) eller kostnadsstrukturerna (billigare lastbilstransporter eller högre banavgifter) kan snabbt göra ett skifte olönsamt. Detta kan vara problematiskt för företag som gör investeringar i transportlösningar över flera år, något som några svenska storföretag fått erfara. En annan nackdel är att den totala miljöförbättringen i dessa fall inte alltid är så stor på grund av ökade lager eller expresstransporter med lastbil. Genom att även ta in de ökade lagernivåerna i beräkningen av koldioxidutsläpp ser vi att ett skifte till koleffektiva transporter i extrema fall till och med kan leda till högre totala utsläpp.

Avhandlingens studier visar framförallt en lösning som har potential att undvika matchningsproblemet. Genom att införa riskdelningskontrakt mellan operatörsledet och speditörsledet kan kostnadsstrukturerna hos speditören ändras så att matchningsproblem kan undvikas. D.v.s. genom att ändra speditörsledets kostnadsstruktur på ett sätt som gör det rationellt att inte söka allt för stort utnyttjande så kan kostnadsökningen för varuägare hållas nere, vilket gör det mer lönsamt att skifta. Även ändringar i skatter och avgifter som syftar till att göra vanliga transporter dyrare har undersöks, men visar varierande resultat. Sådana skatter leder inte alltid till mer koleffektiva transporter. Däremot leder de till dyrare transporter vilket i sin tur kan leda till mer lager och större koldioxidutsläpp.

Om koleffektiva transporter ska implementeras i stor skala krävs att kostnadsstrukturer hamnar mer i linje med vanliga transporter och att kontrakt som bättre fördelar risker och vinster kommer till allmän användning. Därmed stimuleras samarbete mellan alla parter för att uppnå bästa samhällsekonomiska effekt. Några olika kontraktsformer analyseras i den här avhandlingen, men för att påverka kostnadsstrukturer krävs styrmedel. För att förstå vilken kombination av styrmedel som skulle få avsedd effekt, och vilken typ av kontrakt som är mest lönsamt i en given situation, krävs mer forskning. Först då kan vi förvänta oss att se minskande koldioxidutsläpp från godstransporter.

Abstract

The transport sector accounts for approximately 20% of EU-27 greenhouse gas (GHG) emissions, and 27% of U.S. GHG emissions. With the Kyoto Protocol, Sweden and several other nations have agreed to reduce these emissions. Such goals are implemented because of the social cost of GHG emissions – by reducing the GHG emissions (and any other externality), the social costs are reduced and social welfare improved. But according to several researchers, environmental improvement projects also improve firm profits. More efficient operations reduce costs, it is claimed, while a "greener" or more sustainable company profile can lead to price premiums as well as more loyal customers.

Consequently, politicians and lobbyist argue that reducing transport emissions by shifting to low-carbon transport solutions leads to a win-win situation, where social welfare as well as firm profits are improved. Often, solutions that involve consolidating freight and moving it to more carbon-efficient transport technologies are advocated as the most advantageous. For such initiatives the technology already exists, so change is only a matter of implementation. Large multi-nationals have also taken a lead in this direction. Firms such as Coop, Volvo, and Walmart have all implemented projects to reduce their transport emissions.

But when aggregate data is examined, these firms seem to be outliers. Freight transport emissions in Europe have increased, the share of rail-bound transports has decreased, and most freight consolidation projects seem to fail. If there is political ambition, economic incentives, and available technology, why then is there almost no shift to low-carbon freight transports?

This thesis explores this question by analyzing how micro-level behavior on the transport market can explain observations in macro-data. More specifically, it investigates what incentives the contracts on the transport market create for a shift to low-carbon freight transport. Formally, the overall purpose of the research in this thesis

is to *increase the understanding of the incentives to shift to low-carbon freight transport.* This is explored in a three-phase research structure where, first, macro-data is analyzed, after which theory is built using two multiple case studies, which serve as input to three mathematical modeling studies of different parts of the operator-service provider/forwarder-shipper chain of actors.

By considering the chain of actors on the freight transport market as a service supply chain, the research in this thesis is able to use methods from, and make contributions to, the sustainable supply chain management literature as well as the literature on transport contracting. With this literature as the point of departure, the studies show that there is a matching problem associated with the implementation of low-carbon transports: with the currently used contracts it is usually not rational for the actors on the market to shift to low-carbon transports, even though the total cost on the market, on aggregate, may be reduced from shifting. It is therefore unlikely that, with current market and cost characteristics, there will be a large-scale shift to low-carbon transports.

Nevertheless, there are situations where shifting is rational for all actors. Creating such situations normally requires implementing long-term contracts, where the actor with the most accurate market information makes a long-term commitment to reduce the risk for the actor making the investment. The models in this thesis show how such contracts can be designed. However, the models also show that situations where implementation is rational are very sensitive to changes in external parameters such as demand volatility, making implementation high risk in many cases. Another downside is that the environmental improvement is not always as large as one would expect due to inventory build-up and extra truck transports. By including also emissions from warehousing and extra transports in the calculations, the models show that a shift may in extreme cases lead to more GHG emissions.

For low-carbon transports to be implemented in large scale, their costs need to be more in line with conventional transports, and contracts that allocate risks and profits better need to be implemented. Several contracts are analyzed in this thesis, but to change costs, regulation is needed. To better understand what combination of regulation that provides the desired effect, more research is needed. The research in the thesis also suggests that more research is needed along four dimensions: other carbon-reducing efforts on the transport market, other possible structures of the transport market, more research about haulers' decision making, and theory testing. Not until these issues are better understood, and contracts and regulation implemented, can a substantial shift to low-carbon transports be expected.

Key words: *low-carbon transport, green logistics, sustainability, operations and the environment, supply chain management, incentive alignment*

Appended Papers

I. Eng-Larsson, F., Lundquist, K-J., Olander, L-O. & Wandel, S. (2012). Explaining the cyclic behavior of freight transport CO_2-emissions in Sweden over time. *Transport Policy,* 23, 79-87.

II. Eng-Larsson, F. & Kohn, C. (2012). Modal shift for greener logistics – the shipper's perspective. *International Journal of Physical Distribution & Logistics Management*, 42(1), 36-59.

III. Eng-Larsson, F. & Norrman, A. (2014). Modal shift for greener logistics – exploring the role of the transport contract. Forthcoming in *International Journal of Physical Distribution & Logistics Management,* 44(10)

IV. Berling, P. & Eng-Larsson, F. (2014). Selling green transports to a retailer – investment, pricing, and contract choice. *Submitted*

V. Berling, P. & Eng-Larsson, F. (2014). Pricing and timing of consolidated deliveries in presence of an express alternative – financial and environmental analysis. *Submitted*

Related Publications

Eng-Larsson, F., & Vega, D. (2011). Green Logistics in Temporary Organizations: A Paradox? Learnings from the Humanitarian Context. *Supply Chain Forum: An International Journal*, 12(2), 128-139.

Eng-Larsson, F. (2012). *Green logistics through modal shift – exploring the role of the transport capacity contract*. Licentiate thesis, Lund University, Sweden

Pålsson, H., Eng-Larsson, F., Abbasi, M., Olander, L-O., Wandel, S., Smidfelt Rosqvist L., Lundquist, K-J., Hiselius, L., Stelling, P. (2013). *Mot koldioxidsnåla godstransporter – tillväxtdynamiskt perspektiv på logistik och godstransporter fram till 2050*. Trafikverket 2013:120, Stockholm, Sweden

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1 Introduction

This research starts with the observation that while there on the surface seems to be incentives to shift to low-carbon freight transports, very little change can be seen in aggregate data. This chapter describes the approach to analyze this seeming paradox; that the incentives to shift may not be as clear cut as expected, or even non-existent, when one starts to investigate the micro-level decisions in more detail. The chapter then presents the purpose, research objectives, and the perspective taken in the thesis. It closes with a description of the disposition of the thesis.

1.1 Background

With the increased interest in sustainability issues and corporate social responsibility, many firms have become dedicated to reduce the greenhouse gas (GHG) emissions from their transport operations. For instance, in a press release from 2011, Volvo wrote the following:

> "Between 2006 and 2010, emissions of carbon dioxide from the Volvo Group's transportation of goods and products in Europe was reduced by 22 percent … cargo space is being used more efficiently, thus enabling the transportation of more goods at the same time … The Volvo Group has also reduced its carbon dioxide emissions in Europe by using more marine and train solutions to supplement truck transportation … [one] example is Viking Rail, a train concept launched by Volvo Logistics in 2008 for cargo between Germany and Sweden …. Our objective is to reduce carbon dioxide emissions from our transportation in Europe by 30 percent by 2015, with 2006 as the base year." (Volvo, 2011)

This is well in line with the current political ambition. The transport sector accounts for approximately 20% of EU-27 GHG emissions (EEA, 2014), and 27% of U.S.

GHG emissions (EPA, 2014). With the Kyoto Protocol, Sweden and several other nations have agreed to reduce these emissions. For the EU, the goal is to reduce GHG-emissions from transports by 60% (EU, 2011). Such goals are implemented because of the social cost of GHG emissions (see e.g. Stern, 2006; Perman et al., 2003; or Baumol and Oates, 1988). The GHG emissions are externalities – by-products from value adding transports – that incur social costs as the planet's climate and people's health are affected. These costs are accounted for by the society rather than the firm that produced or ordered the production of the emissions. By reducing the GHG emissions (and any other externality), the social costs are reduced and welfare improved.

However, private firms like Volvo are usually not managing their operations based on welfare considerations. Instead, environmental improvement projects are generally initiated to improve long-term profit. According to several researchers, environmental improvement projects often lead to both cost reductions and revenue improvements: reduced costs from more efficient operations, and price premiums and more loyal customers due to a "greener" or more sustainable company profile (Plambeck, 2012; Nidomulu, 2009; Berns et al., 2009; Porter and Kramer, 2006; Klassen and McLaughlin, 1996). Large multi-nationals have therefore taken a lead. Volvo is one example. Another example is Walmart. According to The Economist (2009), Walmart is "working to double the fuel efficiency of its truck fleet by 2015, thereby saving more than $200 million a year at the pump", adding that, "it should be clear that there are many ways that firms can actually improve their margins while cutting emissions". In other words, reducing transport emissions leads to a win-win situation, where both social welfare and firm profits are improved.

Politicians and lobbyists often claim the most promising ways to reach such win-win situations involves consolidating freight and moving it to more carbon-efficient transport technologies. For instance, in a well-cited report by World Economic Forum and Accenture (2009) on how to "decarbonize" supply chains, the *introduction and implementation of cleaner vehicles*, the *reduction of the speed of the supply chain* and the *transfer of freight from air and long-haul road freight to ocean, road and rail freight* are all regarded as high potential and/or easily implemented initiatives. Mainly, this is because the technology already exists and change is only a matter of implementation. The European Commission has stated that "efficient co-modality is needed", and has as one of its ten goals for transports to "Optimizing the performance of multimodal logistic chains" (EU, 2011, p. 9). Similarly, shipment consolidation (with or without a modal shift) has been heavily promoted by the EU's Action Plan on Urban Mobility (European Commission, 2012; Allen et al., 2012) as a way to reduce costs and environmental impact in, for instance, urban areas. These are the same strategies seen in the press release by Volvo: "cargo space is being used more efficiently… using more marine and train solutions to supplement truck transportation".

But when aggregate data is examined, firms such as Volvo and Walmart seem to be outliers. Freight transport emissions in Europe were 18% higher in 2011 than in 1990 (Eurostat, 2014). The share of rail-bound transports has decreased by more than 7% over the last ten years (Eurostat, 2014). And out of the 150 urban consolidation projects set up in Europe, only 5 remained after subsidies were withdrawn (SUGAR, 2011). If there is political ambition, economic incentives, and available technology, why then is there almost no shift to low-carbon freight transports?

There may be several explanations as to why this is the case. Technology uncertainty, organizational difficulties, unclear regulation, and general infrastructure deficiencies have been suggested as potential problems obstructing a shift to low-carbon freight transport (e.g. Storhagen et al., 2008; McKinnon, 2003). While these issues, or just the perception of them existing, may create barriers, this thesis argues that even with those problems taken aside, there is yet another fundamental problem that underlies much of the freight transport market, which significantly obstructs a shift to low-carbon freight transports: a matching problem.

In Sweden, as well as in many other countries, a majority of all freight transports are outsourced by shippers to a third party. Transports are then sold and purchased using short term or long term contracts (Mellin and Sorkina, 2013; Jafaar and Rafiq, 2005; Hong et al., 2004). As highlighted by e.g. Huge-Brodin et al. (2013), this may lead to a situation where both sellers and buyers are interested to shift to low-carbon transports but, due to market and contract characteristics, there may be limited possibilities to match these interests through the contractual relation on the market.

If the parties go ahead anyway, the situation is unlikely to survive in the long-run. As an example, in 2012, Lammgård showed that while service providers/forwarders were struggling to run a profitable intermodal truck-train operation, the contracted intermodal train operators showed back-to-back profits, year after year, for the very same operation. Clearly, there was profit in the system. However, the contracts used on the market created a profit allocation that was skewed, which is not feasible in the long-run even for the most environmentally concerned firm. Here, neither technology uncertainty, regulation, nor transport quality was the problem. The problem was purely market-based: the contracts used on the market created barriers. Volvo saw a similar situation, with difficulties running their Viking Rail solution profitably. In fact, despite Volvo's emphasis on GHG reductions, in 2014, the Viking Rail project was discontinued.

To better understand the incentives that create these situations, the contracts that match demand and supply need to be analyzed. From the literature, it is well known that contracts[1] impact the incentives for a firm to behave in a certain way, both directly through changes in cost structures, and indirectly through policy changes in the system[2] in which the contract is implemented (Bolton and Dewartripont, 2005; Narayanan and Raman, 2004; Cachon, 2003). For instance, a new contract may change the purchasing price structure so that larger purchasing quantities are optimal – but if the contract also implies longer lead times, then the inventory policy at the buying firm needs to be changed if service levels are to be kept constant (see e.g. Chopra and Meindl, 2007; Axsäter, 2007). The costs incurred by such changes can make a shift irrational, even when all other aforementioned problems are absent. It may even make a shift irrational even though the shift could, with a less skewed profit allocation, have led to profit improvements for all firms. That is, while it may seem optimal to shift to low-carbon transports when the situation is viewed *von oben*, these "global incentives" may vanish once each firm's individual incentives are investigated in more detail. If there is a desire from society that more firms shift to low-carbon transports, these incentives need to be better understood.

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[1] In line with the convention in the operations management literature (Cachon, 2003), "contract" here refers to the operational details of a formalized transaction between two actors on the market. That is, it does not refer to a physical document with all its levels of detail, nor does it concern any of the legal aspects of a contract. Rather, it refers to, in an abstract sense, some of the key aspects of the interface between a buyer and a seller from an operations perspective, including for instance pricing, order sizes, and delivery frequencies.

[2] A system is "a set of parts coordinated to accomplish a set of goals" (Churchman, 1968 p. 29), and here refers to the logistics system (with its environment) of either an operator, service provider or shipper. See further Section 1.3.

1.2 Purpose and Research Objectives

In the sustainable supply chain management literature (e.g. Seuring, 2013; Tang and Zhou, 2012; Carter and Rogers, 2008), incentives to reduce environmental impact from operations is often discussed. However, these discussions show little or no concern about the fact that transport operations are often outsourced and performed by a third party. In the transport research literature, on the other hand (e.g. Flodén and Woxenius, 2013; Brusset, 2009), this is well understood, and the discussion on how to shift to low-carbon freight transport is often discussed from the "production" perspective of the third party. However, these discussions show little or no explicit concern about how shipper operations will or can be affected by such a shift, and how this affects incentives to shift.

Following the call for research on sustainability aspects of contracting by Seuring (2013) and Tang and Zhou (2012), this thesis aims to fill that void. This is done by empirically and analytically investigate how incentives on the transport market, as dictated by the contracts used to buy and sell transports, impact the shift to low-carbon transport solutions. Formally, the overall purpose of the research in this thesis is therefore to *increase the understanding of the incentives to shift to low-carbon freight transport.* To achieve the overall purpose, the thesis is broken down into three sequential research objectives, as seen in Figure 1.1.

1.2.1 Research objectives

The first objective concerns the greater system in which the transport market exists and operates. As discussed by Pålsson et al. (2013), the firms of the transport market are directly responsible for freight transport emissions, although the degrees of freedom of their decisions are constrained by decisions made in several related systems, collectively referred to by Pålsson et al. as "the large system" (see also Figure 1.2). This includes, for instance, those systems in society that control infrastructure or vehicle technology. This means that any theorizing about the transport market should be aware of this larger system, since it will act as the (possibly changing) environment of the smaller system. Thus, following the advice of researchers advocating a systems approach (Checkland, 1999; Forrester, 1994), the first objective serves to investigate the dynamics of the system where the interesting behavior is observed. The general idea is to get an overview of this system, on aggregate level, that is,

RO1. *To identify how changes on the freight transport market and changes in adjacent systems in society impacts freight transport emissions.*

Having identified the dynamics of the system in which the actors of the transport market operate, the natural next step is to make an effort in understanding the reasons to some of the observed development. In other words, to explain the observations in the macro-level data, we need to better understand micro-level decision-making. While this involves analytical theorization, empirical work is needed to create a conceptual foundation for the theorizing (Landry et al., 1983). The theorization will then build on empirical foundations, as argued to be lacking in the supply chain literature in general (Sodhi and Tang, 2014) and the sustainable supply chain management literature in particular (Seuring, 2013). The second research objective therefore concerns the changes observed at the different actors when shifting to low-carbon transports. In line with the overall purpose of the thesis, the second research objective is formulated as,

RO2. *To explore what operations changes a shift to low-carbon freight transport leads to, and under what circumstances such a shift is made.*

With both a broad understanding of the transport market and its environment (RO1) and a more specific but anecdotal understanding of the firms' observed changes (RO2), the final objective is to generate a more general understanding about the incentives to shift by theorizing based on the results and conjectures from the previous studies. Note that a single general model incorporating all aspects from the previous studies is not the main objective. Rather, the objective is to analyze a few major mechanisms by modelling three different contracting situations, based on previously observed system characteristics and contracts. The aim is to show how these contracts can be designed, as well as to understand what effects the implementation of these contracts have on profits and emissions. In that, the research indicates when there are incentives to shift under such contracts. Thus, this part of the research in particular aims to fill the call by

Seuring (2013) and Tang and Zhou (2012) on how contracting and procurement affect environmental output. The third research objective is

RO3. *To explain and predict under what circumstances, and to what extent, there are incentives for the actors on the freight transport market to shift freight to low-carbon transports.*

1.2.2 Addressing the research objectives in five papers

The three research objectives were addressed in five separate but connected studies (the licentiate, Eng-Larsson, 2012, is one mixed-method study), as seen in Figure 1.1. Each objective has a slightly different angle, which creates three distinct phases. The first phase, the *identify* phase, is the system overview, which explores the historical change in factors that impact the carbon content of freight transport. The *explore* phase seeks empirical insights about incentives to shift through multiple-case studies of firms on the transport market. Finally, the *explain and predict* phase uses mathematical modeling techniques to consolidate the findings from the previous phases and reach theoretical insights about the incentives to shift.

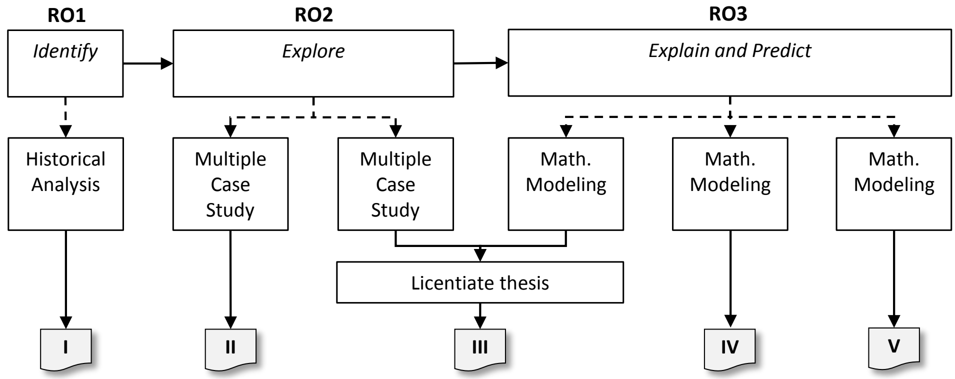

Figure 1.1. Outline of the research structure, the studies, and the five papers (I-V) in which the research is reported.

As seen in Figure 1.1 and Table 1.1, the research output from the five studies is reported in five academic papers, all appended to this thesis[3]:

I. Eng-Larsson, F., Lundquist, K-J., Olander, L-O. & Wandel, S. (2012). Explaining the cyclic behavior of freight transport CO_2-emissions in Sweden over time. *Transport Policy,* 23, 79-87.

II. Eng-Larsson, F. & Kohn, C. (2012). Modal shift for greener logistics – the shipper's perspective. *International Journal of Physical Distribution & Logistics Management*, 42(1), 36-59.

III. Eng-Larsson, F. & Norrman, A. (2014). Modal shift for greener logistics – exploring the role of the transport contract. Forthcoming in *International Journal of Physical Distribution & Logistics Management,* 44(10)

IV. Berling, P. & Eng-Larsson, F. (2014). Selling green transports to a retailer – investment, pricing, and contract choice. *Submitted*

V. Berling, P. & Eng-Larsson, F. (2014). Pricing and timing of consolidated deliveries in presence of an express alternative – financial and environmental analysis. *Submitted*

The first paper reports the system overview study, which is a quantitative (empirical) analysis of how different macro-economic factors and firm-level greening measures have impacted the development of freight transport CO_2-emissions in Sweden from 1990 to 2008.

Papers II and III present case studies of shippers and logistics service providers, respectively. For practical reasons, the investigation is limited to intermodal transports. Paper II presents a multiple case study of six shippers of different sizes that have successfully shifted to intermodal road-rail transports. Paper III focuses on the next upstream tier, and presents two cases of service providers that have contracted capacity from intermodal operators.

[3] In all papers, I have been involved in all stages of the research. For Paper I, the research idea was a joint effort of all authors as part of the LETS2050 research project (see further http://www.lets2050.se). In working with the paper, I was responsible for creating and executing the analysis and writing the technical parts of the paper (including the introduction). For the second paper, I was the main author. The third paper is based on the licentiate thesis, for which I was the sole author, and in writing the paper I was the main author. Papers IV and V are joint efforts where both authors were equally involved in all phases of the research as well as in the writing of the papers; names are in alphabetic order.

The findings from these studies are then used as inspiration for the last phase reported in Papers III, IV, and V. Paper III models the operator-service provider (forwarder) contract, and analyzes what incentives these contracts create for a shift to intermodal road-rail transport. Paper IV and V model the service provider-shipper contract, but from slightly different perspectives: Paper IV analyzes situations where one large shipper initiates the low-carbon transport service by making a long-term capacity reservation; Paper V analyzes situations where several small shippers are consolidated on the same low-carbon transport solution. Whereas Paper III concerns only intermodal solutions, the last two papers are slightly more general, and concern any type of low-carbon transport solution (hybrid vehicles, biogas vehicles, intermodal solutions, etc.) that incurs a larger upfront investment cost and/or semi-fixed departure cost but has lower operating costs than "normal" truck transports, that is, any low-carbon transport solution that exhibit similar basic characteristics as intermodal transports.

Table 1.1. The papers' positions relative the operator-service provider-shipper chain of actors on the transport market

Operator	Service Provider	Shipper	
Paper I			**RO1: Identify**
Paper III		Paper II	**RO2: Explore**
Paper III		Paper IV Paper V	**RO3: Explain and Predict**

1.3 System, Perspective and Scope

The thesis will apply a *systems perspective*, where the different actors on the market are seen as subsystems of the same (abstract) larger system. To apply the supply chain literature to this system, the system is abstracted as a transport *service* supply chain. Hence, the transport market is seen as a supply chain in which the final transport service is built up through a number of subsequent tiers that buy and sell "components" of the service between one another. Figure 1.2 depicts the overall system for this thesis, and can be seen as an adaptation of the conceptualization by Manheim (1984) as further developed by Wandel and Ruijgrok (1993), Lumsden (2007) and Pålsson et al. (2013).

Although this perspective arguably neglects much of the complexities of the market[4], it serves its purpose here in highlighting the major actors of the market and the trade that they engage in, which is the focus of this thesis (for slightly different conceptualizations, see Martinsen, 2011; Naula and Ojala, 2002; Sheffi, 1986; for a thorough description of the Swedish intermodal market see Flodén and Woxenius, 2013).

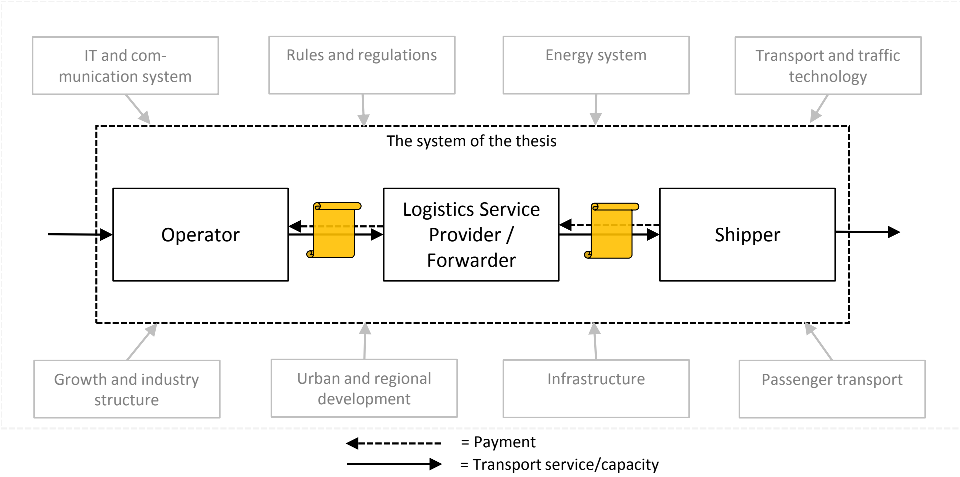

Figure 1.2. The overall system of the thesis. The contracts regulate transport capacity and payments between operators and service providers, as well as transport service and payments between service providers and shippers. The transport market is surrounded and affected by subsystems in the "large system" through, e.g., regulation. Compare to Pålsson et al. (2013)

As seen in Figure 1.2, the overall system consist of three main actors, or roles[5]: *operators*, *logistics service providers/forwarders*, and *shippers*. Each of these actors manage their own

[4] A rather stylized representation is chosen for tractability and generalizability. Obviously, the structure is more complicated in reality and heavily context dependent. For instance, as highlighted by Flodén and Woxenius (2013) and Sternberg et al. (2013) in Sweden and most of Europe there are often several stages of outsourcing (e.g. an LSP may use a truck carrier that subcontracts a carrier that subcontracts a train operator). Further, big firms like Coop may act like a forwarder and contract directly with an operator (own account). Also note that infrastructure operators are outside the scope of this thesis.

[5] Note that a *firm* can, and often does, comprise several of these roles, if not all. For instance, large logistics companies (e.g. Schenker) sometimes have a forwarder role as well as an operator role, which may blur the distinctions slightly. Large industrial companies or retailers may skip the intermediary or even have all roles in-house

subsystems using different types of resources to satisfy the demand from the downstream actor, with the degrees of freedom constrained by decisions in "the large system". The *shipper* is the buyer and the end user of the freight transport. It is within the shipper's logistics system that the demand for transportation arises. The shipper's demand for transport services is normally met by a *forwarder* or *logistics service provider*. The service provider satisfies one or several shippers' demands for transportation by consolidating their demands on transport capacity from road vehicles, trains, ships, or airplanes. In this thesis, however, we focus on road and rail transport. The service provider normally does not own or operate (much of) this capacity, but rather plans the transports by managing a transport flow, or a firm-level transport system. The transport resources (e.g. vehicles) are normally owned and operated by an *operator*. On the trucking market, this segment is highly fragmented. This thesis focuses on Sweden and Europe where, in most countries (though this differs between countries), the market consist mostly of small haulers or carriers, many times consisting only of a driver and a truck (Trafa, 2014). Rail operators tend to be few and relatively large.

The overall system of the thesis include all these actors and all transactions between them involving freight transports, whether made on long-term contracts or through a spot-market. As will be seen in coming sections, however, this thesis makes a distinction between operator-service provider transactions and service provider-shipper transactions, since these normally comprise different types of *contracts*, making the distinction crucial for the topic of this thesis.

The service supply chain perspective implies that the "transport market" is a geographically constrained segment of the total market. The focus is on a specific lane between two regions. This is the same perspective as in de Vany and Saving (1977), and is a plausible perspective since it is the type of supply market the final customer is facing when purchasing transports between facilities. Transport planning in its geographical sense is thus exogenous to the studies in this thesis, but is reflected in the cost structures of the firms of the market. This perspective also captures the observation that for low-carbon transports with special infrastructural needs, e.g. trains or biodiesel trucks, there are large barriers of entry to compete between two specific regions, whereas there are low barriers of entry for normal trucking services. This means that those offering low-carbon transports often enjoy a technology monopoly, but face competition from other technologies that caps what price they can offer.

The perspective also has an implication when analyzing the costs that arise on the operating level. Among operators, there are several types of costs. Fixed costs exist on both firm level and vehicle level (e.g. depreciation), semi-fixed costs exist for each departure (e.g. slot-fees, road tolls), and variable costs are driven by time (e.g. driver cost), distance (e.g. fuel) as well as volume (e.g. handling) (Akeriekonomi, 2014). However, since we consider a geographically constrained segment, distance variable and time variable costs become variable only per shipment. That is, the variable transportation costs will only vary in the amount of shipments between the regions since distance and transport time is considered fixed. How these costs are transferred downstream will depend on the contracts used in the downstream relations. This is further explained in the appended papers.

In that, the overall system of this thesis is a geographically constrained transport market, similar to the systems in e.g. Lundin (2011), Agrell and Lundin (2011), Brusset and Temme (2005), and Berglund et al. (1999). In each paper, a different subsystem within this overall system is addressed.

1.4 Structure of Thesis

The thesis is structured in the following way. In the next chapter, related literature is reviewed, with emphasis on sustainability in supply chains, and transport contracting. This is followed by a description of the research methodology underlying the studies in the thesis, including a brief discussion about the epistemological perspective (Chapter 3).

Chapter 4 presents summaries of the five papers that are appended to the thesis. The summaries highlights the objective of each paper and its main findings, and discusses briefly how each paper connects to the three objectives. This is followed by a synthesizing discussion in Chapter 5, where the findings from the papers are consolidated to form a tentative theory about why there is virtually no shift to low-carbon transports, despite the often highlighted political ambition and economic incentives. After this, the thesis concludes and discusses theoretical contributions and managerial insights as well as indicating some directions for future research (Chapter 6).

All papers are found in the appendix.

2 Frame of Reference

As stated in the introduction, the overall purpose of this thesis is to increase the understanding of the incentives to shift to low-carbon freight transport. To achieve this purpose, literature on two major topics will be discussed: literature on sustainability in supply chains and literature on transport contracting. The review aims to provide an overview of the research areas from which the research departs and, in particular, the research areas to which it contributes. The chapter closes with explicitly highlighting the most relevant research for the coming sections.

2.1 A Note on Literature Classification

Since all researchers have their individual way of thinking about research and classifying it, this initial section will just briefly explain the broad perspective taken in this thesis on the types of research found in supply chain management and and related fields.

Throughout this chapter, literature will be referred to along two dimensions, each dimension having two possible outcomes. First, literature will be said to be either qualitative or quantitative. Second, literature will be said to be either empirical or theoretical. For instance, a paper using mathematical models to describe and analyze a situation would be classified as quantitative theoretical, while a traditional case study would be classified as qualitative empirical. While I believe this to be an exhaustive representation, it is not mutually exclusive. A single paper may very well fall into more than one of the four categories, for instance because of the use of several methods. However, this classification will not, to any larger degree, be used explicitly. Rather, it will be reflected in word-use throughout the chapter.

2.2 Sustainability in Supply Chains

Already in 1987, Brundtland et al. (1987) defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Since then, the concept has become much discussed and integrated into the research in many different fields. The supply chain/operations management field is no exception. As witnessed by recent reviews by Seuring (2013), Tang and Zhou (2012), Carter and Easton (2011), Seuring and Muller (2008), Srivastava (2007), and Corbett and Klassen (2006), research on sustainability has exploded in the last years in the supply chain community. According to Srivastava (2007), this reflects the issue's relevance in the corporate community:

> "In early environmental management frameworks, operating managers were involved only at arm's length. Separate organizational units had responsibility for ensuring environmental excellence in product development, process design, operations, logistics, marketing, regulatory compliance and waste management. Today, this has changed."

A similar formulation is found in Carter and Easton (2011, p. 59):

> "The broad concept of sustainability, and the key interfaces that sustainability has with supply chain management, strongly suggests that sustainability is … license to do business in the twenty-first century. And supply chain management is an integral component of this license."

As can be seen in the aforementioned reviews, the research on the topic now covers operational details as well as long-term corporate strategies, with empirical as well as theoretical perspectives, quantitative as well as qualitative. In the following I make a brief review of this literature, to provide reference points for some of the coming discussions as well as to position the research of this thesis to previous research. I reiterate that the idea is to give a broad overview – for more detailed reviews on each of the research objectives, the reader is referred to the respective set of papers. Also, note that although sustainability is often broadly defined as incorporating concerns regarding profits as well as social and environmental issues (see e.g. Elkington, 2004), the last years' research, as seen in the reviews, has primarily focused on the *environmental* aspect, particularly on greenhouse gas emissions (Seuring, 2013; Carter and Easton, 2011). Consequently, this is also the focus of this thesis and most of the presented research below.

2.2.1 Sustainable Supply Chain Management

On the most general level, several researchers have tried to pinpoint what sustainable supply chain management entails (Seuring, 2011; Pagell and Wu, 2009; Carter and Rogers, 2008). Carter and Rogers (2008) use a conceptual theory building approach to synthesize the literature on sustainable SCM at that point in time, and devise a framework to guide future research. Pagell and Wu (2009) investigate leaders in sustainable SCM to build a theory about what elements are necessary to create a sustainable supply chain. Seuring (2011) reviews previous theory building research, as well as empirical research, and uses Wacker's (1998) ideas to construct a qualitative theory about what constitutes sustainable supply chain management. This leads to a number of hypotheses.

Other researchers use past evidence in a more normative way, to argue for the incentives to implement sustainability measures. The logic behind these arguments is usually that more efficient operations reduce costs while, at the same time, a "greener" or more sustainable profile can lead to price premiums as well as more loyal customers and, in the long-run, a more innovative firm. According to Nidumolu at al. (2009, p.1):

> "Sustainability isn't the burden on bottom lines that many executives believe it to be. In fact, becoming environment-friendly can lower your costs and increase your revenues". (Nidumolu et al., 2009, p. 1)

Other researchers provide similar arguments. According to Plambeck (2012), firms can both reduce costs and increase revenues by implementing sustainability measures targeting their supply chain operations. She provides examples from both a large corporation and a small start-up, to argue for her case. Corbett and Klassen (2006) claim that "lean is green", implying that sustainability measures that lead to more efficient operations reduce costs. Berns et al. (2009) show that apart from cost savings, sustainability projects may also lead to improved brand name and competitive advantage.

While much of these claims are based on anecdotal evidence, empirical studies seem to verify their claims. For instance, using archival data of firms' environmental and financial performance, Klassen and McLaughlin (1996) find significant positive returns for strong environmental management (indicated by environmental performance awards), and significant negative returns for weak environmental management (as indicated by environmental problems). Konar and Cohen (2001) investigate the issue further, by analyzing the environmental and financial performance of S&P 500 firms. They find that bad environmental management has been negatively correlated with firm value. They also find that the positive impact on firm value is smaller for firms in traditionally polluting industries.

From a number of papers, it is however clear that determining the expected effects of implementing sustainability measures is difficult, as the effects are often systemic in nature. For instance, Cachon (2011) shows that relocating retailers to minimize inbound transport emissions reduces the environmental impact from freight transport, but increases environmental impact from passenger transports to the retailers. Pazirandeh (2012) shows that a relocation of manufacturing may impact both transport and production emissions, but also passenger transport emissions during a transient phase when the new facility is ramping up.

It is therefore important not to jump to conclusions – the environmental impact of a supply chain should be studied as holistically as possible (McKinnon, 2003). There is a growing body of literature on this topic, as the operations management[6] (OM) community is becoming increasingly interested in environmental aspects. As shown in a recent review by Tang and Zhou (2012), research now covers more or less all domains of OM, from strategic issues such as supply chain design to more operational issues such as inventory control. One way to discuss the different research streams, and their interrelation, is by using the framework provided by Aronsson and Huge-Brodin (2006), which is an extension to a hierarchy framework by McKinnon (2003). In the framework, decisions are separated into four hierarchies based on decision scope and horizon:

- Product design
- Strategic decisions
- Tactical decisions
- Operational decisions

[6] Note that I consider the supply chain manamgenet literature a subset of the operations management literature.

Aronsson and Huge-Brodin (2006) stress the hierarchical relationship of the decisions: according to the authors, a decision further up in the hierarchy sets the boundaries and create opportunities for decisions further down the hierarchy. For instance, no matter how optimally planned a delivery route may be (operational decision), it must be re-optimized if the spatial relations are rearranged (strategic decision). This means that one must consider how decisions further up the hierarchy may affect those in the lower levels and vice versa when evaluating potential ways to reduce emissions.

Tang and Zhou (2012) show that there is plenty of research for each level of the hierarchy, classifying research as analyzing either *product design*, *technology selection*, *strategic issues in remanufacturing*, *supply chain design*, *supply chain operations (manufacturing, inventory control, logistics and distribution)*, and *reverse supply chain operations*. While all of these are of (indirect) interest to this thesis, technology selection and supply chain operations are directly related to the work, which is why I will focus on these issues in more detail in the following. A well-cited list of possible supply chain decarbonization measures is provided by World Economic Forum and Accenture (2009). In Table 2.1, this list is sorted according to the decision hierarchy of Aronsson and Huge-Brodin (2006) and to which literature stream it belongs, using the classification given by Tang and Zhou (2012).

2.2.2 Technology selection

While there is a large stream of literature on strategies for replacing, investing and divesting in production capacity (see e.g. Rajagopalan, 1998, and references therein), there is less research discussing the environmental implications of the technology choice, or the optimal choice given environmental concern at the implementing firm. Stuart et al. (1999) is perhaps the first example. The authors consider the problem of how to select product and processes when taking into account several types of environmental considerations. They develop a mixed-integer programming model to solve the problem, taking into account the potential trade-offs between environmental considerations and yield, as well as reliability. In Drake et al. (2010), a somewhat similar problem is considered, as they investigate how cap-and-trade and carbon tax regulation affect a firm's technology choice. They show that expected profits are higher and emissions are less under a cap-and-trade type of regulation, but that the expected production is larger under carbon taxes.

Table 2.1. Decarbonization measures, with corresponding research streams and supply chain decision levels

Supply chain decision level (Aronsson and Huge-Brodin, 2006)	OM research stream (Tang and Zhou, 2012)	Decarbonization measures (World Economic Forum and Accenture, 2009)
Product design	Product design	Reduce weight and volume of packaging
Strategic decisions	Supply chain design	Optimize the location of agriculture
		Improve network planning through transformation projects
		Optimize manufacturing location
	Technology selection	Introduce clean and environmentally efficient technologies
Tactical decisions		Transfer freight from air and long-haul road freight to ocean, road and rail freight
		Rely on alternate transport services to deliver goods home
	Supply chain operations	Decrease transport speed and increase load fill
		Provide training to road transport contractors and building operators
		Introduce traffic management techniques
Operational decisions		Minimize emissions from operating activities
	Reverse supply chain operations	Improve percentage of total supply chain waste which is recycled

There is also research that more explicitly investigate the choice of different *transport* technologies. From a supply chain perspective, this has been analyzed by e.g. Hoen et al. (2010), who investigate how mode choice is made in a supply chain under different levels of carbon regulation. They find that even though a shift can reduce emissions significantly, it is heavily dependent on regulation. Another example is Kleindorfer et al. (2012), who consider a post service's fleet renewal problem when choosing between electric and conventional distribution vehicles. They develop a model to determine the optimal investment strategy over a 15 year horizon. A similar problem is studied by Wang et al. (2013), who develop a dynamic model to find the optimal balance between investments in two different modes of transport, with different scale economies, over time. Using data from Coca-Cola, they show that the investment in the environmentally preferable alternative should increase over time.

The transport technology selection is also addressed in the mode choice literature. Often, especially in transport policy documents from the EU, a modal shift equals a shift from truck to intermodal train-truck transport. And as is often the case when there is political interest in an issue, there is a wealth of research on the topic as witness in the review by Bontekoning et al., 2004. This research can be said to focus on three different types of actors (Storhagen et al., 2008): customers, producers, and society. The research that focus on customers, that is, the shippers, predominantly focus on understanding the mode choice decision (e.g. Macharis et al., 2012; Woodburn, 2003). The research on transport producers – the majority according Bontekoning et al. (2004) – predominantly focus on finding more efficient ways to produce and sell intermodal transport services (Puettman and Stadtler, 2010; Andersen et al., 2009). Lastly, research that focus on society has more of a policy perspective, investigating for instance how effective different policy measures are in ensuring a transfer of freight from truck to intermodal truck-train transport (e.g. Tsamboulas, 2007; Blauwens et al., 2006).

2.2.3 Sustainable operations

When Tang and Zhou (2012) discuss sustainable operations, they mention three types of operations: manufacturing, inventory control, and logistics and distribution. Although there has been much research on environmental issues in manufacturing (e.g.

Gong and Zhou, 2010), this is mainly outside the scope of this thesis. Instead, out of the three types of operations, focus is rather on inventory control and logistics and distribution – in particular the interrelation between the two. Note that in this literature there is bound to be some overlap with the technology selection literature. Hoen et al. (2010) is a good example, as they investigate the technology shift from an operations perspective, investigating its effect on inventory policies.

In the supply chain literature, several papers have investigated shipment consolidation strategies in two-stage supply chains with one central warehouse and several retailers. It is often assumed that there is one central decision-maker that can decide on shipment and inventory policies. Under such assumptions, there are usually both financial and environmental benefits from consolidation, and focus is rather on developing optimal policies for the shipment dispatch and inventory holding. In this vein of research, quantity-based consolidation has been analyzed by Cheung and Lee (2002) and Kiesmüller and de Kok (2005), while time-based shipment consolidation is considered in Marklund (2011), and Howard and Marklund (2011). A related stream of literature that does analyze shipment consolidation from a *decentralized* perspective is the literature on the problem of joint replenishment (in the sense that transportation and inventory decisions are made by different parties). Dror and Hartman (2007) use cooperative game theory to investigate fair allocation of costs among a number of firms that share ordering costs. While they show how such an allocation can be constructed to avoid free-riding, they assume that the transport buyers administer this themselves. This would in practice result in a lot of extra work that most firms are unlikely to be willing to perform, especially those who have outsourced their transports to a third-party. Therefore, in this thesis, when I discuss consolidation I will assume that this is administered by a service provider, although groups of firms may ask for collective quotations and then share costs. Since I am interested in how the contract affects incentives to change, this last redistribution of wealth falls outside of the analysis.

There is also a stream of research in the transportation research field, focusing on freight transport operations without involving inventory concerns (e.g. Arvidsson, 2013; McKinnon, 2007; Aronsson and Huge-Brodin, 2006; Woxenius, 2005). While this stream also exhibits some overlap with the technology selection literature, it tends to be less general in terms of technology and focus more on the context specific problems of the operation or implementation of transport technology. With this perspective, the systemic effects generally come from the planning and control of the transport or logistics system. For instance, while it is generally argued that slow transports over short distances with high vehicle load factors is the best environmental option (McKinnon, 2007; Aronsson and Huge-Brodin, 2006), Arvidsson (2013) show how maximizing vehicle load factors may lead to more emissions depending on the routing of the vehicle. To understand such systemic effects, Woxenius (2005), provide a conceptual model similar to decomposition models from transport economics (e.g. Kveiborg and Fosgerau, 2007). With his model, the main factors behind growth in transport-related CO_2-emissions are given as:

- Output – economic output of nation or firm
- Tonkm/Output – transport intensity
- Vehiclekm/Tonkm – traffic intensity
- CO2/Vehiclekm – emissions factor

For every ratio, there are a number of potential decisions that affects it. By targeting a ratio through a certain decision, the impact of different measures to reduce emissions can be assessed. The observation by Arvidsson (2013) is then explained by the fact that while traffic intensity is minimized, the emissions factor increases. Another example is given by Kohn and Huge Brodin (2008). In their paper, the authors show that, contrary to popular belief, the centralization of a warehouse in a distribution system can reduce total supply chain CO_2-emissions. This can be explained by decomposing the different effects: While centralization tend to increase transport intensity, the larger intensity can make a shift to less polluting transport solutions financially attractive, which will reduce both traffic intensity and the emissions factor.

2.3 Transport Contracting

In any supply chain or logistics system, the major source of environmental impact is the transport activities performed within the system (Wu and Dunn, 1995). According to Wu and Dunn (1995)

> "Transport is the single largest source of environmental hazard in the logistics system…Transport is a prime consumer of fossil fuels such as oil and natural gas, and

> vehicles generate noise and emit many toxic chemicals. Transport requires an infrastructure of roads, airports, harbors, rail right of ways and fills up and often pollutes landfills with dismantled vehicles, parts, and toxic substances. Efficient use of transport can help alleviate these problems and protect the environment" (Wu and Dunn, 1995 p.32)

With the increased interest in environmental issues as reported in the previous section (see e.g. Srivastava, 2007), the environmental impact from transportation has come under scrutiny by both politicians and researchers. In previous research, most researchers view the transport system from a global perspective with a central decision maker, be it either a single firm's transports (see e.g. Cetinkaya and Lee, 2000) or a nation's (see e.g. Kveiborg and Fosgerau, 2007). However, as seen in previous chapters, transport operations are often outsourced to third party providers (see e.g. Mellin and Sorkina, 2013), meaning that any real change to low-carbon freight transport will only come about if there are incentives to change for all actors involved in the change.

Within economics and management sciences (including operations and supply chain management) there is a large body of research investigating contracting or agency relationships. Contract Theory (Bolton and Dewartripont, 2005), Agency Theory (Eisenhardt, 1989a), and the Theory of Incentives (Laffont and Martimort, 2009) are all theoretical platforms used to describe, explain, and predict behavior in situations where a principal is interested in having an agent act on behalf of the principal. The problem is that the agent often has reasons to act in her own self-interest, that is, she has incentives to maximize her own utility or payoff, which may not be the best action for the principal. Such situations arise in many situations, for instance, among employer (principal) and employees (agent), voters (principals) and politicians (agents), or, as we will see in the next session, among a firm (principal) and his supplier or service provider (agent). In the following, I will therefore give a brief review of this literature, with emphasis on the supply chain and operations literature on the topic.

2.3.1 Supply chain contracting

In many definitions of supply chain management, *coordination* is stressed (Fugate et al., 2006). When a supply chain is coordinated, the decentralized decisions made by the agents of the supply chain are those that maximize profitability for the supply chain as a whole (e.g. Cachon, 2003; Lee and Whang, 1999). Due to the central role of coordination in supply chain research, the topic has seen vast amounts of research from both empirical, often qualitative perspectives, and from a theoretical perspective, borrowing from and contributing to contract theory (e.g. Bolton and Dewartripont, 2005). However, compared to the economics literature, contracts are studied with a slightly different approach in the operations and supply chain literature (Hezarkhani and Kubiak, 2010). According to Tsay et al., (1999):

> "What distinguishes SCM contract analysis may be its focus on operational details, requiring more explicit modeling of materials flows and complicating factors such as uncertainty in the supply or demand of products, forecasting, and the possibility of revising those forecasts, constrained production capacity, and penalties for overtime and expediting." (Tsay et al., 1999)

In the qualitative, often empirical, research stream on the topic, the research is normally focused on *incentive alignment* (see e.g. Naryanan and Raman, 2004) or *risk and gain sharing* (see e.g. Norrman, 2008; Simatupang and Sridharan, 2005). That is, the research focuses more on the process that lead to supply chain coordination. In this research, it is said that *misalignment* occurs when the supply chain players' decisions are based on local rewards and penalties, which are usually different from the overall supply chain's (Simatupang and Sridharan, 2002). According to Naryaman and Raman (2004), misalignment occurs due to hidden actions, hidden information, and badly designed incentives. The preferred solution, they argue, it to redesign contracts to align the incentives. But although examples of coordinating contracts used in practice have been reported, they are rare. One example is provided by Dana and Spier (2001) and later Cachon and Lariviere (2005), who describe the revenue-sharing contracts used in the video-rentals industry in the U.S; another example is Norrman (2008), who presents two cases of volume-commitment contracts. According to Fugate et al. (2006), practitioners prefer flow coordination such as VMI to price coordination or non-price contractual coordination such as quantity flexibility.

Consequently, most research on supply chain contracts is theoretical, as reviewed by Hezarkhani and Kubiak (2010), Cachon (2003), and Tsay et al. (1999). In general, the research focus either on investigating when and how contracts used in practice can lead to coordination, or on theoretically deriving contracts that lead to coordination in certain situations. The first type of contracts are sometimes referred to as *specific* contracts, whereas the second stream is referred to as *general contracts* (Leng and Zhu, 2009). While this *positive* versus *normative* approach to studying supply chain contracts is one of the key dimensions in which the research differs, there are several other key differences, often due to slightly different assumptions owing to the motivating observation. Based on the aforementioned reviews, a compilation of such assumptions and other difference-dimensions are given in Table 2.2. Note that this is not an exhaustive list. Depending on the context in which a contract is studied, there may be other, specific dimensions that are less general (e.g. innovation or product differentiation).

In the operations and supply chain management literature, there is also much research on contracts in other setting than "traditional" supply chains. For instance, Aksin et al. (2008) investigate the contract design when subcontracting call center operations from a service provider to an operator. As it turns out, this setting share several similarities with the situation studied in Paper IV, since in both situations it is of importance to consider the potential difference in demand during different days, calling for multi-period models of the contracting horizon. Other service related contract studies in the same spirit include Roels et al.'s (2010) study of collaborative service contracts, Hubler and Spinler's (2012) study of service repair contracts, and Cachon and Feldman's (2011) study on service subscription contracts.

2.3.2 Third party logistics contracting

There is also research that focus more specifically on the logistics and transport market. The qualitative empirical research often focuses on the complex bundled services offered by third-party logistics providers, which include transportation. Much of this literature is reviewed in Selviaridis and Spring (2007). The general conclusion from this research is that environmental concern is rarely made when purchasing these services. The major decision variable is price, and this seems to be the case also for transport services (Martinsen and Bjorklund, 2012; Wolf and Suering, 2010). Nevertheless, the way the price is quoted, that is, the form of the contract, may differ. Mellin and Sorkina (2013) show that dedicated and open-book-contracts, in which the vehicle is dedicated to the buyer who pays according to a cost-plus arrangement, are the most commonly used contract form on the Swedish transport market. They also show that the contract length is usually 1-2 years.

Table 2.2. Key dimensions, and possible choices for each dimension, in supply chain contract modeling (based on Hezarkhani and Kubiak, 2010; Koole, 2010; Cachon, 2003; Tsay et al., 1999)

Dimension	Aspect	Possible choices	Explanation
Endo-geniety	Type of contract	General contract	Contracts based on general rules to optimize welfare
		Specific contract	Contracts based on specific rules based on observation
Player preferences	Rationality	Economically rational	Players maximize expected profit
		Other preferences	Players make decisions with biases due to experience, inertia to change, limited computational possibilities, sense of fairness
	Risk aversion	Risk neutral	All players maximize expected profit
		Risk avert	Certain profit is preferred to uncertain profit
Game character-istics	Compliance regime	Voluntary compliance	The agent can deviate from contract to maximize profit
		Forced compliance	The agent cannot deviate from contract
	Information symmetry	Full information	All costs, parameters, and rules are known by all players
		Private information exist	Some information is only known by a subset of players
	Decision sequence	One-shot	All players make decisions simultaneously
		Sequential	Players make decisions sequentially
	Length of contract	Single period	One demand period (season) is considered
		Multiple periods	Several demand periods are considered
	Demand process	Deterministic	Demand is known
		Stochastic	Demand is uncertain
Market structure	Number of sellers	One	Only one seller
		Many	Several sellers on the market
	Number of buyers	One	Only one buyer
		Many	Several buyers on the market

The theoretical transport contracting literature, differs from the contract theory literature in that it tends to focus on determining the optimal policy *for a buyer,* rather than on contracting dynamics. For instance, Ball et al. (1983) analyze a buyer's optimal balance between in-house and outsourced transport services, using network flow models. In more recent work, Henig et al. (1997) consider a multi-period problem where, in each period, a buyer has to balance reserved (transport) capacity with (transport) capacity from the spot-market to replenish a storable good, and define the optimal inventory policy. Alp et al. (2003) combine vehicle dispatching, inventory control, and contract design literature to create a carrier contract model, and provide a heuristic for finding the shipper's optimal contract. Lundin and Hedberg (2012) also discuss the shipper's contract selection among four contract types: dedicated service, periodical service, truckload service, and less-than-truckload service. Using data from a grocery retailer in Sweden they show that a shift to LTL-contracts, in which the shipper only pays for truck space between origin and destination, can reduce shipper costs by 10%.

In another stream of research, more closely related to contract theory, Brusset and Temme (2005) investigate transport contracting between a shipper and a carrier. They present a one-period model where the shipper can purchase transport service through a reservation (long-term contract) or through a spot-market (short-term contract). They determine optimal policies for the carrier and the shipper, and show how the addition of a long-term contracting option outperforms pure spot-market purchases under information asymmetry. In a multi-period extension, Brusset (2009) analyzes the optimal contract choice for the players, and find that longer contracting periods favor quantity flexibility contracts over spot market purchases or minimum purchases commitments. However neither of these studies take inventory effects at the buyer into account. This is the case in Serel et al. (2001), who build on Henig et al. (1997), by constructing a contracting model where the buyer behaves as in Henig et al.'s model. Based on this, they determine and evaluate the optimal pricing policy for the seller numerically under the assumption of linear production cost and lost sales. They further analyze the optimal pricing policy given that the buyer uses a standard base-stock policy.

2.3.3 The trucking market

While some of the above literature considers trucking services explicitly (e.g. Brusset, 2009), there is another stream of research adopting a more *von oben* perspective on the contracting of services on the transport market. This view is predominantly present in the economics literature (but also within operations management), and examine market characteristics and cost structures.

de Vany and Saving (1977) use a stochastic model, incorporating demand and supply uncertainty, to analyze the pricing patterns of the trucking market. In their model different long-haul legs are seen as different products that can be produced using the same capacity. They show that the even if carriers on a competitive trucking market are price-takers, the same transport service is sold at different prices because shippers pay to avoid congestion. Boyer (1980) argued that the model did not properly match reality and that the predicted changes in prices were several order of magnitudes less than empirically observed. In a response, de Vany and Saving (1980), make an additional extension and show that their model does provide insight to the pricing mechanisms of a competitive trucking market.

In more recent work, Hubbard (2001) uses empirical data from the trucking market in the US to test the prediction from transaction cost theory that when markets are thinner, firms rely more on long-term contracts with their service providers. He finds a strong connection for the claim for long-haul transports. That is, that for long-haul transports, spot-market purchases are more common when there is a large selection of service providers and operators. Agrell and Lundin (2011) builds on this by considering the governance of the trucking market. They show that a market with only carrier cooperatives, in equilibrium, offer more trucking services at lower prices (i.e provide "thicker" markets) than markets with investor-owned forwarders. In a related paper, Sternberg et al. (2014) provide a more detailed picture of the complexities of the governance of the many actors of the trucking market. Flodén and Woxenius (2013) describes these forces in action, as they investigate the interaction between road and intermodal road-rail transport when CargoNet, a large Nordic intermodal operator, decided to exit the Swedish market.

Interestingly, the more macroeconomic transport research display some overlap with the heterodox economic research based on growth cycle theory (e.g. Lundquist and

Olander, 2010; Lipsey et al, 2005; Schon, 2000; Breshnahan and Trajtenberg, 1995). The growth cycle theory is based on Schumpeter's observation that there are cyclic patterns in economic growth, lasting about 40 years, which are interrupted by severe structural crises. This is due to a number of mechanisms, but are, according to several researchers, largely driven by the diffusion of general purpose technologies (e.g. Lipsey et al., 2005). These general purpose technologies give rise to a *transformation* period when the industries based on the new technology grow, and a *rationalization* period, when the technology is implemented in old industries to improve productivity. Lundquist and Olander (2010) observed that growth in freight transport work also seems to follow a cyclic pattern, with transport growth rates being higher than the growth in GDP in times of strong economic growth and much lower in times of slower growth. That is, markets become "thicker" in times of high growth. This overlap is further explored in Paper I.

2.4 Summary and relation to research objectives

The main sources on which this thesis builds, as well as the main streams of literature to which it aims to contribute are reported in Table 4.1. As seen in the review, the thesis draws inspiration from two major research topics: sustainability in supply chains and transport contracting. These topics have been researched from many perspectives by researchers from different disciplines. As this implies that the breadth of the research, on such a general level, is very large, the above review has aimed at giving a brief overview of some of the major works that have contributed to these topics, looking at theoretical as well as empirical, and qualitative as well as quantitative, research.

As seen in the reviews by Suering (2013) and Tang and Zhou (2012), research on sustainable supply chain management is increasing, with contributions made in several subfields. Seuring (2013) notes that while there is much quantitative theory development being pursued, it is sometimes lacking sound empirical observations to support its assumptions. Both Seuring and Tang and Zhou also calls for more research on environmental aspects in relation to contracting and procurement, a gap that this thesis aims to partially fill. From the vast selection of empirical research, the works by Plambeck (2012), and Klassen and McLaughlin (1996) highlights the often discussed incentives to why a firm should shift to low-carbon freight transport. Klassen and McLaughlin (1996) provide evidence that environmental improvements in general improve firm value; Plambeck (2012) argues that improved operations may lead to both reduced costs and increased revenues. This is a motivation that permeates this thesis.

From the many subfields of sustainability and supply chains discussed in Tang and Zhou (2012), two are of particular interest for this thesis: technology selection and sustainable operations. The technology selection literature analyzes optimal (or in competitive environments, the equilibrium) capacity levels of different technologies, which is one of the key issues of this thesis. The empirical investigations of the transport market, especially those by Storhagen et al. (2008) and Woodburn (2003) serve as input for the explorative phase addressing RO2. The theoretical analyses by Wang et al. (2013) and Kleindorfer et al. (2012), serve as inspiration for the theory development phase addressing RO3, in particular Paper IV. Related to this research is that on sustainable operations, especially that handling the interaction between decisions on inventory and transport operations. Here, the inventory control papers by Ulku et al. (2012) and Hoen et al. (2010) provide interesting points of departure for the theory development phase, by discussing the environmental performance of transport operations (shipment consolidation and modal shift respectively) in a supply chain context, with special interest for Paper V.

The other main topic is transport contracting, where much of the reviewed literature draws inspiration from contract theory and its application in the supply chain literature. The main sources of inspiration include the general overview by Cachon (2003), the argumentative text by Naryanan and Raman (2004) and the multi-period service contract paper by Aksin et al. (2008). All of these papers provide building blocks necessary for the theory development addressing RO3, but also a perspective of alignment which is present in the studies related to RO2. On a more context specific level, Alp et al. (2003) and Serel et al. (2001) provide the major previous work that the theory development of this thesis build on, where Serel et al.'s analysis of the pricing of capacity reservations is perhaps the research most closely related paper to Paper IV.

Lastly, with the ambition of addressing the "stand-off" or equilibrium on the transport market, where little investment is seen, the general perspective of the market is based partly on de Vany and Saving's (1977) model of the transport market, while the large system overview (RO1) uses the ideas presented by Lipsey et al. (2005) to analyze the development seen on the transport market.

Topic	Literature Stream	Key References	Relevance for thesis
Sustainability in supply chains	Sustainable Supply Chain Management	Seuring (2013), Tang and Zhou (2012), Plambeck (2012), Klassen and McLaughlin (1996)	Highlights incentives for, and effects of, shifting to low-carbon freight transport
	Technology selection	Wang et al. (2013), Kleindorfer et al. (2012), Storhagen et al. (2008), Woodburn (2003)	Shows how firms could optimally choose and combine different transport technologies
	Sustainable Operations	Ulku et al. (2012), Hoen et al. (2010),	Analyzes the environmental impact from transportation and the interaction between transportation and inventory control, including shipment consolidation
Transport contracting	Supply chain contracting	Aksin et al. (2008), Naryanan and Raman, (2004), Cachon (2003)	Provides frameworks and modeling building blocks for analyzing incentives stemming from contracts
	Third party logistics contracting	Alp et al. (2003), Serel et al. (2001)	Shows how firms could optimally design the transport contract
	The trucking market	Lipsey et al. (2005), DeVany and Saving (1980)	Discusseses development and market mechanisms of the transport market

3 Research Methodology

This chapter presents a short description of the epistemological perspective, and then describes the research phases underlying the work presented in this thesis. The chapter starts by explaining the overarching idea of the research, before each phase of the overall structure is discussed in more detail.

3.1 A Note on Epistemology

Before I explain the methodological choices made throughout the work with the thesis, a brief note on my epistemological perspective may be in place. I am, however, hesitant to put a label on the perspective, since such statements, as recognized by Sayer (1992), tend to be misinterpreted. According to Sayer (1992),

> "At the center of social science's internal crisis have been attacks on orthodox conceptions usually termed 'positivist' or 'empiricist'. So many different doctrines and practices have been identified with these terms that they have become devalued and highly ambiguous, or even purely pejorative." (Sayer, 1992 p. 7)

If one were to choose a specific direction or thought tradition to describe the perspective of the thesis, an epistemological idea not too different from the classical scientific method as advocated by e.g. Blaug (1992), Kaplan (1973), or Hempel and Oppenheim (1965) is perhaps the most accurate one. While Sayer – an advocate of the Frankfurt school of thought – argues that theories in social science should focus *not* on explaining and predicting causalities as in the natural sciences, but on abstracting and conceptualizing thoughts and ideas, Kaplan – and advocate of the scientific method – argues that there is, in principle, no difference between a theory in natural and social sciences,

> "I do not believe that the role of theory in behavioral science is any different from what it is in physical or biological science. There are, of course, differences in the number, power, and weight of the theories which have been established concerning these different subject-matters; but everywhere, so it seems to me, theory works in essentially the same way. What is important is that laws propagate when they are united in a theory: theory serves as matchmaker, midwife, and godfather all in one …" (Kaplan, 1973 p. 303).

Since a primary objective of this thesis is to make contributions to theory (build theories), the different views on what constitutes a theory is of importance. To explain the take on "theory" in this thesis, I will refer to Hempel and Oppenheim's (1965) view that a theory consist of at least one universal law plus a set of initial conditions that logically imply the event in question. This means that any model or framework can, potentially, be regarded as a theory. Also, with this view, explanation is only different from prediction in that explanation takes place after the event while prediction takes place before the event (Blaug, 1992). Consequently, a theory will have both explanatory and predictive powers, and can thus also be used to devise normative advice.

The general argument against this view is, as expressed by Sayer, that

> "Social scientists are invariably confronted with situations in which many things are going on at once and they lack the possibility, open to many natural scientists, of isolating out particular processes in experiments." (Sayer 1992, p.3)

That is, even if it was of interest to derive laws that explain causalities in the social sciences, it would be impossible due to its inherent complexity. This argument, which has been expressed in slightly different versions over the course of several decades, has been extensively refuted by several authors throughout history. Economists have been the most vivacious. For instance, according to Blaug,

> "There are good reasons why falsificationism is hard to practice in economics…However, exactly the same factors [that makes it hard] operate in physics, chemistry, and biology..." (Blaug, 1992 p. xv)

Morgenstern (1963) gave a more direct response to a similar argument, by simply noting that "It is so easy to mistake one's own limitations for those of the method or the subject matter."

I will not go as far. But when one starts to compare social, physical, or natural systems, it feels rather presumptuous to assume that the study of a social system would be so much more complex than the study of a physical system like, say, a human body or our planet's climate, that a whole new paradigm of thought is necessary.

That said, the rest of this chapter will be spent on trying to convey a clear and transparent picture of the steps carried out in the working with the thesis. First, I will explain in a bit more detail the purpose of the thesis and show how this is reflected in the research structure, before the different stages of the process itself are explained. The focus will be on the overarching course of study. For more details about the individual studies, the reader is referred to the appended papers.

3.2 The Overall Research Structure

In this thesis, the research is structured around the three-phase research structure seen in Figure 3.1. Note that while it depicts a linear flow of events, the chronological order of these events is less straightforward since much work is done in parallel, with iterative and overlapping tasks.

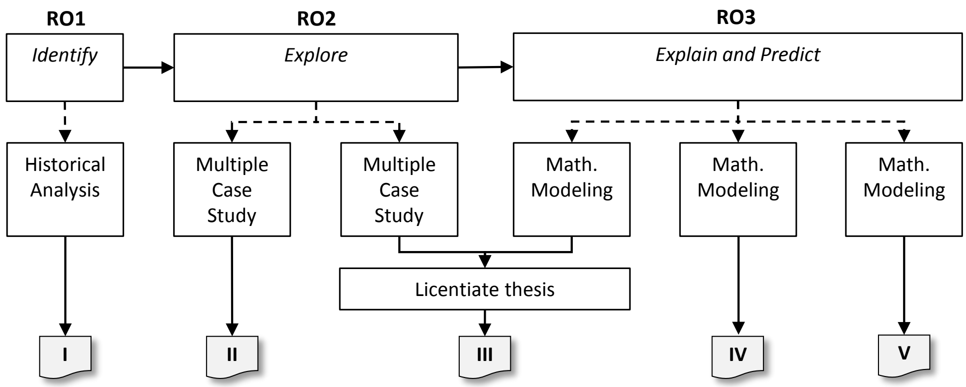

Figure 3.1. The research structure

There are several reasons to this overarching research structure. Doctoral studies have a measure of uncertainty. Even though there is always a plan, this plan is updated through deliberate, theoretically and practically motivated decisions throughout the research process. So while part of the explanation is evolution, much of the explanation is that it is based deliberate decision-making.

In practice, the research reported in this thesis started with the study reported in Paper II. Six shippers where interviewed in a multiple case study about the obstacles of shifting to intermodal road-rail transport. These firms highlighted the potential incentive problem on the freight transport market. It also became evident that, in order to take the research further, and thoroughly analyze the mechanisms at play, a step back was first needed. That is, I decided to follow the advice by e.g. Checkland (1999), and identify and investigate the behavior of the system where the interesting behavior was observed. This resulted in the historical analysis in the system overview – the Identify phase – reported in Paper I. This study was performed together with some of the researchers involved in the LETS2050 research program, which provided insights from several other disciplines, including economic geography and economics.

With these studies in place, the overall ambition of the research was becoming clear. The underlying ambition was going to be to explain why no shift to low-carbon transports were seen. That is, the ambition was to present positive theories about how the world is, or would be like (Hacking, 1983). In other words, I wanted to *not just* provide a description (this is however a part of the research), but to provide explanation and prediction. According to Wacker (1998):

> "By definition, theory must have four basic criteria: conceptual definitions, domain limitations, relationship-building, and predictions … Theory-building research seeks to find similarities across many different domains to increase its abstraction level and its importance. The procedure for good theory-building research follows the definition of theory: it defines the variables, specifies the domain, builds internally consistent relationships, and makes specific predictions." (Wacker, 1998 p. 361)

It was also clear that in order to achieve this, I had to proceed in a fashion related to the classical scientific method, combining observation and formal theorizing. According to the Oxford Dictionary (2014), the scientific method is: "a method or procedure … consisting in systematic observation, measurement, and experiment, and the formulation, testing, and modification of hypotheses". Through qualitative reasoning based on observations from a case study, a theory or proposition can be created to explain the observation. This covers the first part of the scientific method.

However, such reasoning alone may lack the internal consistency and predictive power advocated by Wacker (1998). That is, with only a qualitatively induced theory, it will become difficult to deduce testable hypotheses, which, in the most extreme view, means that the theory cannot be contested. To come to terms with this, in most areas of research, mathematical models have emerged as a tool for deducing insights. This is reflected in Eykhoff's (1974) definition of a mathematical model as "a representation of the essential aspects of an existing system (or a system to be constructed) which presents knowledge of that system in *usable form*". By using mathematical reasoning in creating the theory, it is argued, variables and parameters are explicitly defined, the internal consistency of the inductions are ensured, and the many possible deductions from the model can be systematically tested.

Nevertheless, as discussed by Sodhi and Tang (2014, p. 31): "we cannot build theory unless there are at least some known facts to justify certain assumptions". And case studies following the processes suggested by e.g. Yin (2003) or Miles and Huberman (1994) are excellent for making *structured observations* about how the world is – facts to justify our assumptions. If, for instance, the observation is made that *when A occurred, X changed to Y*, then it takes a positivist of humean dimensions to denounce the causality of the observation (observer bias taken aside).

The first case study had provided some initial structured observations to build on. However, it had also indicated that much of the obstacles to shift to intermodal transport (or any other type of low-carbon transport solution) may lay upstream from the shippers. Consequently, to adequately fulfill Wacker's (1998) criteria, more observations were needed.

Another multiple case study was thus initiated, focusing on the relationship between operators and forwarders. This both provided some insights about the observations from the first set of firms, but also led to other insights about the mechanisms at play in this part of the "transport service supply chain". Based on these insights, it was possible to construct a simple model to capture some of the incentive issues of the operator-forwarder relationship. The research, which was planned and executed alone, was presented in a monograph and publicly defended for the degree of licentiate. The key insights from this research was reduced to article-form and presented in Paper III.

With the finalization of the second case study, the Explore phase of the research moved into the theoretical Explain and Predict phase. It had become evident that a number of different contract and market structures existed. Based on prior theoretical knowledge along with these insights, two theoretical studies were performed to capture two of these structures, as reported in the last two papers (Papers IV and V).

This combination of evolution and deliberate decision-making resulted in three distinct (but, for sure, not always sequential) phases, each with its own underlying method. The thesis thus combines structured observations (explore) with mathematical modeling (explain and predict) to develop theory that addresses the overall purpose. The end result are models that are motivated and validated by the observations, from which hypotheses can be deduced and tested by statistical methods. However, the whole research starts with a historical system overview study (identify).

3.3 Identify

The *identify* phase consisted of a historical system overview study, which was carried out to gain a better understanding of the full system. This was done by investigating how different factors have impacted freight transport CO_2-emissions in Sweden from 1990 to 2008. The analysis was conducted using a *decomposition analysis*, in which the aggregate was decomposed into a number of hypothesized driving factors. This type of analysis allocates a contribution to each factor at each point in time, qualitatively similar to a regression. That is, at each point in time, the analysis tells us how much a certain factor (say, for instance, GDP) has contributed to the increase or decrease in freight transport emissions. The major difference compared to regression analysis is that in a decomposition analysis, the relation between the endogenous variable and the exogenous variables is, per definition, known a priori.

A decomposition analysis can be carried out using several methods. Some of the commonly used decomposition methods, e.g. the arithmetic mean Divisia Index method, are convenient to work with and have been widely applied also in the transport research field (e.g. Kveiborg and Fosgerau, 2007). Although computationally simple, these methods leave a (sometimes large) residual term which may, in cases, distort the results and "leave a new puzzle for the reader" (Sun, 1998, p. 87). To come to terms with these methodological problems, several refinements of existing methods have been suggested in which 'perfect decomposition' is achieved, i.e. decomposition which does not leave any residual term. Examples are the Logarithmic Mean Divisia index method (see e.g. Ang and Liu, 2001 and Sorrell et al., 2009), the refined Laspereyes index method (Sun, 1998) and the Shapley value decomposition method (Albrecht et al., 2002).

For our decomposition we choose to rely on the method referred to as Shapley decomposition (Albrecht et al., 2002) or refined Lespeyres method (Ang et al., 2003; Ang and Zhang, 2000; and Sun, 1998). Although computationally heavier than other 'perfect' decomposition methods (e.g. the log-mean Divisia Index method) we choose this approach as it provides a simple, intuitive, interpretation based on Shapley (1953): each factor's contribution to the aggregate is the mean of its marginal contributions for all possible, equally probable, combinations of the given factors.

For the analysis, data was gathered from Statistics Sweden, the Swedish Institute for Transportation and Communication analysis, the Swedish Environmental Protection Agency and the Swedish Energy Agency. Data depict transports within Sweden undertaken by Swedish as well as foreign enterprises. This is further explained in Paper I.

3.4 Explore

During the Explore phase, two *multiple case studies* were conducted among firms on the transport market. The first study focused on the relationship between shippers and their service providers, the other on the relationship between service providers and their operators (an overview is presented in Table 3.1). The following section describes the general motivation for using case studies for explorative purposes and provides a discussion about how validity concerns were addressed during the process. The discussion is kept on a fairly general level; more detailed descriptions are available in the respective appended papers.

Table 3.1. Overview of the two multiple-case studies of the Explore phase (by corresponding paper)

	Paper II	Paper III
Unit of analysis	A shipper's logistics system	A service provider's transport capacity mix
Cases	Six firms, from three types of industries, which had overcome the barriers of a modal shift.	Two service providers, that were seen a representative, and "that had just implemented a full intermodal train".
Data	Interviews made in teams of two (all but one of the cases), websites, and official documents. Interview guide was used. Sites were selected based on where the transport purchasing department was located.	Interviews made with two people at each firm, websites, and official documents. Interview guide was used. Sites were chosen based on where people with detailed strategic as well as operational knowledge of the solution were located.
Analysis	Single-case and cross-case analysis. Data was organized, tabulated and matched with literature. Meta-matrix was used for cross-case analysis.	Cross-case analysis. Data was processed and abstracted to construct a formal model that captured both cases. Most analysis was made in the modeling stage (see next section).

3.4.1 Using case studies for exploration

It is generally argued that poorly understood phenomena, which cannot be studied outside the context in which it occurs, are best targeted through case study research (Yin, 2009; Voss et al., 2002; Benbasat et al., 1987). Case studies are rich empirical descriptions of some phenomenon at a specific instance, or over time, and can take many different forms (Eisenhardt and Graebner, 2007; Yin, 1994). Case studies can be single or multiple, qualitative or quantitative, and aim to investigate something general or something very context specific (Yin, 2009). According to Eisenhardt and Grabner (2007), "the central notion is to use cases as the basis from which to develop theory inductively". This is how the case studies are used in this thesis. For instance, the purpose of Paper II was "to understand the operational changes and the contextual factors that determine whether the changes are possible and/or necessary for successful implementation [of modal shift]". The studies were designed to inform us about the perceptions and observations on micro-level. Did transport quality change? Did inventories change? How was the solution contracted? By starting the theory development in this way, the belief is that models developed later are more conceptually valid (Landry et al., 1983) and thus form a firm basis for further development and testing.

The overarching idea of how to use the case findings were the same for the two case studies – as the first step for theory building. Both studies also focused on the intermodal truck-train market. However, the studies had slightly different individual purposes. In accordance with Eisenhardt (1989b), the difference in purposes was reflected in the logic guiding the case selection processes.

As seen above, the first study (Paper II) aimed to understand what contextual factors and operations changes that are possible and/or necessary for a shipper to make a fit to the current intermodal production system. In the first study, the design was set up to draw as theoretically general conclusions as possible. Therefore, a multiple case study design was chosen in which cross-case replication logic could be applied (Yin, 2009; Meredith, 1998; Miles and Huberman, 1994). The sample, which consisted of six companies from three industries, was chosen so that several industries would be covered while certain factors such as product types and geography were held constant between the cases.

The second study (Paper III) aimed to investigate the contracts of the intermodal market and the incentives they create for a shift to more intermodal transports. Two case companies (Bring Frigo, Volvo Logistics) where chosen with the purpose of being representative for a certain phenomenon (compare Yin, 2009, or Miles and Huberman, 1994): the contracting and implementation of a full intermodal train. The purpose was never to draw general conclusions from the cases alone, but to have them illustrate and logically validate the model construction and the findings from the modeling which was performed in parallel with the case interviews.

For both studies, the sample selection process was performed in two steps. First, companies that had just implemented an intermodal solution were identified through the trade press and by industry experts. These companies were contacted by the research team to get an understanding of their suitability and willingness to participate in the study. From this, the sample was narrowed down to six and two companies respectively. For both studies, data was collected through on-site interviews following interview guides, with official documents such as financial and sustainability reports as well as company web-pages as additional sources of information. Data was analyzed through pattern matching techniques and, in the latter study, was iteratively compared to the solutions from the modeling phase.

3.4.2 Ensuring trustworthiness in the Explore phase

The Explore phase was meant to create insights by exploring the context in more detail. Although such exploration may be done without any particular process in mind, for this research it was decided that both studies were carried out following a structured case research process, as suggested by e.g. Yin (2009) and Stuart et al. (2002).

Several sets of quality criteria have been suggested for discussing the trustworthiness of case study research, all based on slightly different underlying ontological and epistemological perspectives. While some argue that qualitative research cannot be judged by the same quality criteria as other research (e.g. Guba and Lincoln, 1994), I follow Blaug (1992) in my belief that all research that aims at analyzing phenomena which is not purely abstract or subjective (such as perceptions) can be discussed along similar dimensions, with similar concerns regarding quality. Based on Shenton (2004), Riege (2003), Yin (2003), and Miles and Huberman (1994), I therefore choose to provide an overview of how trustworthiness was ensured by highlighting measures taken in the two studies to ensure Confirmability, Reliability, Internal Validity, External Validity. The discussion is summarized in Table 3.2 below.

Confirmability refers to whether the "interpretation of data is drawn in a logical and unprejudiced manner" (Riege, 2003, p. 81) and mirrors objectivity concerns in less qualitative research. According to Miles and Huberman (1994), the level of confirmability is determined by how well and explicit methods are described, how well all necessary information is provided, and if data is available for reanalysis by other researchers. In both studies, this was addressed through different measures triangulation and rigid documentation of the process. For instance, more several data sources were used for each case. This was especially pronounced in the first study, where the end-result was inference based solely on the qualitative investigation (in the second study, inference was based on a combination of qualitative investigation and modelling, as described in next section). During the research, we made sure to follow a clearly planned process based on literature, including interview guides and constant matching between findings and theory.

Table 3.2. Measures taken to ensure trustworthiness in the exploration phase

Criteria	Measures taken
Confirmability	Use interview guide based on literature Triangulation between informants and secondary sources Interview transcripts were reviewed by respondents to get feedback Iteratively matching theory and empirics
Reliability	Use of semi-structured interview guides Detailed documentation throughout process, including voice recordings of all interviews Clear description of how hypotheses were updated throughout the process Discussion of limitations (at the end of this chapter)
Internal validity	Interviewing informants with the vastest knowledge of the unit of analysis Triangulation with secondary data sources Multiple respondents at each company in second study Interview guide sent out in advance Multiple members of the research team in first study Notes taken by all members of the research team, both members' notes were reviewed by the other member and discussed within the team Follow up questions to informants as new information was revealed from other sources or cases Cross-case analysis in first study Pattern matching analysis in both studies
External validity	Details about the context including firms and respondent positions, data collection periods, data collection methods, number of informants Replication logic in first study Generalization only to propositions and suggestions which are used as inputs in further studies

Reliability refers to how stable and consistent the process of inquiry has been. According to Shenton (2004), the traditional "positivist" approach to ensure reliability is to demonstrate that the results of the study can be replicated. In a qualitative study, this translates to structure and transparency in methods and the overall process followed in the research. This was ensured by having a well-structured and well-documented process for each study. For instance, interview guides were used in both studies. The respective processes are further explained in the respective papers.

Internal validity refers to how well a study tests or measures what is actually intended to be tested or measured. In qualitative studies this is always an area of concern: When a study is aiming to capture a phenomena that must be proxied through the observation and perception of informants as well as the perception and interpretation of the researcher, internal validity always suffers from potential biases. A first set of biases relates to the informants. These may have insufficient or even the wrong information about the unit of analysis, or they may not – voluntarily or involuntarily – communicate the information they have. For instance, in the first study, the informants may not have correct information about the actual operations changes made in conjunction to the shift, or they may choose to withhold the information. To ensure that people with sufficient knowledge were used as informants, we interviewed those who were claimed by others in the company to have the vastest knowledge of the intermodal solution under study. To ensure that the informants also communicated the information they had, we sent out the interview guide in advance so that the informants could find any information that they needed to answer the questions. To ensure that the communicated information was accurate, the responses were triangulated with secondary data, including website information and annual reports. In the second study, triangulation was also achieved by interviewing several informants at the same time in the same room so they could validate each other's responses. A second set of biases relates to the researcher. The researcher may misunderstand answers from the informants, causing severe researcher bias. To reduce this potential bias, all interviews were voice recorded while all members of the research team took notes. These notes were discussed after the interview, and any ambiguities were handled in follow up questions. The recording was transcribed and sent to the informant(s) for verification. If other sources of information, or other cases, caused any concern in previously gathered data, informants were yet again confronted with follow up questions.

The last set of biases is in the analysis, where a researcher may misinterpret information. To reduce such biases, the analysis closely followed processes suggested by Yin (2003) and Miles and Huberman (1994), using pattern-matching and cross-case analysis techniques.

External validity concerns the generalizability of the results. The nature of case studies means that the findings cannot generalize to other context, but some argue that the findings can be "analytically generalized" (see e.g. Riege, 2003). Addressing this criteria involves assessing how well the study is congruent with, or connected to previous theory, and whether the descriptions are rich enough for a reader to assess transferability. In the first study, were it was desirable to achieve a matter of generalizability solely based on the qualitative inquiry, this was addressed through replication logic in the case selection phase. Also, we made sure not to overstate potential theoretical generalizations. For the second study, this was addressed in the modelling phase.

3.5 Explain and Predict

The third phase of the research was the theoretical Explain and Predict phase. This phase was executed through three modeling studies, each focusing on a slightly different situation. The first study focused on the operator-service provider interface, and the contracting of intermodal transport capacity. The study is reported in Paper III. The second and third studies focused on the service provider-shipper interface, and are reported in Papers IV and V. Paper IV focused on when one large shipper makes a long-term capacity reservation, and Paper V focused on when several small shippers are consolidated on the same transport solution (an overview of the three studies, based on the characteristics presented in Section 2.3, is given in Table 3.3). The following section describes the general motivation for using modeling for this phase of the research, and briefly discusses how validity concerns were addressed. As in the Explore phase, more detailed descriptions are available in the appended papers.

Table 3.3. Overview of the three modeling studies of the Explain and Predict phase (by corresponding paper)

	Paper III	Paper IV	Paper V
Endogeniety	Specific contracts (per-trailer and per-train contracts) and general contract (three-part tariff)	Specific contracts (unit price and capacity reservation contract)	Specific contracts (direct delivery and consolidated delivery)
Player preferences	Rational and risk neutral	Rational and risk neutral	Rational and risk neutral
Game characteristics	Forced compliance, full information, sequential (Stackelberg), one-period, stochastic demand	Forced and voluntary compliance, full information, sequential (Stackelberg), one contracting period but several replenishment periods, stochastic demand	Forced compliance, full information, sequential (Stackelberg), one period, stochastic demand captured through an expected cost at shipper
Market structure	One seller (operator) and one buyer (forwarder/service provider)	One seller (forwarder/service provider) and one buyer (shipper)	One seller (forwarder/service provider) and several buyers (shippers)

3.5.1 Using mathematical models to explain and predict

According to Bertrand and Fransoo (2002, p. 244),

> "OM research has not been very successful in developing explanatory or predictive scientific models of operational processes, that is, models that can be used to explain or predict the output or performance of the process as a function of process characteristics, process states and inputs to the process. This is a major roadblock to the field, since the development of effective methods to improve performance assumes that scientific knowledge of the process is available."

In this phase of the research, the aim was to meet this claim, by developing explanatory and predictive models for the contracting of low-carbon transports. There are several reasons why formal modeling was used for this phase. According to Casti (1989), modeling enables further inquiry and bring clarity and order to one's observations and experiences.

A model may also help in assessing possible policies without the high costs associated with changes in the real-life system (Wandel, 1985). This was one of the key motivators in this research. The models were developed to show both how the contracts could be designed but also to evaluate what the consequences of an implementation would be. For instance, if a service provider implements a capacity contract with the shipper, what are the likely consequences? Will emissions be reduced? Will there be incentives to make the change? Do the results indicate a matching problem?

A part from this, the process of building a model is in itself a powerful tool as the researcher is forced to consider all functionalities of the system. In the words of Morgenstern (1963, p. 21)

> "The difficulties of formulation are, indeed, formidable. It is well-known and has often been said, that formulating a problem is often already the assurance of its solution."

According to Bass (2004, p. 1834) "Models are abstractions and simplifications of reality…Useful models capture the essence of reality in a way that enhances understanding of phenomena". Since a model is just a model, only those components and relations of the object that are relevant for the purpose of the model are represented; that is, each model reveals and orders only a few aspects of a limited part of reality. Whether or not this simplified version of reality is useful will be determined by how well the model can, despite its incompleteness, "predict the effect of changes in the system on the system's over-all effectiveness to acceptable and useful accuracy" (Ackoff, 1956 p. 286).

Modeling as a research strategy can fulfill several purposes (Wandel, 1985 p. 323):

1. to describe relations, states, and events in some part of reality;
2. to explain past states and events in the object;
3. to predict future states and events in the studied system; or
4. to guide decisions in the real world system being modeled.

In other words, models may be used for building theory with descriptive elements as well as explanatory or normative elements. Some even argue that mathematical models are the most powerful way to generate theory, (e.g. Morgenstern, 1963). In the research in this thesis, mathematical models were used for the studies reported in papers III, IV, and V. The models all have normative elements, depicting how to design contracts in certain situations. However, emphasis is on the descriptive, explanatory, and predictive elements. For instance, in Paper IV, the purpose is to "investigate the service provider's problem, and *analyze the environmental implications of the optimal decisions*". That is, emphasis is on points 1-3 above.

To fulfill the theory quality criteria given by Wacker (1998), the theory development phase followed a process similar to those suggested by Koole (2010) and Landry et al (1983) (see Figure 3.2), without the implementation step. Thus, all studies had a conceptualization phase, a formal modelling phase, and a model solution phase. Similar model types were used in each of the three studies, with some minor differences in how these steps where executed.

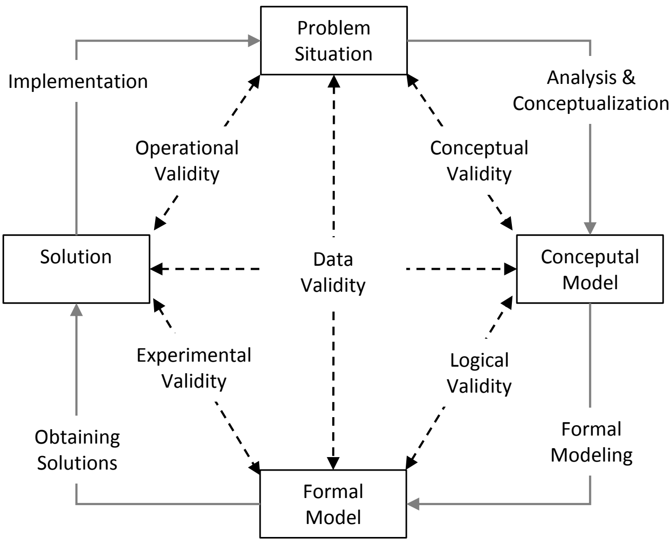

Figure 3.2. Validity in operations modeling, Landry et al. (1983, p. 212)

3.5.2 Ensuring trustworthiness in the Explain and Predict phase

To provide an overview of how the trustworthiness of the modeling phase was met, I rely on the five measures presented by Landry et al. (1983), which are seen in Figure

3.2. Similar frameworks, highlighting more or less the same validity aspects, have been presented and/or discussed by Bertrand and Fransoo (2002), Oral and Kettani (1993), and Mitroff et al. (1974).

Conceptual validity describes how well the conceptual model of the system under study captures the main aspects of the system. In this research, much effort was put on ensuring high conceptual validity, to avoid the caveats pointed out be e.g. Bertrand and Fransoo (2002) at the beginning of this chapter. To ensure that the model was grounded in reality, structured observations were conducted as reported through the two multiple-case studies reported in the previous section. The exploration phase was connected to the explain and predict phase according to Table 1.1 in the introduction chapter: the first multiple case study of the service provider-shipper relation was used as inspiration for Papers IV and V, while the second multiple case study of the operator-service provider relation was used as inspiration for the model in Paper III. For all three modeling studies, the case data was used to inform the model construction. For instance, observations regarding market structure, power, and cost relations were used to ensure proper model setups. The measures taken to ensure trustworthiness in the explain and predict phase are summarized in Table 3.4.

Logical validity is concerned with how well the formal mathematical model captures the conceptual model of the system. This means verifying whether all important aspects of the conceptual model have been properly included in the formal model, as well as to evaluate the internal coherence of the model. This is perhaps the most difficult aspect of modeling, since all logical models are subject to assumptions and simplifications. Since these simplifications are in part driven by what effect they have on analytical tractability, the researcher often faces a delicate balance between realism and tractability. That is, in the words of Morgenstern (1963), one may become limited by one's capabilities of using the analytical tool. To establish logical validity, the major assumptions underlying the models that are difficult to observe in practice (e.g. demand processes, information symmetry, and rationality) were based on previously well-accepted assumptions from inventory theory and contract theory. While this is in no way a guarantee for them being the best way to limit the system, there is at least consensus in the literature, from a multitude of studies, that these assumptions have acceptable impact on the results. One such major assumption was, for instance, that demand can be modeled as a stationary stochastic process when the goods do not experience seasonality, as is common in the operations and inventory literature. With each set of assumptions, different formal setups were tried and tested to see which one fitted the abstracted system the best. By using (mostly qualitative) data from the cases, plausible solutions could be tested to investigate output so that the results were acceptable and, more importantly, believable. To further establish logical validity, the formal models were reviewed by, and discussed with, other researchers.

Experimental validity refers to solution mechanism of the model. According to Landry et al. (1983, p. 213), "the difficulties of experimental validation are mostly technical in nature and are often relatively easily dealt with since they usually require the involvement of model-builders only". It deals with the efficiency in obtaining solutions and the sensitivity of the solution. Since the studies in this thesis deal with relatively small problems, efficiency is not an overly important aspect. Instead, focus was on finding an interesting an accurate way of representing reality. In the modeling studies, analytical solutions were sought when possible. When complexity did not allow for such results, that is, when realism was preferred to tractability, we resorted to numerical techniques. In all such situations, large scale sensitivity analyses were constructed so that observations of a rather general nature could be drawn, even when computational time became somewhat large. To establish experimental validity, the models were also reviewed by other researchers throughout the process.

Operational validity concerns the quality and applicability of the model solution. In the words of Bertrand and Fransoo (2002), it concerns "whether the solution of the model assists managers in making decisions in the real world". This is mostly a concern for normative models, developed to provide a solution to a management problem, while this thesis has a positive purpose, aiming more at providing and arguing for one potential explanation to an observation. Consequently, operational validity is not an applicable measure. It could nevertheless be an issue if the results of the study were to lead to more operationalized policy recommendations.

Data validity is concerned with the "sufficiency, accuracy, appropriateness, and availability of the data (both soft and hard data), within acceptable cost limits" (Landry, 1983, p. 214). These data can be used in any phase of the study – to form a conceptual model, in constructing the formal model and in devising solutions from the model. In all studies, qualitative data was gathered from the different cases to construct conceptual models of the system under study. This data was unfortunately not on the level of detail that would had been desirable, due to non-disclosure policies. Still, based on the cases, cost structures could be devised which, together with cost data from internet and oral sources, formed input data for the construction of the formal model as well as for the model solutions.

Table 3.4. Measures taken to ensure trustworthiness in the explain and predict phase

Criteria	Measures taken
Conceptual validity	Structured observations to abstract reality (as reported in previous section) Iteratively testing assumptions of models against observations from previous studies
Logical validity	Base models on well-known theory Trial and error using different modeling assumptions Peer-review of formal model
Experimental validity	Analytical solutions when possible Large-scale numerical studies for heuristic solutions Sensitivity analysis for important parameters Peer-review of model solutions
Operational validity	Aligned with purpose
Data validity	Results compared to results of similar models Results compared to observed cases

3.6 Limitations

Despite the precautions taken in designing and executing the research, this research like many other studies has methodological limitations that I wish to be transparent with before results and implications are discussed.

Focusing on the complete research process, the quality of the outcome of a phase will always be limited by the quality of the preceding phase. Even though much effort was spent on gathering valid information about the decisions that rule the shift to low-carbon transports among shippers and service providers, the lack of internal validity associated with qualitative inquiry (that is, the fact that inference is based on information proxied through informants) introduces sources of possible "error" that may propagate through the process. Still, the models and their findings are well in line with the observations, which indicate that these errors may not be of great magnitude. Nevertheless, the fact that a fourth phase in which the model's predictions are tested on a large scale has not been performed limits the information about the true external and operational validity of the research. If the findings of such large scale data analysis would be aligned with the model predictions, one could feel fairly comfortable in drawing normative conclusions from the models – an angle which is downplayed at this point.

Another potential limitation in the process of the research is the scope of the qualitative inquiry. Although the observations were structured and performed following well-accepted methods, the scope of the observations are not quite matched with the scope of the models in papers IV and V. More precisely, while the models in papers IV and V cover the observations presented in Paper II, they also generalize to other situations which exist at least in theory, but have not been properly observed during the work with this thesis. This limitation in scope means that it cannot be verified that some of the possible challenges that occur in theory actually exist in reality. It does however not limit the validity of the conclusions for the contexts that were observed in Paper II. Verifying those claims is an interesting venue for further research.

Another potential limit is the inherent limits associated with theory development in general: that some assumptions have to be made to make progress in terms of analysis. Striking a balance between realism and tractability means that some important aspects may have been wrongfully disregarded, as the observations did not point to them as being important. While this may limit the validity of the results, it is part of science. The best way to see whether this limits the results is by testing the developed theories, or try to build new models with slightly different assumptions and see whether the predictions better match the observations and/or provides more theoretical insights. As discussed in the papers and in later parts of this thesis, such exercises are left for future research.

Linked to this is the assumption that the positive theory about the market is based on rational behavior. It can be contested, as in Kalkanci et al. (2010), whether this is the case. There is certainly plenty of evidence that consumers not always behave in an economically rational way. Whether this is true for the decision-making on the transport market is uncertain. The idea with economic models is never to provide an absolute law that every firm follows exactly, rather to pinpoint main mechanisms which would be expected to be followed by the average firm. It is nevertheless my belief, after observing the transport market in the work with this thesis, that the rationality assumption is rather fitting, perhaps more on the transport market than many other markets, although an exploration of this in depth is possibly an interesting venue for further research.

4 Summary of Appended Papers

In this chapter the five appended papers are introduced and summarized. For each paper I also provide a discussion of its main contribution to the overall objective and its explicit contribution to the research questions. All papers are co-authored as explained in the introduction. For more detailed descriptions, the reader is referred to the respective paper.

4.1 Revisiting the Research Objectives

As seen in the introduction, the purpose of this thesis is to *increase the understanding of the incentives to shift to low-carbon freight transport.* To achieve this purpose, the research was broken down into three sequential research objectives:

RO1. *To identify how changes on the freight transport market and changes in adjacent systems in society impacts freight transport emissions.*

RO2. *To explore what operations changes a shift to low-carbon freight transport leads to, and under what circumstances such a shift is made.*

RO3. *To explain and predict under what circumstances, and to what extent, there are incentives for the actors on the freight transport market to shift freight to low-carbon transports.*

These three objectives were addressed in five research papers, all appended to the thesis, with slightly different focus as seen in Table 4.1. While the first paper presents an overview of the full system, the other papers focus either on the operator-service provider relation or the service provider-shipper relation. Papers II and III present the empirical foundation for these relations respectively, which is then used in Papers III-V for the explain and predict phase of the research. In the following, I present the objectives and main insights from the papers.

Table 4.1. The papers' positions relative the operator-service provider-shipper chain of actors on the transport market

Operator	Service Provider	Shipper	
Paper I			**RO1: Identify**
Paper III		Paper II	**RO2: Explore**
Paper III		Paper IV Paper V	**RO3: Explain and Predict**

4.2 Paper I: Explaining the cyclic behavior of freight transport CO_2-emissions in Sweden over time

4.2.1 Objective

This paper presents the results of the historical system overview. The paper analyzes how macro-economic and firm-level factors have impacted freight transport CO_2-emissions in Sweden from 1990 to 2008.

In previous studies on the topic (e.g. Kveiborg and Fosgerau, 2007), economic growth is often considered to be the main factor behind, and tightly coupled to, the increase in freight transport work and freight transport emissions. However, although one can notice differences in the contribution from economic growth and other factors at different points in time, focus has predominantly been on end-state figures rather than dynamic behavior.

This paper extends previous research by specifically addressing the *dynamics* of the observed development. It focuses on the current "growth cycle" (see Chapter 2), and analyzes Swedish data in a Shapley decomposition model, where growth cycle is theory is used to provide a possible explanation to the behavior in the underlying factors. The analysis aims to uncover the changing roles of different factors, and how the interplay between them change at different points in time.

4.2.2 Main findings

The paper makes several contributions. First, the analysis shows that the results from the decomposition is well in line with what could be expected from reasoning based on growth cycle theory. In the transformation period, the firms that drive growth are more concerned with growth than efficiency and firm-level efficiency factors have, in general, low positive impact on emissions. During the rationalization period, efficiency improvements are driving growth and firm level efficiency factors instead have a small moderating effect. Relating to the overall system, most of these changes are made by shippers, whose change in demand drives changes among service providers and operators. The implication is that since the observed development is well in line with predictions from growth cycle theory, firms are rationalizing in more or less the same rate as could be expected. That is, the environmental improvements that can be seen in aggregate data are probably an artefact of cost savings, rather than the other way around. This is especially important from a policy-perspective since, according to the growth cycle theory, freight transport work will grow quickly once growth takes off again (see e.g. Lundquist and Olander, 2010; Schon, 2000). Whether or not this also leads to an increase in emissions depends on what traffic intensity and emissions factors the industry present by then (the “large system”). These factors are possible to address through regulation.

Second, the paper shows how different “greening” measures among operators, service providers and shippers have impacted the aggregate emissions from freight transport. In the case of modal shifts, the combined efforts in Sweden has lead to a 7% *increase* in emissions over the period, indicating a shift to more polluting modes of transport. For other measures, including freight consolidation not contingent on modal shift, the total impact over the full period is a small negative effect. The good news is that the latter offset the former. The bad news is that end result is still a 28% increase in freight transport emissions, since more goods are shipped over longer distances (albeit more efficiently).

4.3 Paper II: Modal shift for greener logistics – the shipper’s perspective

4.3.1 Objective

Over the last decade politicians in Europe have stressed that a modal shift of freight transport, from road transport to intermodal road-rail transport, is a promising way to reach the target reductions in CO_2-emissions as dictated by national and international agreements (see e.g. EU, 2011). But despite political effort and financial stimulation, very little progress can be seen. As seen in Paper I, the general trend from 1990-2008 is rather a shift to *more* polluting modes of transport.

Despite this, some shippers have gone against the mainstream and shifted to intermodal road-rail transport. In this paper, six such firms are investigated in a multiple-case study. While most previous research has addressed the issue from the carrier's perspective (see e.g. Bontekonig et al., 2004), arguing for ways to improve the service production to better fit the shippers' demand, this paper addresses the shift from the shipper's perspective. The purpose is to understand what contextual factors and operations changes that are possible and/or necessary for the shipper to make in order to fit the current intermodal production system. The scope is illustrated in Table 4.1.

4.3.2 Main findings

Based on literature, the paper provides a conceptual model highlighting potential factors and operations changes that enable a modal shift. These includes contextual factors that drive the decision to shift, factors that impact the transport quality after the shift, and operations changes that determine whether or not this change in transport quality impacts total performance. Note that logistics performance measures the incentives to shift – if this is reduced there would be no incentives to shift. The literature-based framework is then refined in a series of case studies.

The findings indicate that contextual factors stressed in the carrier-focused literature, or rule of thumb decisions made by shipping logistics management, do not always clearly predict the success of a modal shift (as discussed by e.g. Woodburn, 2003; Stank and Goldsby, 2000). While, for instance, volume and product value varied greatly, some common denominators among the cases emerged: they all spent significant time and resources on the purchase; most of them highlighted carrier performance rather than mode performance as the crucial driver of performance; all had stable flows (but of varying volume); and, lastly, all had management that could make ‘holistic’ simultaneous decisions on inventory policies and transport purchases.

Through the cases, the study illustrates the different ways for a shipper to shift to intermodal transports. Large shippers can have a solution set up tailored to their needs, which was the case for one of the shippers. With such a solution, transport quality may very well be (and was!) at par with trucking. For smaller shippers, the option is rather to join a consolidated solution with shipment frequencies set by the service provider. Joining a solution in this way meant a reduction in transport quality, which in several cases led to increased inventory holding and/or scheduling changes to keep performance constant. This highlights the system effects associated with the change in transports,

The study also discusses the general complaint among the shippers that there is a lack of service supply. In most cases, shippers had to spend significant time and resources in actively pursuing service providers, as these were unwilling to invest in large-scale solutions when they already had well-functioning road-networks. The paper suggests, without investigating further, that risk-sharing may be a potential way to release this dead-lock.

4.4 Paper III: Modal shift for greener logistics – exploring the role of the contract

4.4.1 Objective

This paper continues Paper II’s investigation of the contracting of intermodal transports by moving further up the transport service chain, to the contractual relation between operators and service providers (see Table 4.1). In Paper II, several of the shippers complained about the limited supply of low-carbon transports in general, and intermodal transports in particular. By moving up the chain, this paper investigates what incentives there are for service providers to use intermodal transport capacity in its fleet serving downstream shippers.

More formally, the purpose of the paper is to investigate the contracts between operators and service providers and the incentives they create for a modal shift. This is done through a mixed-methods study, where qualitative case interviews and quantitative modeling is combined. Two cases of contractual relationships between a service provider (Bring Frigo, Volvo Logistics) and its intermodal train operator on a specific lane were investigated. The case findings were then consolidated and used as input for a simple model of the contractual relation. Findings were sought from an extensive numerical study.

4.4.2 Main findings

Based on the cases, three simplified contract types are investigated. In the paper, these are referred to as “per-train”, “per-trailer”, and “three-part-tariff” contracts. The first contract type mimics the one observed in the two cases. With such a contract, the service provider is contracting a full train from the intermodal operator over a fixed period of time, e.g. two years, and the service provider is responsible for utilizing the contracted capacity. The second type of contract is one in which the service provider contracts any amount of trailers. This is a more flexible contract type suggested by the service providers in the study. With such a contract the operator is responsible for filling any unused capacity of the train. The last contract type is purely theoretical, but provides perfect coordination.

The fact that the cases reported that per-train contracts were used is well in line with e.g. Storhagen et al.’s (2008) claim that operators have a strong production focus, since such a contract transfers the risk of unused capacity to the service provider. In the cases, the service providers argued that this limited their possibilities to shift to intermodal transport.

The paper shows, in a numerical study using data based on the cases, that the current market conditions lead to a situation where the operator’s best choice generally is to transfer the risk but capture the profit. This means there are very little incentives for the service provider to use intermodal transports at all. The end result is that only truck transports are used unless there is strong pressure from downstream shippers, or a very low alternative profit for the service provider (i.e. truck transport is expensive). That is, with current market conditions, there will not be a shift to low-carbon transports unless shippers demand it as an order qualifying factor or start paying a large premium for it.

While a three-part tariff does not lead to the largest amount of intermodal traffic when analyzed in isolation, such a contract may offer a solution to the dead lock of the market. Implementing the contract means that the operator must give up some profit and retain some of the risk. This means that on short term, such a contract may seem less profitable to the operator. However, with a more long term focus, the contract becomes a more attractive option. Instead of arguing for operators to be more customer-focused, policy-makers and other stakeholders may have more to gain by having both actors being more cooperation-focused.

The paper shows that the contract structure is important in controlling the incentives for a service provider to contract low-carbon transports. It also shows that, ceteris paribus, there are few incentives for the operator to offer any other contract form, and thus there are few incentives for the service provider to use intermodal transport capacity unless pressured from downstream shippers.

4.5 Paper IV: Selling green transports to a retailer – investment, pricing, and contract choice

4.5.1 Objective

This paper returns to the contractual relation between a service provider and a shipper (in this paper the shipper is referred to as a "retailer"). Specifically, it looks at one of the situations observed in Paper II; when a large shipper initiates the low-carbon transport service, and offers to make a long-term capacity reservation to the service provider. The low-carbon service in this paper can be any type of low-polluting transport service (e.g. hybrid diesel vehicle, biogas truck, intermodal truck-train) for which the operating costs and emissions are lower than for a normal truck transport, but the periodic cost (departure and investment cost) is higher.

Building on insights from Paper II and Paper III, the paper's purpose is twofold: 1) to solve the service provider's investment and pricing problem, and 2) to analyze the environmental implications of these decisions. That is, assuming the service provider is rational, the paper aims to understand the environmental effects of having a shipper taking (some of) the risk associated with an investment in low-carbon transports. It thus seeks to answer a number of questions. How much low-carbon transport capacity should a service provider like Volvo or Bring Frigo invest in if a capacity contract is used for a large client? Should the service provider accept a capacity contract, or is it more profitable sticking to a "normal" volume contract? And, based on these choices, what are the environmental implications of the service provider's optimal decisions?

4.5.2 Main findings

The paper makes three contributions.

The first contribution is to extend the capacity contracting literature to a multi-period setting, where the buying firm can keep inventory between periods. Compared to previous work on problems in multi-period settings (e.g. Henig et al., 1997; Serel et al., 2001), the paper relies on a slightly different approach. To derive closed form expressions, tools are used from the literature on periodic review capacitated production-inventory systems (see e.g. Alp and Tan, 2008; Angelus and Porteus, 2002), which are embed in a Stackelberg contracting model. By proceeding in this way, the paper extends previous work to also compare contracts, and conduct sensitivity analyses to understand the impact of e.g. carbon taxes.

The second contribution is in characterizing the players' optimal decisions, and identifying some interesting structural properties. In the paper, we illustrate how, under capacity contracts, a carbon tax may lead to less green capacity and a higher expected environmental footprint. As discussed by Krass et al. (2013), carbon taxation is an indirect tool used by regulators to provide incentives for firms and people to make the "right" technology choice. However, as the paper shows, this is not necessarily the outcome of such taxation: if a regulator decides to make conventional vehicles more expensive to operate, it will not create incentives for investments in green vehicles, it will only make transports more expensive.

The third contribution is in comparing financial and environmental results under volume and capacity contracts. The paper shows that a capacity contract leads to a larger share of transports by green vehicles. However, a capacity contract also leads to more inventory at the retailer. This creates a trade-off between different types of environmental impact. According to a report from World Economic Forum and Accenture (2009), warehousing accounts for roughly 10% of all logistics-related emissions. McKinnon et al. (2012) argue that warehousing accounts for 2-3% of the world's total energy related emissions. Consequently, when the usage of more green vehicles is coupled with more inventory, the environmental impact from holding inventory may even offset the reduction in environmental impact from transports. In the paper we illustrate numerically when this is the case, and when each contract is preferred to the other.

In the sustainability literature, long-term relationships between service providers and retailers are often advocated. For instance, Plambeck (2012) states that "[firms] must find ways not only to reduce emissions under their direct control but also to influence emissions caused by their suppliers and customers—by providing them information and incentives, and collaborating or even vertically integrating with them". In this paper, it is shown that if firms (retailers) decide to work with their service providers in long-term relationships through capacity contracts, it may indeed lead to a more environmentally sustainable situation. However, as long as the greener service cannot be sold at a higher price, there are often not enough incentives for the service provider to transfer much or all of the firm's freight to green vehicles. Even though the operating cost for green vehicles are usually lower, the dedicated nature and the higher fixed costs of the green vehicles create a larger risk for the service provider than conventional vehicles. If a large scale shift is to be seen, this risk needs to be compensated for. Bring Frigo has tried to move in this direction with little results: "Goods owners are not willing to take this risk at all", they have stated, "we have tried. But right now it is a buyer's market" (Eng-Larsson, 2012). Nevertheless, there are examples where a large retailer have decided to move in this direction (see e.g. Coop, 2014). And there is more hope for service providers. According to Ehrhart (2010), "what will further drive the demand for greener products is the very fact that sustainability has become a key success factor in shaping the reputation of a company and its brands. For multinational companies, in particular, it is important to have a consistent approach to sustainability along the whole value chain". Whether or not this increased focus will lead to a different transport purchasing behavior remains, however, to be seen.

4.6 Paper V: Pricing and timing of consolidated deliveries in presence of an express alternative – financial and environmental analysis

4.6.1 Objective

The last paper considers the second shipper contracting possibility seen in Paper II; when several small shippers (in the paper referred to as "customers") are consolidated on the same low-carbon delivery. While, as seen in Paper II, there are some anecdotal evidence of such solutions, they seem more popular in theory than in practice. For instance, in urban contexts, SUGAR (2011) reports that 150 projects have been setup in Europe, but only 5 have survived after subsidies have been withdrawn. Also as seen in the introduction, Volvo's Viking Rail project was only in operation for five years before it was discontinued. In this paper we ask ourselves why this may be the case. When does the service provider have incentives to offer a consolidated low-carbon transport solution? How should she design it to create incentives for customers to join the solution? And what are the implications of this?

As in the previous paper, the low-carbon option in this paper can be any type of low-polluting transport option (e.g. hybrid diesel vehicle, biogas truck, intermodal truck-train) for which emissions are lower than for a normal truck transport, and where the cost per shipment is significantly larger than volume variable costs.

Since the shippers are small, the service provider initiates the low-carbon option, and offers every customer to join the solution in exchange of a rebate on the shipment price. That is, every customer is offered to choose between two long-term contracts: 1) a contract that guarantees direct delivery at full cost; or 2) a contract that provides delivery at fixed intervals at a reduced cost per unit. The service provider faces a trade-off: to have the most time-sensitive shippers join the consolidated solution, the frequency must be high, which makes it difficult to reach the scale economies of the solution; but by not having the most time-sensitive shippers join, there will be less demand per time unit, which also makes it difficult to reach the scale economies.

In the paper, this trade-off is addressed with two different ways to set the rebate for contract number 2. The first captures cases when the service provider has the possibility negotiate with each shipper individually and thus offer a different price to each shipper. The second captures cases when this is not possible, and the same unit price must be offered to every shipper that joins the consolidated delivery. In either case, the service provider must choose what price(s) to charge (or rather, rebates) and what shipment interval to have for the consolidated delivery option, taking into account that customers join the consolidated option when it is profitable for them to do so.

The paper analyzes the service provider's simultaneous pricing and scheduling decision, and investigates the implications of the optimal policy.

4.6.2 Main findings

The paper has both normative and explanative contributions.

First, it adds to previous research on optimal shipment consolidation policies (e.g. Marklund, 2011). This literature focuses on a central decision-maker implementing a consolidation policy for downstream retailers. Owing to that, pricing is not an issue. This paper extends this literature, by using arguments from contract theory to explicitly highlight how the pricing and scheduling decisions are interrelated. In the paper, we show that the simultaneous pricing and scheduling problem can be simplified and solved through a search, both for cases when price discrimination is possible and when it is not. This means that a simple search algorithm can be constructed to solve the service provider’s problem by quickly determining 1) which customers to engage in the consolidated solution, 2) what shipment frequency to set for the consolidated solution, and 3) what rebate to offer each customer to make them willing to join the solution. Although, in reality, the final prices are always a matter of negotiation, a tool can be developed based on this to quickly assess which strategy a service provider should pursue before negotiating with each customer individually. Should only a few customers be targeted? Should a high-frequency or low-frequency solution be offered? Should a small or a large rebate be offered? This paper shows how to make these initial decisions based on a forecast of the demand for each customer per time unit and its expected time-sensitivity; that is, how much the customer is likely to have to be reimbursed for reductions in transport quality.

Second, the paper provides insights as to when shipment consolidation is feasible, and what type of consolidation is feasible in which situation. Clearly, the feasibility will depend on the service provider's possibility to set individual prices for each customer. If this is possible (and not costly), it is always more profitable to take advantage of this. But the possibility to set individual prices also affects which customers to include and what shipment interval to choose for the consolidated service. In general, two extreme types of consolidation policies can be optimal: consolidation over "space", where several customers are consolidated at a high shipment frequency; and consolidation over "time", where only one or few customer's demand is consolidated at low shipment frequency. The first type of policy is profitable when many customers are sufficiently homogenous in their time-sensitivity. The second type of policy is profitable when customers are not homogenous, but there are one or a few very time-insensitive customers. When individual prices can be used, the policies are on a continuum: as customers become more heterogeneous, the consolidated solution should be adjusted to fit the less time-sensitive customers. When standard prices are used, the strategies are usually of an either-or-character: either all customers should be consolidated or a selected few (or none whatsoever).

To be profitable, the service provider must accurately match consolidation policy with customer heterogeneity. This match may be difficult to do in practice, since it requires knowledge of all customers' willingness to pay. Perhaps more importantly, as heterogeneity changes (e.g. due to demand shocks), the optimal policy may change while, in practice, a solution's design is often fixed for several years because of long-term investments. Also, the change in heterogeneity may lead to a situation where the optimal policy is to *not* have a consolidated solution. As seen in this paper, these situations are not uncommon. Taken together, this may provide some insights as to why shipment consolidation is rare in practice and why so many consolidation projects have failed.

Lastly, the paper discusses the environmental implications of the optimal decisions. Although taxation of the conventional technology seem to lead to more customers joining the consolidated solution, the environmental benefit of this is not clear-cut. As in the previous paper, the low-carbon option leads to more inventory. Further, as more customers find it optimal to use the consolidated solution, the shipment interval is reduced, which increases transport emissions. To reach a point where emissions increase due to regulation seem, however, to be rather unlikely in the tests performed.

5 Conjectures and Discussion

The papers in this thesis have in different ways and from different perspectives analyzed the sale and purchase of low-carbon transports. As explained in the introduction, judging from media, research, and public debate there are economic as well as political incentives to shift to low-carbon transports but, despite this, very little change can be seen. This section aims to synthesize some of the main implications from the combined work of the papers, and provide a simple framework for interpreting the theoretical ideas in relation to the question of why such little action is seen.

5.1 Towards a Tentative Theory of How Incentives Control the Shift to Low-Carbon Transports

Even though there are many potential problems obstructing a shift to low-carbon transports, in the following, I will make a more detailed argument for why there is a matching problem, and why long-term contracts may be the solution only in certain situations. As we will see, the matching problem will remain even if transport quality is certain and identical between low-carbon and conventional transports, if infrastructure is problem free, and if the costs of using low-carbon transports are *lower* than what they are today. Although other aspects may indeed be important in specific cases, the matching problem is fundamental: it inhibit shifts that at first sight may seem profitable for all players.

For this argument, consider a transport (service) market[7] with the following basic characteristics, which are argued for in more detail below[8]:

1. Freight transports are outsourced, and performed by another company than the final user of the transport service.
2. Low-carbon transports exhibit greater economies of scale than regular transports: low-carbon transport solutions have lower fuel consumption and operating costs but come at a higher upfront cost.
3. Freight transport and inventory levels are systemically linked: reaching scale economies in transportation will lead to more inventory and/or larger backlog.

For the first point above, something which is often overlooked in the debate on low-carbon transports is the fact that the freight transport market is, in many cases, highly decentralized, in the sense that transports are performed and sold by specialized companies that do not own the goods they transport. As seen in the thesis, in Sweden and many other countries, the vast majority of transports are sold by third party providers (forwarders, cooperatives, etc.) and bought by manufacturers, retailers, and other firms that experience a demand for freight movement (see e.g. the survey by Mellin and Sorkina, 2013). When a transport operation is outsourced, the operation is planned and controlled by the service provider to maximize the service provider's profit (at least in the long run). This means that for many firms, transports are planned and operated by a service provider (given the firm's demand specifications about when and how to perform the transport), while the firm itself (the shipper) primarily plan and control production and inventory.

Next, the "paradox" often expressed by politicians and media is the fact that low-carbon transports, like most other "green" technologies, ought to be cheaper to use than

[7] The capacity market is implicitly handled through characteristic 2, and is discussed at the end of the chapter. That is, focus is on the downstream relation between a service provider and shipper. The service provider is assumed to have get a technology monopoly by implementing the low-carbon teachnology.

[8] It ought to be stressed that it is by no means my intention to capture all types of transport markets with the above set of characteristics. There will always be markets that violate one or several of the characteristics, and some of these I will touch upon later. It is however my belief, as I argue for below, that these characteristics are fairly general and captures many of the transport markets as of today. As we will see, these characteristics lead to a problematic situation.

normal technologies due to lower energy consumption. More fuel efficient vehicles are indeed in most instances less costly to operate, but tend to come at a higher investment cost when implemented (see e.g. Wang et al, 2013), and/or have a higher departure cost due to operators pushing the cost structure downstream (see Papers III and V). In other words, low-carbon transports display larger economies of scale than normal transports – they are more economical, but only on scale. In systems where dispatch frequency and distances are fixed, the implication is that the volatility of the revenue generating volume is important (see Paper IV): if demand is too volatile the underage and/or overage costs may outweigh the scale economies. In systems where dispatch frequency is not fixed, but distances are, the implication is that volume is important (see Paper V): it is optimal to operate a low carbon transport solution with a larger load (i.e. at lower frequency) than conventional transports. This was also seen in Paper II.

Lastly, a crucial, and perhaps not intuitively straight forward, point shown in Paper II, IV and V: when a service provider implements measures to realize the scale economies of the low-carbon transport solution, non-transport costs such as inventory holding costs tend to increase at the shipper. If dispatch frequency is fixed, less volatile order quantities can be achieved, but it will lead to more inventory or a larger backlog at the shipper. This was seen when capacity reservation contracts were investigated in Paper IV. If on the other hand dispatch frequency is not fixed, longer lead times can be implemented, but it, too, will in most cases lead to more inventory or a larger backlog at the shipper. This was observed when time-based consolidation was investigated in Paper V. While, in the latter type of structure, one could find cases where this does not happen, it is highly unlikely given the assumption on cost structure.

In the following, I argue that the non-existent shift may, in large, be due to the incentives that arise from these three characteristics. To illustrate how, consider the simple example[9] in the following section.

[9] Note that when I refer to cost, it includes fixed and variable transport costs for the service provider, inventory costs for the buyer, as well as the service price (which is a negative cost for the seller and a positive cost for the customer). Assume for now that this price is exogenous, but possibly different for the two services. I will relax this assumption shortly. Costs are purely for illustrative purposes, but adhere to the general characteristics.

5.2 An Example

Assume that a *service provider* can choose between two technologies, one *conventional* and one *low-carbon*. The technologies have different economies of scale (in line with point 2 above). If the transports are run at a high frequency and/or with a highly volatile load per shipment[10], the conventional technology incurs an average cost of, say, 6 and the low-carbon technology 8. If, on the other hand, the transports can be run at lower frequency with a more stable load, dispatch costs and underage/overage costs can be reduced, so that the conventional transport costs 5 and the low-carbon transport costs 4. That is, it is always cheaper for the service provider to run transports with a larger and/or more stable load (ceteris paribus), but the cost reduction is greater for the low-carbon technology (a cost reduction of 4 versus a cost reduction of 1).

Now, the service provider has a customer, i.e. a *shipper*. The shipper can choose to purchase either the high frequency and/or variable load service, or the low frequency and/or stable load service. The shipper cannot directly influence which technology is used, but with everything equal, a low-carbon technology is slightly better for the shipper as it may come with a small goodwill profit[11]. If the shipper chooses the first type of service, it will incur a cost of 3 if the service provider uses the normal technology and a cost of 2 if the service provider uses the low-carbon technology. If the shipper chooses a low frequency and/or stable load service, which leads to more inventory and/or larger backlog, a cost of 5 is incurred when the normal technology is used and a cost of 4 if the low-carbon technology is used (in line with point 3). Note that none of these costs include the price for the service – we will come to this in a second. Also note that we leave the operator out of the equation for now. This is discussed towards the end of the chapter. With this example, we can see what may happen on a transport market that fulfill the three characteristics.

By letting the shipper and the service provider interact on a *transport service market* (in line with point 1), we get the cost matrix illustrated in Table 5.1. The service provider controls decisions regarding which technology to use (vertical decisions) and the

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[10] I bundle these because the resulting effects are the same whether or not the service is just high frequent, just accepts volatile loads or both.

[11] See Chapter 2. This is also in line with the cases from this thesis.

shipper controls which service to purchase (horizontal decisions). The service provider's cost is the first number in each parenthesis and the shipper's is the last. The arrows indicate a cost reduction. Assume now that there are no long-term contracts. Decisions can thus be seen as simultaneous. The shipper is then always better off using the first type of service, so the only equilibrium in this situation is to have a high frequency and/or volatile load service using the conventional technology. However, looking at the table, we see that this is not the socially optimal solution: the total cost of the equilibrium is 6+3=9, but the total cost of having a low frequency and/or stable load service with the low-carbon technology is 4+4=8. That is, *the incentives created by the characteristics above lead to a situation where the total costs are higher than they would be if a benevolent social planner (a purely theoretical construct) enforced a solution or if the decisions were made by the same company*. Clearly, if the shipper could choose technology it would always opt for the low-carbon technology; and, if the service provider could choose service it would always opt for the low frequency and/or stable load service. Despite this, equilibrium is a high frequency/volatile load service using the conventional technology. In other words, we get what was discussed in the introduction and reinforced in Papers II and III: *each player has a genuine interest to shift but has insufficient incentives to do so because of the other player's expected actions*. We have a matching problem.

Table 5.1. Cost matrix and equilibrium. Cost on the form: (*service provider*, shipper)

		Shipper	
		High frequency and/or volatile load	Low frequency and/or stable load
Service Provider	Conventional transport	(*6*, 3)	(*5*, 5)
	Low-carbon transport	(*8*, 2)	(*4*, 4)

More problematic is that the equilibrium of this game is very robust. As long as the points above hold and no additional feature is added, the top left-hand cell will be the only equilibrium. It will also be a suboptimal outcome if the shipper's cost-increase from shifting (i.e. 4-3=1) is smaller than then service provider's cost-reduction from shifting (i.e. 6-4=2).

Obviously, the phrase *no additional feature is added* is key in the above statement. As mentioned in the beginning of the example, the argument and the matrix is based on the assumption that the two services are sold at prices that are exogenously determined and not necessarily different from one another. Clearly, this does not hold in many transport service markets: if the shipper is at least somewhat rational, reduced transport quality (such as a lower frequency) will lead to lower demand unless the price is reduced accordingly (see further in the appended papers). Let us therefore see how the relaxation of this assumption affects equilibrium.

Changing the price for a service means that wealth is transferred from one player to the other (demand is in this example given). If the service provider has the power to change the price, a price change will affect all cells in a column of the matrix. How can this transfer be done in practice? Well, basically, it is just a matter of pricing. A lower price, ceteris paribus[12], transfers wealth from the service provider to the shipper and vice versa, independently of what type of contract is used.

While a wealth transfer will solve the matching problem in many situations, it is sometimes futile. To see this, consider again the values in the table. To make the shipper choose the second type of service[13] , independently of technology, the service provider has to offer a rebate larger than 5-3=4-2=2. This would indeed lead the equilibrium to shift to the lower right-hand cell (the social optimum). But if this is done, the service provider's cost increases to more than 4+2=6, which would be an increase compared to before, and thus irrational. Likewise, it may be in the shipper's interest to offer some kind of monetary incentive to the service provider, so that the shipper can realize the benefits of the low-carbon technology. But to shift equilibrium down to the lower left-hand cell, the shipper must offer a compensation of more than 2, which would lead to a cost increase for the shipper and thus a suboptimal solution. Note that this is under

[12] Any possible demand effects taken aside. As seen in Paper III, a three-part tariff can transfer wealth without demand effects between operator and service provider, which also applies here. The operator-service provider relationship is discussed at the end of the chapter.

[13] for instance, as in Paper IV, a capacity reservation contract

the assumption that it is possible to provide rebates of that size. As seen in Paper V, many times the maximum rebate may be dependent on other shippers' costs structures, which means that it may be impossible to reduce the price enough to shift equilibrium.

5.3 Implications for the General Case

One can make several other attempts to introduce a wealth-transferring component but, in the situation depicted in the table, any attempt to shift equilibrium by relocating wealth without long-term commitment will fail. There is no single way to achieve a pareto-efficient social optimum. That is, based on just a few key characteristics, present in most transport markets, it may be impossible to introduce a shift *despite* the fact that it would lead to lower total costs, *and* despite the fact that it may seem rational at first sight for both players to do so. The end result is that both players blame the other for obstructing a shift.

The general result perhaps provides a greater understanding to the non-existent shift to low-carbon transports. If the algebra of a more formalized model is worked through, it can be seen that if the low-carbon low frequency service above is indeed the global optimum, then the service provider can offer no pareto-efficient wealth-transfer that leads to the social optimum as long as the shipper's perceived benefit of "going green" (the cost difference between using normal and low-carbon technology) is greater than or equal to the social improvement of going green. That is, it is not sufficient that there is a global incentive to use low-carbon transports, *the global incentive must be large enough* for the global optimum to be the equilibrium.

There are however other possible situations, where a pareto-efficient wealth-transfer *is* possible. As long as the low frequency low-carbon service is the social optimum and the shipper's cost change is sufficiently small it will be possible to relocate wealth to shift equilibrium.

A way forward may be to introduce long-term contracts between the service provider and the shipper. As seen in Papers IV and V, this may, in some instances, offer a way to the social optimum (or at least an equilibrium closer to the social optimum). This, however, assumes that the contract horizon is long-enough to cover the investment horizon – otherwise it is not a credible commitment and we return to the structure above.

Another way forward is to change the market to violate the three characteristics. Perhaps one of the most promising ways to do so is to change the upstream contract structure between the operator and the service provider, as shown in Paper III. This contract determines how sensitive the service provider's costs are to scale and thus the extent to which the second characteristic is fulfilled. By changing the contract, the second characteristic may no longer hold and equilibrium outcomes changes. This may however, as seen in Paper III, often be difficult.

Nonetheless, this is as far as we can come by market based initiatives. When such initiatives are not sufficient, other types of initiatives are needed. Market regulation is advocated by some, and has been investigated implicitly in several papers of the thesis. Using the cost matrix, the big difference between regulation through tax and subsidy become clear. Although a sufficiently large tax would shift equilibrium to the lower half of the table, it would not lead to the socially optimal solution (external costs taken aside). A subsidy would shift the socially optimal solution to the left, but the cost of the subsidy will mean that the equilibrium is socially suboptimal. Adding other potential issues such as technology uncertainty further stresses the need to go beyond market based solutions if we are to meet the policy objectives.

It should be noted that the above argument assumes that utilization of vehicles in the transport system where the service provider is shifting to green transports are not close to 100%. Although this represent most situations, there may be situations in for instance line traffic, where vehicles between two points are more or less completely filled. In these instances, vehicle utilization cannot be improved, which means that a shift simply depends on whether or not it is cheaper to run a full green vehicle than a full normal vehicle. Relating this to the matrix, only one of the columns is a feasible solution. Another way to see the situation would be to argue that it violates characteristic number 2, that is, that no economies of scale can be realized by shifting, and that this instance fall outside the scope of the model. In any case, in these instances shifting is not a matter of scale economies, it is simply a matter of economies.

So, in summary: in decentralized freight transport markets, where low-carbon transports have larger economies of scale than normal transports, and the transports are used in a customer's logistics system, shifting to low-carbon may be impossible. Consequently, in such markets, shifting will only be possible if one or several of the characteristics are not apparent. In other cases, contracts can transfer wealth to achieve a socially optimal solution. This may help us understand why there are some anecdotal evidence but no large scale implementation. It also reinforces the findings from Paper I, that freight transports are not seeing radical environmental improvements.

6 Conclusions, Contributions, and Future Research

In this chapter the findings of the research is discussed in light of the research purpose and objectives. Focus is primarily on the synthesized thesis, more detailed discussions for each individual study are presented in the respective paper. The chapter presents theoretical contributions, managerial insights and closes with a short outlook on future research possibilities.

6.1 Revisiting the Research Objectives

In much of the literature on sustainability in supply chains, the many positive outcomes of sustainability projects are often emphasized (e.g. Plambeck, 2012; Klassen and McLaughlin, 1996). By "going green", it is claimed, firms will reduce costs and improve long-term profits, and reap many other positive side effects along the way. Politicians across Europe agree. To simplify and speed up the progress, programs have been set up to advocate and even subsidize projects aiming to shift transport to less polluting modes, or projects aiming to consolidate freight to improve freight transport efficiency (EU, 2011). The technology for such changes already exists. And there seem to be both economic incentives and political ambition to make a change happen. However, when data is examined, very little change can be seen.

This thesis set out to address this conundrum and potential paradox in a series of studies. If there are political ambition, economic incentives, and available technology, why then is there almost no shift to low-carbon transports? Based on literature on (sustainable) supply chain management and transport contracting, the underlying idea guiding the research was that transport contracts and the nature of the system in which the contracts are implemented may have a strong impact on the incentives to shift to low-carbon transports. Consequently, the research set out to investigate these incentives in more detail, with the formal purpose being to *increase the understanding of the incentives to shift to low-carbon freight transport.*

The study was broken down into three sequential research objectives:

RO1. *To identify how changes on the freight transport market and changes in adjacent systems in society impacts freight transport emissions.*

RO2. *To explore what operations changes a shift to low-carbon freight transport leads to, and under what circumstances such a shift is made.*

RO3. *To explain and predict under what circumstances, and to what extent, there are incentives for the actors on the freight transport market to shift freight to low-carbon transports.*

In the following, I will discuss how each of these objectives have been met and, in particular, how they have contributed to the overall purpose.

6.1.1 RO1

The first objective followed from the idea that before any inquiry about a system is made, one should define and explore the overall system first (e.g. Checkland, 1999; Forrester, 1994). To meet the objective, a study (reported in Paper I) was constructed to investigate and discuss historical changes on the transport market and adjacent systems in society (i.e. the "large system"), and what effect those changes has had on the carbon emissions from freight transport over the period. The study presented an overview over the changes in the defined variables over the time period, as well as the resulting carbon emissions. It also provided a theoretically informed speculative discussion about potential explanations to the observations.

One of the key findings from the study was that the observed development seems to align well with predictions from growth cycle theory. According to growth cycle theory, the macro economy follows large cycles over 40-60 years that end and begin in structural crises. Simplified, each cycle has a transformation period when the new industry structure develops, followed by a rationalization period when the new structure settles. Currently, the economy, including the transport market, is in a rationalization period, where processes are incrementally improved using the new technologies from the transformation period on broad scale. These technologies are predominantly different types of IT-solutions or telecom technologies, such as ERP-systems, routing software, GPS, or capacity planning tools. Firms rationalize by implementing these solutions. Since the data is well in line with predictions from growth cycle theory, it also means that firms are rationalizing in more or less the same rate as could be expected from the theory, which has no environmental motifs in its mechanisms. That is, the rationalization is likely not driven by the implementation of low-carbon technologies that happen to cut costs – it is driven by the implementation of cost-cutting technologies that may in some cases reduce carbon emissions. This is supported by findings of Lundquist and Olander (2009), who show overall decreasing transport cost especially during the first years of the 2000's.

This macro-economic observation can be contrasted to e.g. Nidumolu et al. (2009), who argue that sustainability drives innovation. In the case of the transport market, sustainability-concerns may drive technology innovation in related subsystems, but there is very little support that it drives the *implementation* of innovative technology on the transport market, at least not in aggregate data. The overall transport emissions have increased, and emissions directly related to the decisions on the transport market (e.g. traffic intensity) has not improved more than what would be expected based on theoretical predictions and observations from previous growth cycles. This is especially interesting considering the political ambition to reduce freight transport emissions (EU, 2011).

6.1.2 RO2

The second objective followed from the idea that theory development should be grounded on structured observations, something highlighted as a particular problem for the theoretical sustainable supply chain management literature (Seuring, 2013). This objective was met through two studies, investigating different parts of the overall system. The first study (reported in Paper II) investigated the shippers' contracting of transport services, to identify what operations changes that were needed at the shipper to "fit" the low-carbon transport solution (intermodal truck-train), and what contextual factors that enabled the fit. The second study (reported in Paper III) addressed the objective by investigating the service providers' contracting of low-carbon transport capacity, to identify contract types, major costs, and market roles in this part of the overall system[14].

Starting with the service provider-shipper relation from Paper II, an important observation for the coming analyses was that there are different ways for a shipper to contract intermodal transports, which means that demand volume is not always important. Large shippers can have a dedicated solution set up tailored to their needs, which was the case for one of the shippers. With such a solution, transport quality in terms of transit time may very well be at par with trucking. For smaller shippers, the option was rather to be part of a joint solution with shipment frequencies set by the service provider. Joining a solution in this way usually meant a reduction in transport quality (transit time, reliability), with larger inventories as a result. In either case, it was shown that the management of the shipper could make 'holistic' simultaneous decisions on inventory policies and transport purchases. The study also highlighted the general complaint among the shippers that there is a lack of low-carbon service supply. In most cases, shippers had to spend significant time and resources in actively pursuing service providers, as these were unwilling to invest in large-scale solutions when they already had well-functioning road-networks.

To better understand what was limiting the service supply, the study reported in Paper III set out to explore the next upstream relation: that between the operator and the service provider. The study showed that, on the intermodal market that was investigated, much of the explanation could be contributed to the contract form with the upstream operators and the cost structures those contracts gave rise to. For instance, both case companies used contracts that shifted the full risk of the investment to the service provider, an observation well in line with e.g. Storhagen et al.'s (2008) claim that operators have a strong production focus. This was possible due to the market conditions. First, the operators possessed a natural monopoly on this specific technology, which gave them pricing power and the option to choose contract type. Second, the service providers were both facing strong pressure from downstream shippers to offer low-carbon transports. Consequently, the service providers could

[14] The purpose of the entire study, which included a modeling phase, was to also see how these changes affected incentives

either reject the operator and lose downstream customers, or accept to take a higher risk, adjust planning and sales to handle this risk, and see the move as a high risk investment. The two service providers in the study, Bring Frigo and Volvo Logistics chose the latter. As we know, Volvo discontinued it service after a few years.

The above observations also provide insights to the micro-level decision-making that underlie the observations in Paper I. The studies show under which circumstances shifts are made (contract types, cost structure, market roles, demand processes, etc.) and what operations changes that were observed in conjunction with the shift (changes in inventory, planning efforts, etc.), providing a stepping stone for further, mathematic-theoretical, inquiry.

6.1.3 RO3

The observations from the first two phases served as input for the analytical inquiry phase addressing RO3, reported in Papers III, IV, and V. The first of these studies (Paper III), investigated the relationship between an operator and a service provider based on the observations from the intermodal market reported in previous section. This resulted in two major insights.

First, it was shown that the observation that service providers often have to contract a full intermodal train to reach the cost advantage of intermodal truck-train transport is rational behavior, given the observed cost and market structures. When the operator has the pricing power, she has incentives to “push” the investment cost and semi-fixed departure cost downstream to the service provider. This explains Lammgård’s (2012) observation that a service provider may struggle to make an intermodal solution profitable while the intermodal operator makes back-to-back profits. If the service provider does not have sufficient incentives to accept and adapt to the risk of the intermodal solution, e.g. because of lack of resources or capabilities, there will be no intermodal transports at all. Or, if the parties decide to go ahead anyway, they are likely to follow the fate of Volvo. Since this is an effect of the technology monopoly of the operator (on the specific relation), it applies to all transport capacity markets where this is the case.

The second insight was that introducing a risk-sharing contract may release the dead-lock that this behavior creates. If the operator retains some of the risk, the service provider will have more incentives to shift. It should be noted though that risk-sharing is more complicated than sharing the fixed cost of the intermodal train. DHL, for instance, has a solution in Central Europe where this is the case (DHL, 2005). However, just sharing the fixed cost is suboptimal since it does not take advantage of the fact that firms have different capabilities and market information. A three-part-tariff takes such considerations into account implicitly, which leads to higher total profits.

The insights from Paper III were then used as input to studies in Papers IV and V. These investigated the service provider-shipper relation for two situations observed in Paper II: when one large shipper approaches a service provider to set up low-carbon transports; and when a service provider offers several small shippers to join a consolidated low-carbon transport solution.

Paper IV considered a service provider with a single shipper, where the shipper has offered to make a long-term capacity reservation to reduce the service provider's risk in investing in low-carbon transports[15]. The paper showed that this may be a rather good way to incentivize investment: a capacity contract, when profitable, leads to more low-carbon transports than "normal" volume contracts. One example is Coop, who has made a long-term capacity commitment with its intermodal service provider (Coop, 2013). By making the long-term commitment, Coop took most of the risk, which made the (more or less dedicated) solution a feasible investment for the service provider.

The environmental downside is that shifting to capacity contracts leads to inventory build-up. As seen in the paper, this may have a significant environmental impact; in extreme cases it may even offset the reduction in transport-related environmental impact. The financial downside is that the shipper's profitability becomes very sensitive to changes in demand fluctuations. Even a small change may lead to long-term losses, or force the retailer into an unwanted "broker"-role to remain profitable. This

[15] Transports are periodic as in Paper III, so the price charged by the operator in Paper III is (part of) the investment cost for the service provider in Paper IV. It is assumed that the investment cost is variable in volume for the service provider. For the intermodal case, this can be explained by the fact that the periodic train cost may be small compared to other volume dependent costs such as trailer rent and handling. For cases where other low-carbon technologies are being implemented, such as bio-diesel trucks, it can be assumed that the technology monopoly assumption is still valid, which means that investment costs are pushed to the service provider, leading to volume variable investment costs.

sensitivity also implies that there are very few situations in which a capacity contract is both an environmental *and* a financial improvement compared to volume contracts.

The paper also showed the somewhat surprising result that introducing capacity contracts may make it more difficult to assess the effectiveness of regulation such as road tolls or carbon taxes. When capacity contracts are used in a technology monopoly, regulation that makes normal trucking more expensive creates incentives for the service provider to raise the price for low-carbon transports, possibly leading to more trucking and *less* low-carbon transports.

While in Paper IV, scale economies were reached by reducing demand volatility, in Paper V, dispatch was assumed to not be fixed, which meant that scale economies could be reached by increasing expected demand per shipment through a longer intershipment interval, more shippers on each departure, or both[16]. Paper V investigated a situation where a service provider offers shippers to join a low-carbon transport solution with other shippers at a reduced cost. The paper shows that whether or not such a type of solution is feasible depends primarily on two aspects: the heterogeneity among customers in terms of their time-sensitivity, and the service provider's possibility to price discriminate among these customers. If customers are heterogeneous and price discrimination is difficult or expensive, it becomes difficult to reach scale economies simply by including many customers – scale economies have to be realized by a few large clients that are willing to accept a less frequent service. This may make implementing such a solution very difficult, since a very special mix of customers is required. This corresponds well to what was seen in Paper II. It also illustrates why Bring Frigo and Volvo were both very dependent on a few major clients.

[16] The scale economies is also here an effect of costs pushed downstream as witness in Paper III, but are framed slightly different since decisions are not periodic in the same sense as in Paper III. It is assumed that the investment cost is not variable in volume. In the intermodal case, this translates to the cost for the low-carbon transport being a "per-train" type of cost for the whole solution (which may include trailer rent), while express trucks are purchased on a per-truckload basis. In other cases, it translates to situations where the service provider pays per departure for the low-carbon transport but can buy direct express transports with the same transit time.

6.1.4 Overall purpose

So – going back to the overall purpose of the thesis – what can be said about the incentives to shift to low-carbon freight? To sum up, the thesis presents an overview of factors that control freight transport carbon emissions on aggregate level, empirical observations about what effects the implementation of certain low-carbon transport solutions have led to, and analytical models consolidating these finding to explain and predict when and to what extent there are incentives to shift to low-carbon freight transport.

First, the research, the research highlights the matching problem of the transport market. That is, due to market and contract characteristics, it is only under very special circumstances there are incentives for all players on the market to make a shift low-carbon transports, even when it may be globally optimal to do so. In most cases, it is rational for operators to make investments in low-carbon vehicles only when the risk of the investment can be pushed downstream. If this is not possible, investment is unlikely. If it is possible, the service providers/forwarders downstream will face a different cost structure, making it rational for them to seek larger economies of scale. Usually, this can only be achieved by actions that reduce transport quality and thus increase costs at the shippers. In certain cases, the shippers are willing to accept this. In most cases, however, they are not.

The implications of this was shown in the previous chapter; breaking the "equilibrium", where little investment is seen, may be difficult – even when technology uncertainty and other complicating factors are absent. In other words, there are good reasons we get what was observed in Papers II and III: shippers blame service providers for lack of supply, while service providers blame shippers for lack of demand. This, in turn, leads to what was seen in Paper I: very little progress.

Through the analysis in this thesis, several ways to break out of this behavior is also highlighted. Certain long-term contracts may work in certain situations but, as seen in the papers, this is situation dependent. While much work remains, the thesis in particular highlights that the operator-service provider relation may be a key relation to address to enable a shift to low-carbon transport, possibly through contractual changes. A change here will alter the downstream cost structures, which may lead to a change in equilibrium, to a situation where there is more investment. More cooperation will benefit all.

6.2 Theoretical Contributions

As seen in the literature review, as well as in the individual papers, this thesis relates to several streams of literature discussing sustainability in supply chains and transport contracting. In this section, I discuss how the research reported in the papers contributes to these streams. The contributions are summarized in Table 6.1.

6.2.1 Sustainability in supply chains

In the sustainable supply chain management literature (e.g. Seuring, 2013; Tang and Zhou, 2012; Carter and Rogers, 2008), incentives have been discussed previously, but often from a very general point of view. Following the call from Seuring (2013) and Tang and Zhou (2012) on research on sustainability aspects of contracting, this thesis has, on a more detailed level, analyzed how incentives on the transport market, as dictated by the contracts used to buy and sell transports, impact the shift to low-carbon transport solutions. The research in this thesis adds to the sustainable supply chain management research by highlighting how these incentives can lead to situations where no shift is the individually rational option for all players, despite the fact that shifting would lead to a global optimum, where all players would be better off. It also shows that in some instances, long-term contracts may be a way out of the equilibrium.

Two other streams of research on the topic where highlighted in the literature review, based on the review by Tang and Zhou (2012). The first concerns technology selection, which has seen contributions on a more general level where the type of technology is not specified (e.g. Drake, 2010) and contributions where focus is on transport technology (e.g. Wang et al., 2013). This thesis followed the latter track, and focused on transport technology selection, although some of the findings are applicable to other types of technologies as well. The key contribution to this literature is that, in this thesis, the technology was outsourced to a third party and thus could only be influenced through the contractual agreement. I show that this not just complicates the problem, but leads to behaviors that make investment difficult. I also show in Paper IV, that it leads to a situation where regulation may have a very different impact than one would expect.

Table 6.1. Contribution to different literature streams

Topic	Literature Stream	Key References	Main contribution(s)
Sustainability in supply chains	Sustainable Supply Chain Management	Seuring (2013), Tang and Zhou (2012), Plambeck (2012), Klassen and McLaughlin (1996)	Show how incentives from contracts are important in understanding the implementation of sustainability measures
	Technology selection	Wang et al. (2013), Kleindorfer et al. (2012), Storhagen et al. (2008), Woodburn (2003)	Provide a decentralized perspective, where technology choice can be influenced through contract form
	Sustainable Operations	Ulku et al. (2012), Hoen et al. (2010),	Highlight the interplay between transport operations and inventory when implementing low-carbon transportation, and its effect on emissions and costs
Transport contracting	Supply chain contracting	Aksin et al. (2008), Naryanan and Raman, (2004), Cachon (2003)	Provide closed form solutions for multi-period model where inventory is carried between periods; show how strategic decisions impact tactical decisions
	Third party logistics contracting	Alp et al. (2003), Serel et al. (2001)	Highlight the trade-off between inventory and transport emissions
	The trucking market	Lipsey et al. (2005), DeVany and Saving (1980)	Show how the lack of investment in low-carbon freight transport can be an equilibrium

The other stream concerns sustainable operations. In particular, this thesis explores the interconnection between transport and inventory operations. It adds to previous research exploring the environmental effects shipment consolidation models (e.g. Ulku et al., 2012) or mode choice inventory models (e.g. Hoen et al., 2010), by analyzing how strategic contracting decisions affect tactical transportation and inventory decisions. This thesis adds to this stream mainly through the analyses in papers IV and V, and extends the discussion further by including contracting dynamics.

6.2.2 Transport contracting

The other major topic that was highlighted in the literature review is transport contracting. In the general supply chain contracting literature, incentives and coordination has been discussed and analyzed in a large number of papers. The contributions to this literature is mainly technical, as this thesis extends previous models (e.g. those review in Cachon, 2003; and Aksin et al., 2008) to look at multi-period models where inventory is kept between periods. In the theoretical sections of the thesis, closed form solutions are derived for the players' decisions in such situations. From a more managerial perspective, the thesis contributes to the literature by highlighting how strategic decisions (contracting) affect tactical and operational decisions (inventory, vehicle dispatch).

The contracting literature that is more context relevant (e.g. Alp et al., 2003) often have either a buyer's or a seller's focus. This literature is extended as the thesis considers a contracting perspective where both players optimize their decisions simultaneously.

The thesis also makes a contribution to the literature about the transport market, including the research by de Vany and Saving (1977), both through the papers and, perhaps especially, through the discussion section of this thesis, by showing how the non-existent shift can be explained as an equilibrium outcome of a decentralized market. In summary, the main contributions to the different streams of literature is highlighted in Table 6.1.

6.3 Managerial Implications

This thesis involves several decision makers, in particular those on the transport market (shippers, service providers, operators), but also, as seen in Paper I and Papers IV-V, regulators or other actors in society whose decisions influence the decisions of the actors on the transport market.

The major managerial insight, which applies to all entities, is that incentives based on contracts and market structure *do matter* in the implementation of low-carbon freight transport solutions. The fact the transports are outsourced, that low-carbon freight transports exhibit greater economies of scale than conventional transports, and that in realizing the economies of scale, shipper costs increase, often lead to situations where it would be better for the total system to invest in low-carbon transport, but where incentives are distorted so that it is not a rational choice. The end result is that the different actors on the market blame each other for inertia.

If the premise is accepted that this type of matching problem exists, the actors of the transport market, as well as society in large, must think about what could be done to overcome this problem. Part of the matching problem is due to the fact that costs and risks are not well allocated by the currently used contracts. As shown in the thesis, long-term contractual solutions are sometimes a possible way to change this. Paper III-V all highlight different solutions (three part tariffs, capacity contracts, and consolidation contracts) that may work well in different situations. As seen in Table 6.2, each solution has its own context where it is more likely to be lead to a successful implementation. For instance, capacity contracts may be possible for service providers with a large dominant shipper with goods that are not of too high value. Also, for each type of solution, there are different upsides and downsides that need to be taken into account when the contracts are negotiated. The environmental benefits can be large, but this is case dependent and cannot be guaranteed. However, in any of these instances, instead of making one side adjust to the other, shippers, service providers, and operators may have more to gain be being more cooperative.

Table 6.2. Three ways to relocate the risk of low-carbon transports through the contract, a short summary

	Three-part tariff	Capacity contract	Consolidation contract
Suitable in the relationship between	Operator – service provider	Service provider – shipper	Service provider – shipper(s)
Design	Sell long-term contract with price equal to the semi-fixed and variable transport costs, and add a lump-sum payment for the service	Sell long-term capacity commitments at a reduced cost per unit compared to the market price for transport	Sell long-term commitments to using a consolidated transport solution at a reduced cost per shipment compared to direct transports
Financially feasible	In many situations, especially when demand uncertainty is high	If inventory costs of the shipper are low (low-valued goods) and the cost benefit of the low-carbon technology is high	For several homogenous customers, or one or a few very time-insensitive customers
Environmental improvement	Uncertain on short-term, seem promising on long-term	If inventory-related impact is low and/or the cost benefit of the low-carbon technology sufficiently low	If optimal shipment interval is not too small neither too large
Pros	Relatively easy to understand design	Flexible in risk-allocation	Flexible in pricing complexity
Cons	Implementation requires operator to step out of “production focus” and accurately report costs	More inventory, shipper must accept (slightly) more risk, requires good information to set the price accurately	More inventory, shippers must accept longer lead times, requires knowledge of customers’ willingness to pay

In many situations no contractual solution can solve the matching problem. Such situations require changes in regulation or other subsystems in the large system which, as seen in the papers, must be carefully designed to not lead to adverse effects. For instance, as shown in Paper IV, just increasing the cost of conventional transports through a carbon tax or a road toll may lead to less investment in low-carbon transports, since it drives up the price of competing technologies as well. Subsidies or changed rules about infrastructure operation (e.g. the maximum size of trucks or trains) may be better alternatives although more research is needed to provide more accurate guidelines as to how.

6.4 Future Research

To discuss the potential for future research, I will identify a number of gaps along different dimensions of the research.

First, the research on sustainability in supply chains investigate many other aspects than those studied in this thesis. For instance, the report by World Economic Forum and Accenture (2009) highlights many decarbonization initiatives, out which only three have been examined in this work. In Table 2.1, we see that these three all fall into either strategic or tactical decisions as described by Aronsson and Huge Brodin (2006), and only covers technology selection and sustainable operations using the classification of Tang and Zhou (2012). Clearly, several other of the decarbonization initiatives, belonging to other decision levels with inspiration from other literature streams, have strong impact and may also be affected by incentives created by contracts. One venue for further research is to try and apply a similar incentive-oriented perspective on these issues, and investigate them empirically as well as theoretically. One example is the supply chain design issues highlighted by World Economic Forum and Accenture (2009) and discussed in Pazirandeh (2012) and Cachon (2011) – how would the supply chain design be affected if retailers or manufacturers are not governed by the same decision-maker? And more importantly, what would the environmental implications be?

Next, the theory development was much guided by the supply chain contracting literature (e.g. Aksin et al., 2008; Cachon, 2003). In the literature review, I argued that this (theoretical) literature can be described as differing in four main dimensions: endogeniety, player preferences, game characteristics, market structure, as seen in Table 2.2. The three theory development papers in this thesis do cover slightly different aspects of each of these dimensions. For instance, Paper III considers both general contracts and specific contracts. And while Paper III and Paper IV consider one buyer and one seller, Paper V considers many buyers. But there may be other contracts and structures that are of interest to investigate. Could any other type of risk-sharing mechanism work better than those investigated in the thesis? And in terms of structure, would a model where all tiers are investigated simultaneously change any of the results?

While the papers differ along some of the abovementioned dimensions, there are many dimensions in which the papers are similar, especially in terms of assumptions about game characteristics (which is, in a way, natural since they are based on the same observations). It may be of interest to relax some of those assumptions, to see whether including these aspects would bring additional insights. Of particular interest, I think, is to relax the assumption about full information, as it can be speculated that some of the information on the market is difficult or costly to obtain and may cause further incentive distortions, as has been shown in contract theory to often be the case (see e.g. Bolton and Dewartripont, 2005). Will this be the case also on the transport market? There are also aspects such as competition and regulation that are of interest to investigate further – how can, for instance, regulation be designed on a market with capacity reservation contracts to maximize welfare?

There are also some gaps related to methodological choices, as reported in Chapter 3. The empirical observations are anecdotal, and more investigation of other roles may provide an even better understanding of the market. How does, for instance, the one-man-and-a-truck haulers reason regarding contracting and investments in low-carbon transport equipment? How does the size of the hauler impact its possibility to make the investments? And how do other actors on the transport market perceive the market power?

Lastly, and perhaps more importantly, theories need to be tested! Part of the scientific method is the constant iteration of theory development and theory testing. This thesis followed a structure similar to the first steps of the scientific method: using structured observations from which theory is developed (see e.g. Figure 1.1). In order to better understand the implementation of low-carbon transportation, these theories need to be put to empirical test. This could be done both through large scale empirical investigation and through experiments aimed to bring clarity to how the effects created by the incentives can be overcome in the short and long run. Examples from the supply chain contracting literature are given by Cachon (2003). Along the same line, more normative studies could be executed to try to design and devise contracts, regulatory interventions, or even markets where the incentive problems can be overcome. In all, there are plenty of opportunities ahead.

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Appendix – Appended Papers

I. Eng-Larsson, F., Lundquist, K-J., Olander, L-O. & Wandel, S. (2012). Explaining the cyclic behavior of freight transport CO2-emissions in Sweden over time. *Transport Policy,* 23, 79-87.

II. Eng-Larsson, F. & Kohn, C. (2012). Modal shift for greener logistics – the shipper's perspective. *International Journal of Physical Distribution & Logistics Management*, 42(1), 36-59.

III. Eng-Larsson, F. & Norrman, A. (2014). Modal shift for greener logistics – exploring the role of the transport contract. Forthcoming in *International Journal of Physical Distribution & Logistics Management*, 44(10)

IV. Berling, P. & Eng-Larsson, F. (2014). Selling green transports to a retailer – investment, pricing, and contract choice. *Submitted*

V. Berling, P. & Eng-Larsson, F. (2014). Pricing and timing of consolidated deliveries in presence of an express alternative – financial and environmental analysis. *Submitted*