Adaptation to Climate Change in Inland Waterway Transport

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Adaptation to Climate Change in Inland Waterway Transport

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de Vrije Universiteit Amsterdam,
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in het openbaar te verdedigen
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De Boelelaan 1105

door

Olaf Erik Jonkeren

geboren te Alkmaar

promotor: prof.dr. P. Rietveld
copromotor: dr. J.N. van Ommeren

PREFACE

It was in October 2004 when the supervisor of my Master's thesis, Frank Bruinsma, asked me if I would be interested in a PhD position at the Department of Spatial Economics of the VU University. At first, my thoughts about doing a PhD were somewhat sceptical. First of all, I had just received a Master's degree in Business Administration, not in Economics. Second, working hard for a PhD salary for four years, and meanwhile becoming a 'weird' scientist, did not seem very attractive to me. However, the practical focus of the research, combined with a very interesting research topic and the prospect of the title doctor, made me decide to accept the job. Four years and a few months later, I can say I have never regretted this decision. So Frank, I am very thankful to you for pushing me a little bit to take the job at that time.

With Jos van Ommeren as my copromotor and Piet Rietveld as my promoter, I have been able to improve my research skills. Both of you were always close by for valuable support and tips and for motivating words. I am very grateful for that and for your confidence in me.

For producing Chapter 3, I was invited to work with Bart Jourquin in Mons, Belgium. I want to thank him for being able to use his NODUS model, for explaining how to work with this model, and for solving the bugs quickly when I encountered one.

During the entire PhD period I enjoyed working in room 4A-41. I want to express my thanks to Ghebre, Yin-Yen, Vanessa, and during the last few months, Stefan for our interesting discussions on media topics and for the friendly atmosphere.

As well as working on this thesis, some EU and other projects, teaching and supervising students who were writing their Master's theses also needed to be done. Working together on this with Sander, Erik, Hadewijch, Frank, Elfie and Piet has always been a congenial experience and I want to thank them for that.

Without good-quality data, producing this dissertation would never have been possible. Therefore, I would like to thank the people who provided me with the data. First of all, I am very grateful to Dirk van der Meulen for making available the Vaart!Vrachtindicator-data on inland waterway transport trips. I would also like to thank the Centraal Bureau voor de Rijn- en Binnenvaart (CBRB) for providing the data on fuel prices, NEA and the Central Commission for Navigation on the Rhine (CCNR) for the data on regional transport flows and transport costs, and Aline te Linde from the Institute for Environmental Studies (IVM) of the VU for her hydrological modelling data. Finally, I owe thanks to Bert Luijendijk from the Port of Rotterdam for his time, and Hans and Jolanda Pikaart for letting me experience an inland waterway trip from Cologne tot Rotterdam on his 5000 tonnes inland container ship.

Then, apart from all the pleasant work-related memories of my colleagues, I also want to mention several great social activities. First of all, the whisky-meetings with Eveline, Ron, Friso and, of course, the whisky-expert Frank were always very joyful occasions. The flavours vanilla, fruit, peat, medicinal and ‘rotten crosstie’ are still in my memory (although the last-mentioned flavour will not sound familiar to many whisky experts). I hope that we will have many more of those meetings. Also thank you Jos, for your hospitality when Angélique and I visited Oslo. Then, I would like to thank all department members with whom I played football matches during conferences, explored nightlife in Paris, Porto and Liverpool, and had interesting conversations during gatherings at the RE-union.

Thanks also go to my friends who made me relax in the weekends by going out in Alkmaar and playing indoor soccer. The friend whom I want to mention specifically is Erwin, because, besides being my friend, he is above all my brother. Many thanks for your interest in my work and for being my brother.

I also want to express my gratitude to my parents, Jan and Margôt: thank you for all the things you have done for me in my life, for your care and support. And finally, I want to express my love for Angélique and Julia. Thank you both, for enriching my life.

Now let’s celebrate!
Olaf Jonkeren, May 2009

The work contained in this dissertation is carried out in the framework of the Dutch National Research Programme Climate *changes* Spatial Planning. This programme is financed by the Ministry of Economic Affairs. Its aim is to contribute to the knowledge of the impact of climate change on different sectors of the economy in order to make the Netherlands ‘climate proof’.

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CHAPTER 1

INTRODUCTION

1.1 Climate change

The fourth assessment report on climate change of the Intergovernmental Panel on Climate Change (IPCC) mentions that the speed of temperature increase is accelerating. The 100-year linear trend of global surface temperature increase of 0.74°C for the period 1906-2005 is greater than the trend of temperature increase of 0.60°C for the period 1901-2000. This temperature increase is widespread over the globe and is greater at higher northern latitudes. Land regions have warmed faster than the oceans. Rising sea level is consistent with warming. The same holds for observed decreases in snow and ice extent (IPCC, 2007).

From 1900 to 2005, precipitation increased significantly in certain parts of the world, but the area affected by drought has probably increased since the 1970s. With a high degree of confidence it can be stated that some hydrological systems have been affected through increased run-off and earlier spring-peak discharge in many glacier-and snow-fed rivers (IPCC, 2007).

It is very likely that the cause of most of the observed increase in global average temperatures since the mid-20th century is due to the observed increases in anthropogenic greenhouse gas concentrations in the atmosphere. These concentrations of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) have increased markedly as a result of human activities since 1750. Carbon dioxide is the most important anthropogenic greenhouse gas. Its annual emissions grew by about 80 per cent between 1970 and 2004. Continued greenhouse gas emissions at or above current rates will cause further warming and induce many changes in the global climate system during the 21th century (IPCC, 2007). Many studies have been occupied with estimations of this future climate change.

An obvious problem with these studies, however, is that we do not know exactly how the climate will be in the future. A means of dealing with this uncertainty is the construction of climate scenarios. For the Netherlands, the Royal Dutch Meteorological Institute (KNMI) has developed a set of climate scenarios which focus on changes for

2050. The main dimensions underlying the scenarios are described in Table 1.1 (KNMI, 2006).

Table 1.1: Values for the steering parameters of the KNMI’06 climate scenarios for 2050 relative to 1990.

Scenario	Global temperature increase in 2050	Change of atmospheric circulation
M	+1°C	weak
M+	+1°C	strong
W	+2°C	weak
W+	+2°C	strong

Source: KNMI (2006).

In these climate scenarios, two main uncertainties are considered: the level of global temperature increase and the extent of change of atmospheric circulation (wind direction). A strong change of circulation induces warmer and moister winter seasons and drier and warmer summertime situations than a weak circulation change. The combinations of global temperature increase and change of circulation result in four scenarios. The scenario label “M” stands for “Moderate”, while “W” stand for “Warm”. The “+” indicates that these scenarios include a strong change of circulation. Although the climate scenarios have been specifically constructed for the Netherlands, they are based on the outcomes of several international climate models for Western Europe. Therefore, they give a good indication of possible climate conditions in the river Rhine area, which is the area that is considered in this dissertation.

1.2 Inland waterway transport

1.2.1 Literature overview

Within the transport literature, inland waterway transport has received relatively limited attention. An obvious explanation may be that inland waterway transport only takes place in some parts of the world because it is very much dependent on the presence of natural infrastructure. The economically most important places in the world where such natural water infrastructure exists are parts of Europe (the rivers Rhine, Danube and their tributaries), the US (the Great Lakes area and the Mississippi river), and China (the Yangtze and the Pearl river). It is mainly in these areas in the world that inland waterway transport is of significant economic interest, while air, maritime, rail and road transport take place all over the world. It is probable, therefore, that only from countries in those parts of the world where inland waterway transport is of economic importance do scientific publications on inland waterway transport find their way into scientific journals.

From around 1900, the first scientific work on inland waterway transport was purely descriptive, embedded in the economic or geography literature and mainly focusing on the US. Later in the 20th century, studies such as Patton (1956), Johnson (1911) and Chisholm (1907) describe topics such as waterway infrastructure (the network, the number of tonnes transported on water routes, construction of waterways), competition with railroads (Kelso, 1941; Fisher, 1915; Johnson 1909), and policy and regulation issues concerning inland waterway transport (Johnson, 1911; Wilcox, 1931). But, between about 1955 and 1970, studies on inland waterway transport per se are absent in the scientific literature.

From 1970 onwards, articles on inland waterway transport start to appear again, but now the approach is more analytical. For example, Case and Lave (1972), Bongaerts and van Schaik (1984), Miljkovic et al. (2000) and Yu et al. (2006) use an econometric approach to investigate the determinants of transport costs or rates by barge. Hong and Plott (1982) focus on the effect of regulation on transport prices, volume and efficiency; Polak and Koshal (1980) estimate the effect of progress in technology on costs of inland waterway transport; and Babcock and Lu (2000) forecast the transported grain tonnage by barge on the Mississippi river.

Since about 2004, scientific research on inland waterway transport has shifted to containers, probably because of the large growth figures and the focus on efficiency improvements in inland waterway container transport. In this connection, Konings (2003; 2006; 2007), Notteboom (2007a; b), and Notteboom and Konings (2004) are relevant studies.

A few articles deal with a very specific niche of inland waterway transport: sea-river shipping. The concept of sea-river shipping implies that a single vessel navigates both coastal and inland waters. Articles on this topic be found in Rissoan (1994), Konings and Ludema (2000), and Charles (2008).

A last branch of studies that must be addressed is the one that focuses on the effect of climate change on inland waterway transport from an economic perspective. Studies of this kind will be discussed later on in Section 2.5.

1.2.2 Analysis of the inland waterway transport sector

In this subsection, the inland waterway transport sector in Europe and the river Rhine area will be analysed focusing on both the supply and the demand side of the market. The supply side of the market comprises the fleet and the waterway infrastructure, whereas the demand side concerns the volumes transported in the area under consideration.

The supply side

Roughly speaking, there are two ship types: dry cargo ships (for transportation of metal ores, grain, scrap, etc), and tanker ships (for transportation of oil, chemical liquid products, etc). Table 1.2 shows the number of ships in, and the capacity of, the Rhine fleet per segment.[1] Ships for container transport are not mentioned separately because container ships are included in the segment “dry cargo fleet”.

Table 1.2: The Rhine-fleet on December 31th 2006

Country	**Dry cargo fleet**		**Tanker fleet**	
	Units (no.)	Capacity (tonnes)	Units (no.)	Capacity (tonnes)
The Netherlands	3,828	4,684,886	767	944,746
Belgium	1,272	1,541,131	223	324,810
Luxemburg	13	12,821	18	36,189
Germany	1,803	1,944,042	422	673,082
France	1,316	961,213	77	114,386
Switzerland	20	40,582	37	90,468
Total	8,252	9,184,675	1,544	2,183,681

Source: CCNR and European Commission, 2007.

The Netherlands has by far the largest dry cargo fleet. Second is Germany. France and Belgium have fleets that are about equal in units, but the capacity of the Belgian fleet is larger than that of France because French inland vessels are on average much smaller. Both, in the dry cargo Rhine fleet and in the tanker Rhine fleet the Dutch fleet forms about 50 per cent of total capacity. Luxemburg and Switzerland do not play a significant role in both market segments.

Inland waterway transport enterprises can generally be divided into two types of ownership: owner operators and own account transporters. In the case of the owner

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[1] The Rhine fleet is formed by the fleets of the Rhine-countries: the Netherlands, Belgium, Luxemburg, Germany, France and Switzerland (CCNR, 2002).

operators, goods are transported by another company than the one that produces or uses the goods. In the case of the own account transporters, the goods transported by inland waterway vessels are only those destined for, or originating from, the company concerned (Min. V&W and CBS, 2003). The large majority of the inland waterway transport enterprises are owner operators.

Another division of inland waterway transport enterprises is by size. Table 1.3 illustrates the industry structure. The majority of the inland waterway transport enterprises are 'one-ship enterprises'. Shipping companies are inland waterway transport enterprises that own several ships and have an office on shore. Although Table 1.3 only represents the market structure for the Netherlands, it can be regarded as representative for all Rhine countries.[2]

Table 1.3: Dutch inland waterway transport enterprises in 2002

Size of the enterprise	**Number of enterprises**	**Number of ships**	**% cumulative (ships)**
1 ship	2.930	2.930	61,41%
2 ships	230	460	71,05%
3 ships	73	219	75,64%
4 ships	35	140	78,58%
5 ships	21	105	80,78%
6 – 10 ships	39	301	87,09%
10 – 20 ships	28	371	94,86%
> 20 ships	9	245	100,00%
Total	3.365	4771	

Source: Min. V & W and CBS, 2003, p. 47.

The supply side in the inland waterway transport market can thus be characterized by a large number of enterprises with a small number of vessels, and a small number of enterprises with several or many vessels.

A development that has been observed in the inland waterway transport market in recent years is an increase in scale. In the period 2000-2006, the number of inland ships in the Dutch fleet decreased by 2.3 per cent while in the same period the capacity of the fleet increased by 17.7 per cent (Inspectie Verkeer & Waterstaat and Rijkswaterstaat, 2007). This evolution in vessel size in the tanker and dry bulk markets is due to the commissioning of new vessels that are mainly large in size. At the same time, there is no comparable withdrawal of old vessels from the tanker market, and in the dry bulk market small vessels are sold to countries outside the Rhine area (CCNR and European Commission, 2007).

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[2] ECMT (1999) reports that the inland waterway transport sector in Western Europe is highly fragmented.

The inland waterway infrastructure network in Europe stretches from the North Sea to the Black Sea and from Finland to Southern France and Northern Italy, and covers about 36,000 kilometres (Eurostat, 2008). Figure 1.1 represents a large part of this network. The North Sea – Black Sea route has existed since 1992, when the Main-Danube Canal was opened, making the seaports in North West Europe attractive for Danube countries such as Austria and Hungary. Physically, there is an inland waterway connection between North West and Central Europe, on the one hand, and the Rhone area on the other. However, the French canals are in poor condition and only allow for small inland ships.

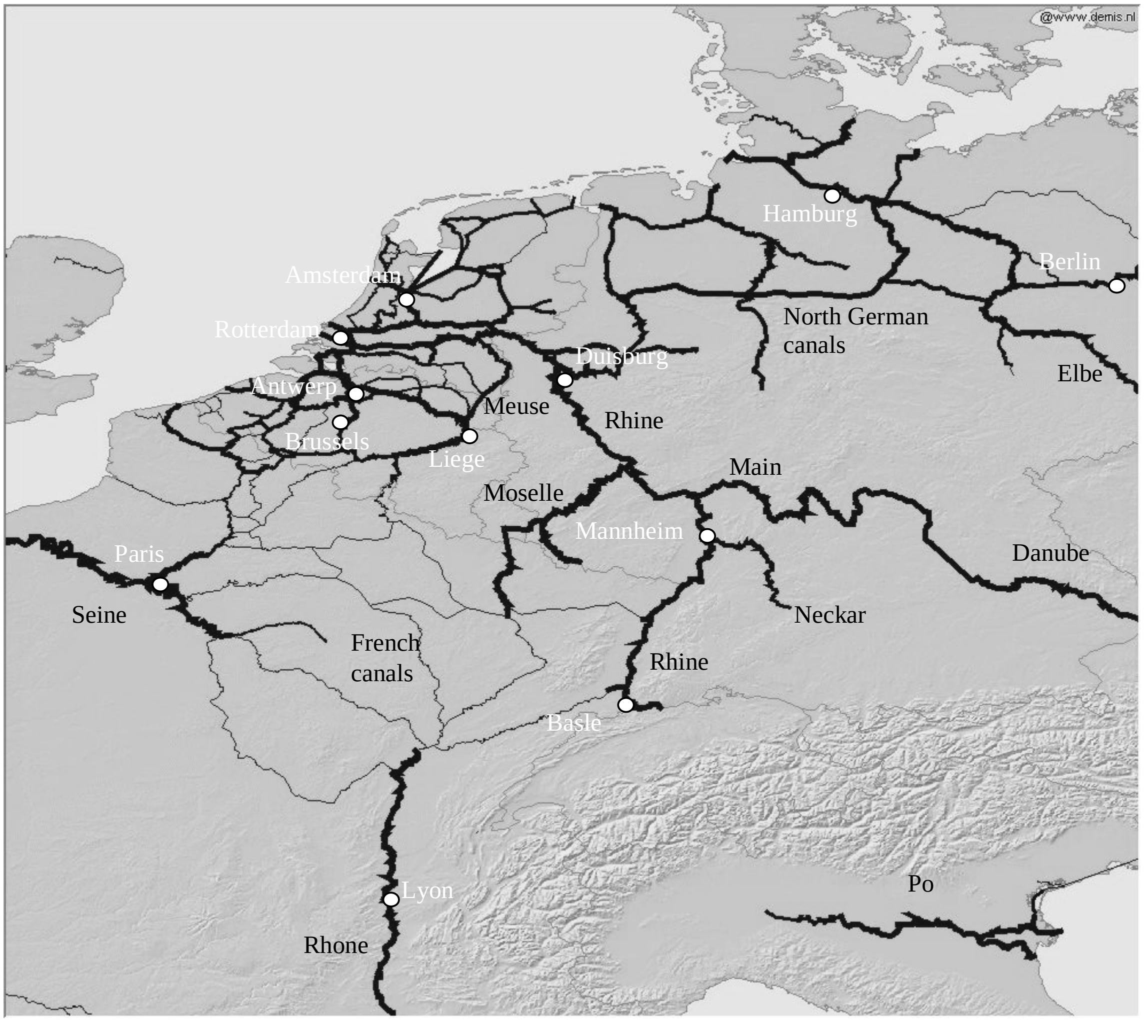

Figure 1.1: Waterway infrastructure in North West and Central Europe

Within Europe the CEMT division[3] is applied to categorize waterways into capacity levels I to V, where a Class I waterway allows the passage of inland ships up to

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[3] This division was made by the Conference of the European Ministers of Traffic in Paris, 1954.

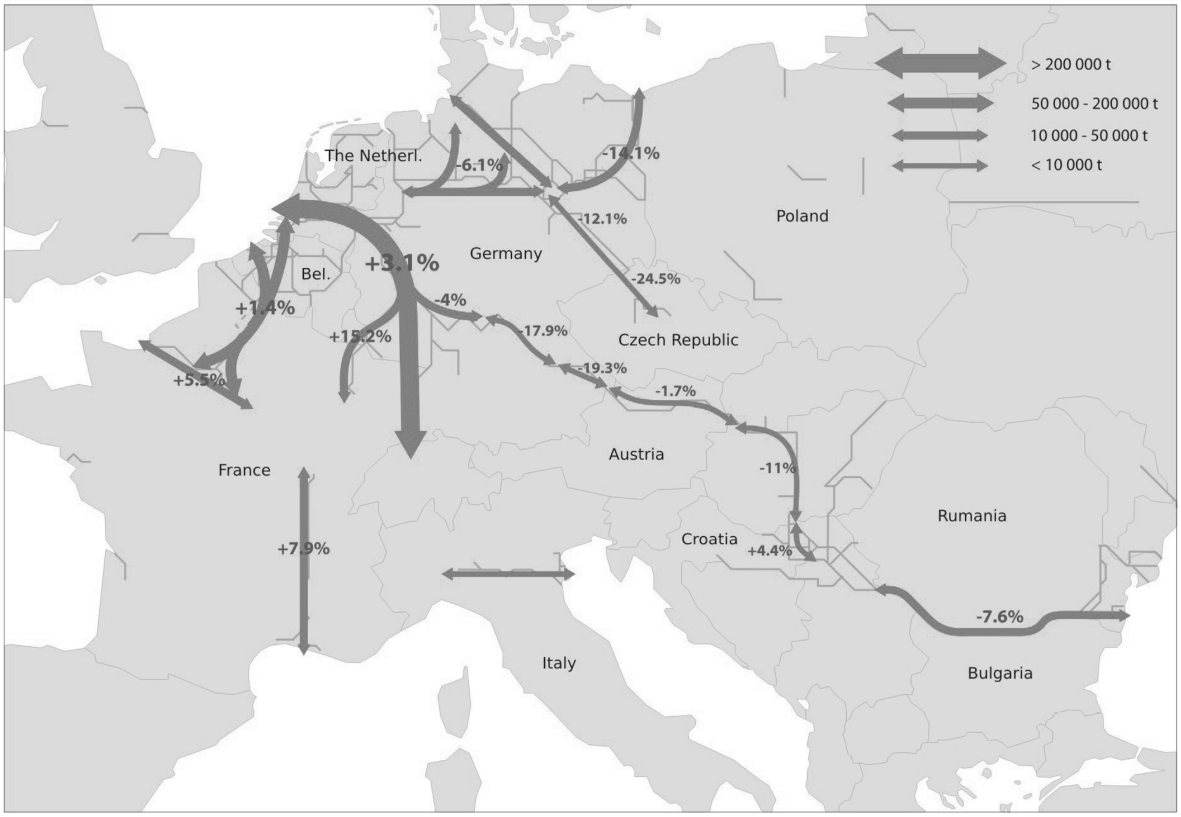

Figure 1.2: Inland waterway transport flows in Europe in 2006

Note: +3.1 per cent (etc.) = percentage change since 2005.

Source: CCNR and European Commission, 2007.

400 tonnes, and a Class V waterway allows the passage of the largest inland ships (of about 8,000 tonnes) and push-tug combinations (up to 18,000 tonnes). From Rotterdam to Duisburg the Rhine river is suitable for such large inland waterway vessels and push-tug combinations, whereas the remaining parts of the rivers Rhine, Moselle, Neckar, Rhone, Seine and parts of the North German canals only allow the passage of inland ships up to 3,000 tonnes and push-tug combinations of a maximum of 6,000 tonnes.

The largest inland ports in Europe in decreasing order are: Duisburg, Liege and Paris. Note that in Belgium and the Netherlands the waterway network has a higher density than in the rest of Europe.

The demand side

The demand for inland waterway transport in the river Rhine area is determined by the intensity of economic activities of industries that are located within this area. Because the inland waterway transport enterprises are hired by the basic industries, they are sensitive to fluctuations in the economic climate.

The average growth in GDP of the EU-27 was 3 per cent in 2006 and 2.9 per cent in 2007. This produced an increase in demand for (inland waterway) transport in Europe. Figure 1.2 shows the main inland waterway transport flows in Europe in 2006 (CCNR and European Commission, 2007).

In 2006, the Rhine corridor, which stretches from Switzerland via Germany and the Netherlands to the North Sea, represented 63 per cent of the volume transported in Europe by inland waterways. The north-south route between France, Belgium and the Netherlands carried about 15 per cent of the volume and the east-west route in North Germany, linking Eastern Europe and the German North Sea ports to the industrial Ruhr area, about 4 per cent. Finally, the Main-Danube route, from the south of Germany to the Black Sea carried for about 10 per cent. The figures on the map indicate the change in volume compared with the year before (CCNR and European Commission, 2007). We can conclude that the Rhine corridor is by far the most important inland waterway in Europe in terms of volume transported. This is mainly because the Rhine corridor connects the seaports of Rotterdam, Amsterdam and Antwerp with large industrial areas in Germany. In 2006, about 320 million tonnes were transported on this corridor.

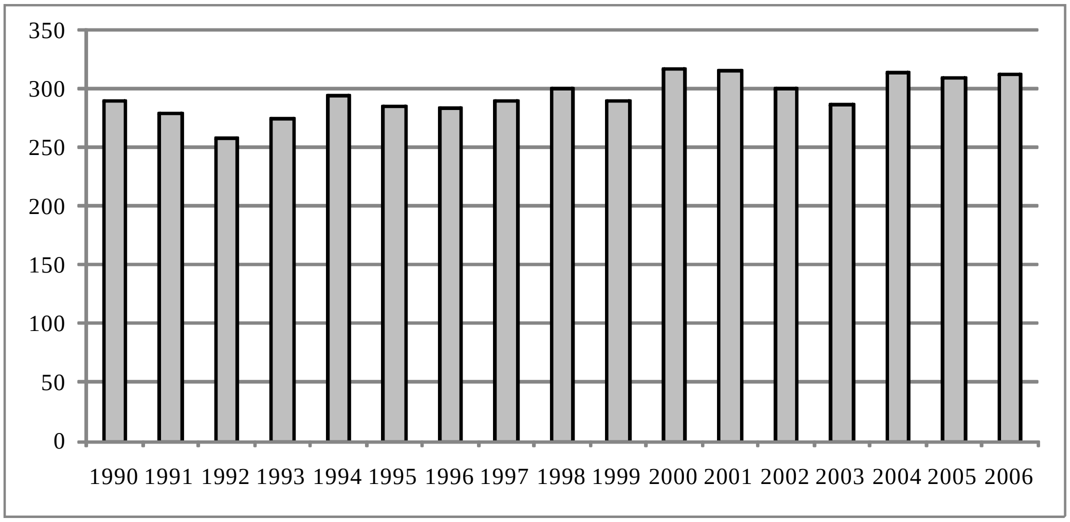

Figure 1.3: Total Rhine transport in millions of tonnes

Source: CCNR and European Commission, 2007.

Figure 1.3 shows inland waterway transport on the Rhine over time with the transported volume in millions of tonnes. As this river route developed long ago, the increase in the volume transported is relatively slow, but structural. It reflects the development of an industrial area that has existed for a long time (CCNR and European Commission, 2007). The cargo types most transported are raw minerals like sand, gravel and building materials, followed by the commodity oil and oil products. The demand for transport of some of the commodities (for example, agricultural products) is subject to seasonality. In total, about 500 million tonnes were transported in 2006 in the EU27 countries (see Table 1.4).[4]

Table 1.4: Transport of goods (x 1000 tonnes) on inland waterways in the EU27 for 10 commodity groups in 2006

NSTR commodity	**Tonnes (x 1000)**
0 Agricultural products; life animals	20,594
1 Food and animal food	25,411
2 Solid mineral fuels	46,195
3 Oil and oil products	86,255
4 Ore and metal residues	53,021
5 Metals, metal unfinished products	21,059
6 Crude and manufactured minerals; building materials	149,880
7 Fertilizer	10,696
8 Chemical products	37,254
9 Machinery, transport equipment, manufactured articles	52,829
Total	503,194

Source: CCNR and European Commission, 2007.

Concerning the modal split in the Rhine countries, inland waterway transport has a relatively large market share in the Netherlands of about 33 per cent. In the other Rhine countries, its share is 16 per cent or lower (see Table 1.5). A strong characteristic of inland waterway transport compared with road transport is its environmental performance. Figure 1.4 shows that for bulk cargo transport, inland waterway transport is 2 to 3 times more environmentally friendly in terms of CO_2 emission than road transport per tonne-kilometre transported.

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[4] Ideally, we would have shown the figures in Table 1.4 for the individual Rhine countries. However, these data are not available without double counting. Nevertheless, it can be said with certainty that more than 90 per cent of the total number of tonnes transported on inland waterways in the EU27 is transported within the 6 Rhine countries.

Table 1.5: Modal split in tonne-kilometres in the Rhine countries (in percentages) in 2007

Country	Road	Rail	Inland waterways
The Netherlands	61.8	5.0	33.2
Belgium	71.1	13.2	15.7
Luxemburg	92.5	4.1	3.3
Germany	65.7	21.9	12.4
France	81.4	15.2	3.4
Switzerland	-	-	-

Source: Eurostat, 2008. Data for Switzerland are not available.

Note: The percentages represent the share of each mode of transport in total inland transport expressed in tonne-kilometres. It includes transport by road, rail and inland waterways. Road transport is based on all movements of vehicles registered in the reporting country. Rail and inland waterway transport is generally based on movements on national territory, regardless of the nationality of the vehicle or vessel.

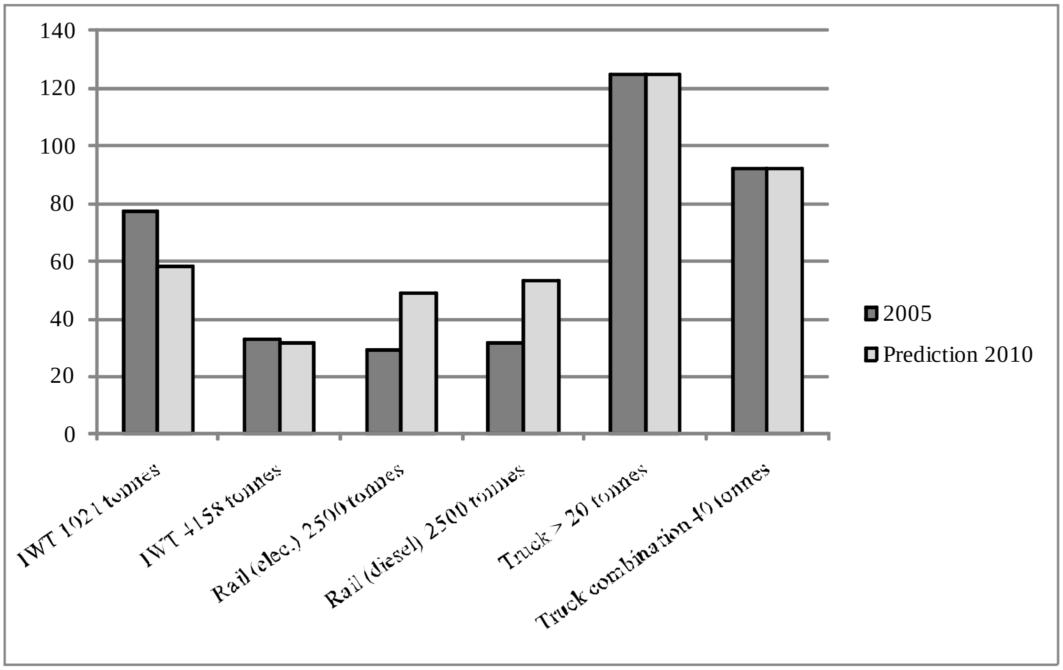

Figure 1.4: CO_2 emission for bulk cargo transport per mode (in gram per tonne-kilometre)

Note: IWT = inland waterway transport.

Source: BVB, 2009.

Special attention should be paid to the Port of Rotterdam as an important originator of demand for inland waterway transport on the Rhine and in Europe. Table 1.6 shows that the outgoing (loaded) volume of international oriented inland waterway transport from the port is about four times larger than the incoming (unloaded) volume in the port. This is an indication of the existence of an imbalance in the ingoing and outgoing transport flows, implying that some barges have to navigate without cargo to the Port of Rotterdam.

Table 1.6: Number of loaded and unloaded tonnes (x 1000) of cargo in the Port of Rotterdam in 2002 (domestic haul excluded)

	Sea	**River**	**Road**	**Rail**	**Pipeline**	**Total**
Unloaded	246,229	19,252	4,690	2,984	0	273,154
Loaded	73,649	78,517	6,958	10,041	53,716	222,880

Source: Port of Rotterdam, 2008.

1.3 Climate change and inland waterway transport

During the last decade, discussions on climate change and transport were mainly focused on mitigation strategies. The central question was: In what ways can the greenhouse gas emissions of the transport sector be reduced? More recently, another element has been added to the discussion on climate change: it is plausible that the climate is now changing rather rapidly, and that raises the issue of what adaptations will be called for in the transport sector.

In this dissertation, the focus is on water transport, since here the climate change impacts may be substantial. Some impacts may be positive. For example, the increase of global temperatures may make water transport in the Arctic areas both possible and economically viable (Johannessen et al., 2004; Somanathan et al., 2007). However, there are also potential negative effects. In particular, inland waterway transport may experience problems related to higher volatilities in water levels. Climate change is likely to affect inland transport on all waterways in North West Europe but, as the river Rhine is by far the most important waterway in terms of transported volume, this study focuses mainly on the Rhine.

The river Rhine is a combined rain-snow river. As a result of climate change, it is expected that the Rhine will be more rain-oriented in the future. More specifically, it is expected that, in winter, precipitation will increase, and higher temperatures will cause a smaller proportion of precipitation to be stored in the form of snow in the Alps. As a result, in winter more precipitation will directly enter rivers, average and peak water levels will be higher, and the number of days with low water levels will decrease. In summer, besides a reduction in melt water contribution, there will be less precipitation and more evaporation due to higher temperatures. As a consequence, inland waterway vessels on the Rhine will experience lower water levels, as well as an increase in the number of days with low water levels in summer and autumn (Middelkoop et al., 2000; 2001). Low water levels imply restrictions on the load factor of inland ships. This suggests that the capacity of the inland waterway transport fleet is (severely) reduced in periods with low water levels, which has economic consequences.

As low water levels hardly occur during winter, the reduction of days with low water levels in winter will be small. However, an increase of days with high water levels in winter implies an increase in the number of days on which inland waterway transport is blocked for safety reasons.[5]

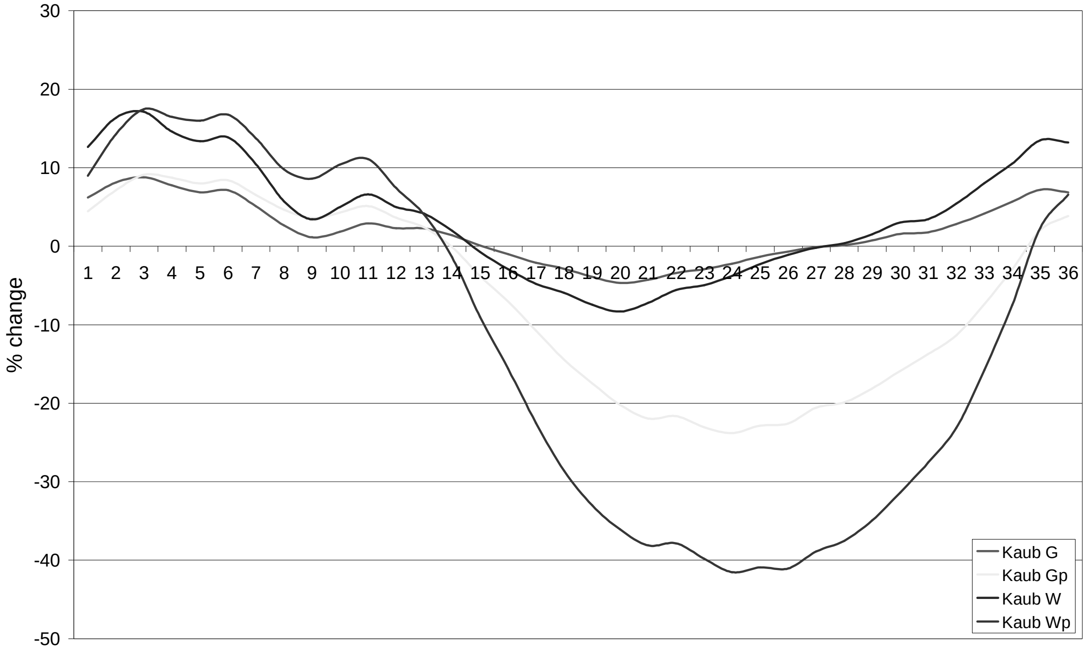

Figure 1.5: Change in discharge of the Rhine during a year under the KNMI'06 climate scenarios at Kaub.

Source: te Linde, 2007.

Figure 1.5 illustrates what the effect of climate change on discharge of the river Rhine at the location Kaub (a small town which is located on the East bank of the Rhine in Figure 2.1) is expected to be under the four climate scenarios that were described in Section 1.1.[6] On the horizontal axis, the time period of one year is divided into 36 periods of ten days. The vertical axis shows the expected percentage change in discharge compared with the

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[5] River dikes are heavily put to the test in periods of high water levels, and they may break as a result of the extra pressure inland waterway vessels impose on these dikes during high water levels.

[6] Discharges can be converted to water levels by means of what is known as Q-h relationship. Formulas exist for this conversion for several locations on the Rhine.

average discharge between 1961 and 1995. The mean rise in discharge in the winter months December, January and February varies from 8 per cent for the G scenario to 16 per cent for the W+ scenario. In the summer months June, July and August, there are only minor changes in discharge in the G and W scenarios. However, the G+ and W+ scenarios (each with a strong change of atmospheric circulation), show a decrease in mean discharge of 22 – 42 per cent (te Linde, 2007).

Because water levels seldom become so high that they result in completely halting inland waterway transport, and because low water levels occur more often and are expected to decrease more sharply than high water levels increase, this dissertation concentrates only on the economic consequences of low water levels on inland waterway transport.

The reduction in discharge in summer and autumn in scenarios M+ and W+ may cause several problems. For example, inland ships may have to reduce their load factor resulting in higher unit transport prices. Also, inland waterway carriers may have to search for alternative routes in the event of extreme low water levels on the planned route, leading to detours and delays. Finally, shippers may decide to use another transport mode, implying a loss of demand for inland waterway transport.

1.4 Goal and structure of the dissertation

1.4.1 Motivation and research questions

Climate change is likely to affect many sectors in the economy, for example, agriculture, tourism and transport. The aim of this study is to contribute to the knowledge on the effect of climate change on one specific transport sector: the inland waterway transport sector. First, this knowledge is relevant since it may contribute to the formulation of policies to adapt to these changes (e.g. de Groot et al., 2006). More specifically, if insight is gained into the possible (economic) consequences of climate change on inland waterway transport, this might enable cost-benefit calculations on adaptation measures. Second, it may become clear how the inland waterway transport sector itself can adapt to climate change: for example, by means of re-routing flows.

This dissertation aims to answer the following research questions:

1. What is the effect of climate change on inland waterway transport prices in the river Rhine area, and, consequently, what is its effect on social welfare?
2. What is the effect of climate change on modal split in the river Rhine area?
3. What is the effect of an imbalance in trade flows on inland waterway transport prices in North West Europe?
4. How will an imbalance in trade flows distribute the burden of higher inland waterway transport prices, due to low water levels, over North West Europe?
5. To what extent will higher inland waterway transport prices result in higher navigation speeds, and, consequently, in a higher emission of greenhouse gases?[7]

Answering these research questions is interesting from different points of view. First of all, scientific research into the inland waterway transport sector is rarely done. Other transport modes have received much more attention. Second, this dissertation contains an in-depth analysis of transport prices. Apart from studies on maritime transport, this type of analysis is rare. Third, this dissertation contains an explicit analysis of climate change impacts on transport and welfare. Fourth, we find indications that transport prices should be regarded as an endogenous factor in studies on trade. Within this branch of the literature, transport prices are usually assumed to be exogenous.

1.4.2 Structure

Figure 1.6 shows the outline of the dissertation. As described in the Introduction, the effect of climate change on inland waterway transport acts via the water level. Low water levels affect transport prices and, consequently, welfare. This causal relationship will be analysed in Chapter 2 by means of an empirical (regression) model and a theoretical (microeconomic) model. Next, in Chapter 3, using a strategic network model, we examine to what extent the change in transport prices will result in a change in the market share of inland waterway transport. In Chapter 4, the topic of imbalances in trade flows and their effect on inland waterway transport prices is assessed. To model this causal relationship we

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[7] This relation between transport prices and speed is also observed in the maritime transport sector: in periods of economic upswing transport prices are high and carriers earn profits. As a result those carriers increase navigation speed.

return to the econometric model in Chapter 2 and extend it extensively. Although the climate aspect is absent in Chapter 4, the topic is essential in order to evaluate the joint effect of low water levels and trade imbalances on transport prices in Chapter 5. An estimation of the interaction effect between the water level and trade imbalance variables forms the core of this chapter. Finally, in Chapter 6, the effect of a change in the transport price on navigation speed is examined in the light of climate change. Finally, Chapter 7 concludes.

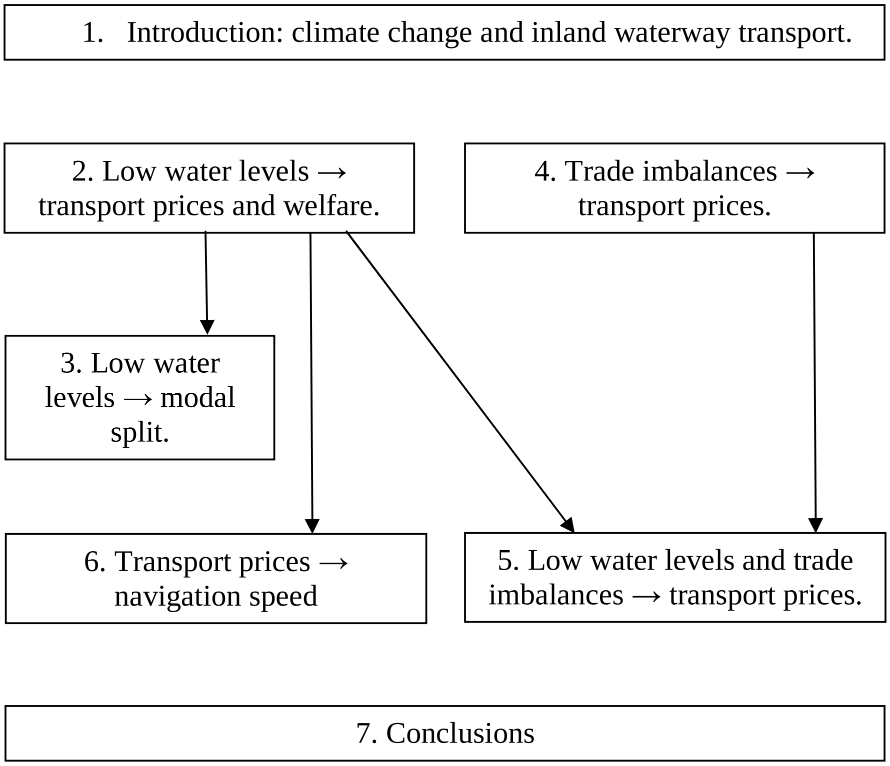

Figure 1.6: Outline of the dissertation

CHAPTER 2

WELFARE EFFECTS OF LOW WATER LEVELS ON THE RIVER RHINE[8]

2.1 Introduction

The summer of 2003 in Europe was probably the hottest since the 15th century, taking into account uncertainties in temperature reconstruction (Luterbacher et al., 2004; Beniston, 2004). Under un-mitigated emissions (of greenhouse gasses) scenarios, summers like 2003 in Europe are likely to be experienced more often in the future (Stott et al., 2004).[9]

Little attention has been given to the effect of changes in the natural environment on transport costs.[10] Examples of the thin literature on the effects of climate change on transportation can be found in Suarez et al. (2005) and Nankervis (1999). In addition, some literature exists on the effects of weather on safety in road transport (for example, Edwards, 1999; Brodsky & Hakkert, 1988).

The current chapter focuses on the effect of climate change on social welfare through inland waterway transport. We concentrate on a part of the European inland waterway transport market, the river Rhine market.

We estimate the size of the welfare loss due to low water levels at a specific location, employing data for the inland waterway transport spot market. Low water levels imply restrictions on the load factor of inland waterway vessels. As a consequence the costs per tonne, and thus also the price per tonne transported will rise. To be more specific, we determine to what extent higher prices per tonne emerge when the water level drops

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[8] This chapter has been based on Jonkeren et al. (2007).

[9] Global warming, especially in the second half of the 20th century, can be explained by an increase of greenhouse gases in the atmosphere with a negligible contribution from natural forcings (Stott et al., 2004; Tett et al., 2002; Mann et al., 1998).

[10] In contrast, a substantial number of studies have examined the effects of transport on environmental costs. We mention for example, Johansson-Stenman (2006) and Button & Verhoef (1998) for road transport, Cushing-Daniels & Murray (2005) and Brons et al. (2003) for rail transport, Schipper, (2004) and Carlsson (2002) for air transport and Eyre et al. (1997), Nordhaus, (1991) and Button (1990) for transport in general.

below a certain threshold, implying additional transportation costs for the economy in times of low water levels. Note that there are some other welfare effects as a result of low water levels which are ignored here. For instance, shippers may suffer from low water levels due to unreliability of delivery.

We focus on water levels at a particular location on the East bank of the Rhine in Germany called Kaub. Although for some of the trips that pass Kaub the maximum load factor may be determined by water levels in tributaries of the Rhine, for the large majority of the trips that pass Kaub, the water depth at Kaub is the bottleneck. The estimated size of the welfare loss thus concerns cargo that is transported via Kaub during low water levels. Figure 2.1 shows the location of Kaub.

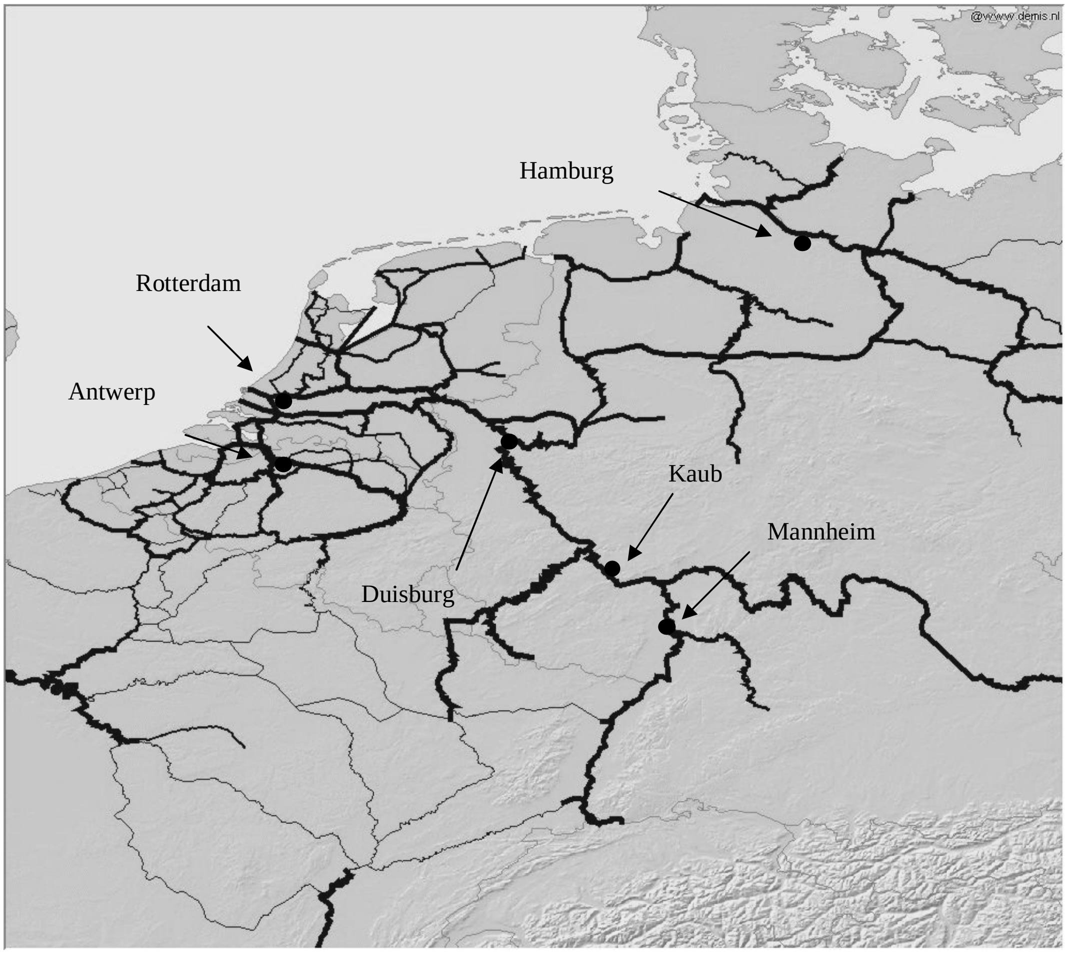

Figure 2.1: Location of Kaub (Germany) at the river Rhine

In Germany the navigability of the Rhine is measured by the ‘Pegelstand’ or ‘Pegel’. Pegelstand is related to actual water depth. There are several locations at the Rhine where the Pegelstand is measured. Each Pegel has its own 0-point. Thus, with Pegel Kaub it is only possible to determine navigation depth in the surroundings of Kaub. For other places, other Pegels are valid. The water depth at Kaub exceeds the Pegelstand at Kaub by about 100 cm. So, at Pegel Kaub 90 cm there is about 190 cm water between soil and surface, the water depth. For the sake of convenience we will employ water depths and regard water depth and water level as synonyms.

Estimation of the welfare loss is based on the effect of water levels on transport prices *per tonne* observed during the period from beginning 2003 to July 2005. In addition, we asses the effect of water level on load factor and transport price *per trip*. Using the latter effect, we are able to demonstrate that the inland waterway transport market can be considered as a competitive market with perfect elastic supply. We estimate the annual welfare loss for the period between 1986 and 2004. We pay special attention to the year 2003 because this year was an extreme year with respect to low water levels and indicative for what might occur more often in the future.

Given the welfare loss of low water levels, policy makers may be able to examine whether investment in projects those aim to make inland waterway transport more robust to low water levels might be economically sound. This subject will be further elaborated on in Section 7.4 on implications for adaptation.

In the next section, the theory concerning welfare implications of low water levels and competitive markets will be shortly addressed, as it is quite standard. Section 2.3 deals with the data we use and in section 2.4 the results will be presented. In section 2.5 we conduct the welfare analysis and section 2.6 offers some concluding remarks.

2.2 Microeconomic welfare theory

Our estimation of the welfare loss is based on two assumptions: perfect competition in the long run and perfect elastic supply.

The inland waterway transport market, and in particular the Rhine market, may be characterized as a competitive market: inland waterway transport enterprises offer an almost homogenous product (transport of different types of bulk goods), there are many suppliers, shippers may easily switch from one inland waterway transport enterprise to another and it is relatively simple to enter the Rhine market out of other adjacent geographical markets. Also Bongaerts and van Schaik (1984) describe the inland waterway transport market as a competitive market. In the short run, inland waterway transport enterprises may generate positive profits, but this lasts only for a short period of time.

The assumption of perfect elastic supply seems reasonable since entry is not limited, even in the short run, due to movements of inland waterway vessels between distinct geographical markets. Also, firms are rather equal and input prices, such as fuel, are likely to be constant as output increases.

Note that one may argue that in reality inland waterway vessels are not equal in terms of size (see also Table 2.1). Large ships enjoy economies of vessel size and operate in the market segment for large shipments (that is, more than 2500 tonnes). However, large ships are not able to underprice small ships, because small ships operate in the market segment for small shipments. So, firms are not able to create a competitive advantage because of economies of scale. Due to the heterogeneity in demand concerning shipment size, different markets (for different ship sizes) exist at the same time. Consequently, within each segment, it is reasonable to assume perfect competition and a horizontal supply curve.

Because the inland waterway transport market can be described as a market with perfect competition and perfectly elastic supply, the economic surplus equals the consumer surplus and the welfare loss due to low water levels equals the reduction in consumer surplus.[11] The assumption of perfect elastic supply is of importance for the correct estimation of the welfare loss. If supply is not perfect elastic, the size of the welfare loss would be larger than reported here.

Although the inland waterway transport sector does not directly serve a consumer market, the assumption of ‘no market imperfections’ implies that the change of economic surplus in the inland waterway transport market, is equal to the change in the consumer surplus on the market of the transported goods (Lakshmanan et al., 2001).

The welfare effect will be determined on basis of the observed price per tonne, p. The price per tonne includes costs like interest, labour, fuel costs, handling time costs etc. The quantity transported is denoted by q. Note that under the assumption of perfect competition, the price per tonne equals the costs per tonne, ($p = c$) and the price per trip equals the costs per trip ($P = C$). The load factor is denoted as θ. We will now distinguish

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[11] For theoretical considerations on perfect competition, see studies of for example Stigler (1957) and Robinson (1934). In these studies several definitions and characteristics of (perfect) competition are discussed. Hausman (1981) and Willig (1976) address the concept of the economic surplus.

between a situation with normal water levels (situation 0) and low water levels (situation 1).

Ships operate with a θ_0 load factor if the water level exceeds a certain threshold level. When the water level drops below the threshold level, inland waterway vessels have to reduce their load factor from θ_0 to θ_1 to be able to navigate safely, so $\theta_1 < \theta_0$. As a result the costs of shipment per tonne at low water levels are $c_1 = c_0 \times \theta_0 / \theta_1$, so transport costs *per tonne* are a factor θ_0 / θ_1 higher given low water levels. As a consequence inland waterway transport enterprises charge a higher price per tonne and the economic surplus is reduced. The welfare loss due to low water levels can be approximated by the following equation:

$$WL = (p_1 - p_0)q_0(1 + \tfrac{1}{2}\varepsilon(p_1 - p_0)/p_0) \qquad (1)$$

where ε is the price elasticity of demand

$$\varepsilon = [(q_0 - q_1)/q_0]/[(p_0 - p_1)/p_0] \qquad (2)$$

In the empirical analysis the annual welfare loss will be based on (1). In that case q_0 is the number of days with low water levels multiplied by the average daily quantity transported during normal water levels. We will show later on that the price per trip at normal water levels is equal to the price per trip at low water levels, $P_0 = P_1$, which implies that $C_1 = C_0$, so the transport costs per trip do not depend on the water level.[12] This finding is consistent with our assumption that supply is perfect elastic.[13] In addition, it suggests the existence of perfect competition in the inland waterway transport market.

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[12] Note that it may be argued that in reality fuel consumption decreases as the water level drops. However, because fuel costs are only about 20 – 25 per cent of the total costs, the costs of a trip with a low load factor is only slightly reduced. A compensating factor is that other costs rise in periods of low water levels, as is mentioned in RIZA et al. (2005). They mention longer waiting times at locks and extra handling as a cause for extra costs in periods of low water levels.

[13] Perfect elastic supply means that firms supply as much as the market wants as long as the price covers the costs of production. This can only occur in markets with perfect competition or monopolistic competition with many firms. Horizontal supply curves may also occur in monopolistic or oligopolistic markets. However, in these market forms firms are price setters and do not supply as much as the market wants.

2.3 Data descriptives

We employ a unique data set, the Vaart!Vrachtindicator, which contains detailed information about trips made by inland waterway transport enterprises in West Europe.[14] The enterprises report information via internet about their trips such as the price per tonne, place and date of loading, place and date of unloading, capacity of the ship, number of tonnes transported, type of cargo, etc. The data has a panel structure but we view it as repeated cross-section data. The data set contains information on inland waterway transport enterprises that operate in the spot market where the price per tonne, and the number of tonnes transported are negotiated for each trip. Inland waterway transport enterprises that operate in the long-term market (and work under contract) and receive a fixed price per tonne throughout the year are not included in the data set.

The database contains 8946 observations of trips, reported between beginning 2003 and July 2005. We exclude all trips that do not pass Kaub, (6059 observations), as we focus on the Kaub-related Rhine market. Then, we exclude a relatively small number of trips (25 observations) referring to container transport since its unit of measurement is volume whereas other products are measured in tonnes. So, we have 2864 remaining trips suitable for analysis.

Table 2.1 shows the distribution of the vessel sizes in the Kaub data set. The Kaub market is dominated by vessels between 1000 and 2000 tonnes. The average capacity of the fleet in the Kaub data set is 1776 tonnes.

Table 2.1: Distribution of vessels over tonnage classes in the Kaub data set

Vessel size	**Share**
0 – 649 tonnes	2.8%
650 – 999 tonnes	12.2%
1000 – 1499 tonnes	31.9%
1500 – 1999 tonnes	20.5%
2000 – 2499 tonnes	11.4%
> 2500 tonnes	21.3%

Source: The Vaart!Vrachtindicator, 2003 – 2005.

The descriptives of the key variables, price per tonne, load factor, price per trip and water level, which play a major role in the theoretical section, are given in Table 2.2 and Figure 2.2. In Table 2.2 we distinguish between trip and day observations.

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[14] More information can be found on the website www.vaart.nl.

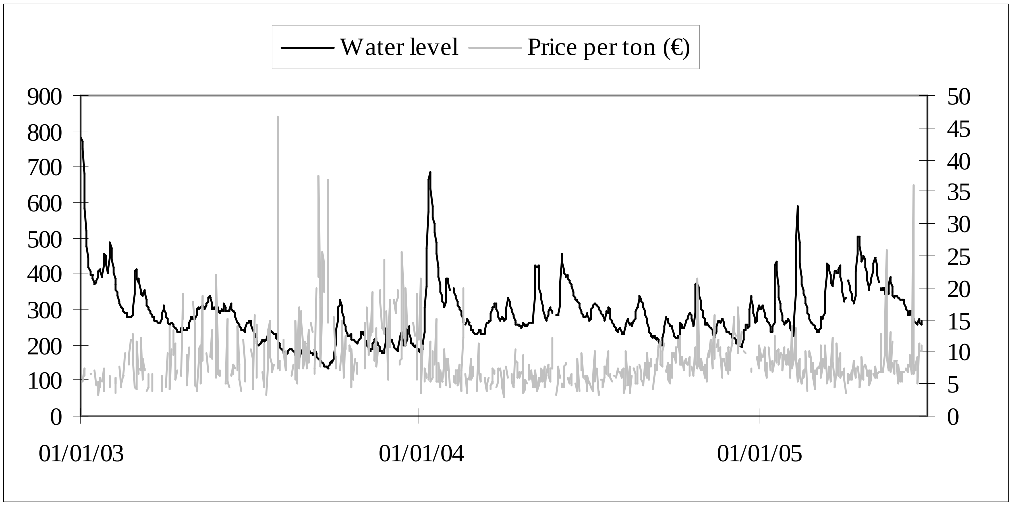
The latter are obtained by taking averages of several trips on a day. We have about 750 valid day observations. The mean price per tonne is about € 8.50 and the mean load factor is 0.78. Figure 2.2 shows the water level variation over a 2.5 year period at the location Kaub. Particularly in the second half of 2003, water levels are below 260 cm, which will be identified later on as the threshold level for low water levels. There is clearly a seasonal pattern (for example, in late summer, water levels are low).

Table 2.2: Descriptives of key variables

Variable	**N (day data)**	**N (trip data)**	**Minimum (trip data)**	**Maximum (trip data)**	**Mean (trip data)**	**Std. Dev. (trip data)**
Water level (Kaub) in cm	903	2849	135.00	780.00	292.66	79.57
Price per tonne (in €)	773	2847	1.80	52.00	8.56	5.39
Load factor (in %)	745	2530	10	101	78	17
Price per trip (in €)	759	2586	1036.55	71000.00	9810.82	5571.08

Source: The Vaart!Vrachtindicator, 2003 – 2005.

The figure shows a strong negative relationship between the price per tonne and water level. For example, in September 2003 water levels were exceptionally low and prices per tonne were exceptionally high. Furthermore, there is a positive relationship between water level and load factor, in line with theoretical considerations: as the water level drops, the load factor drops.



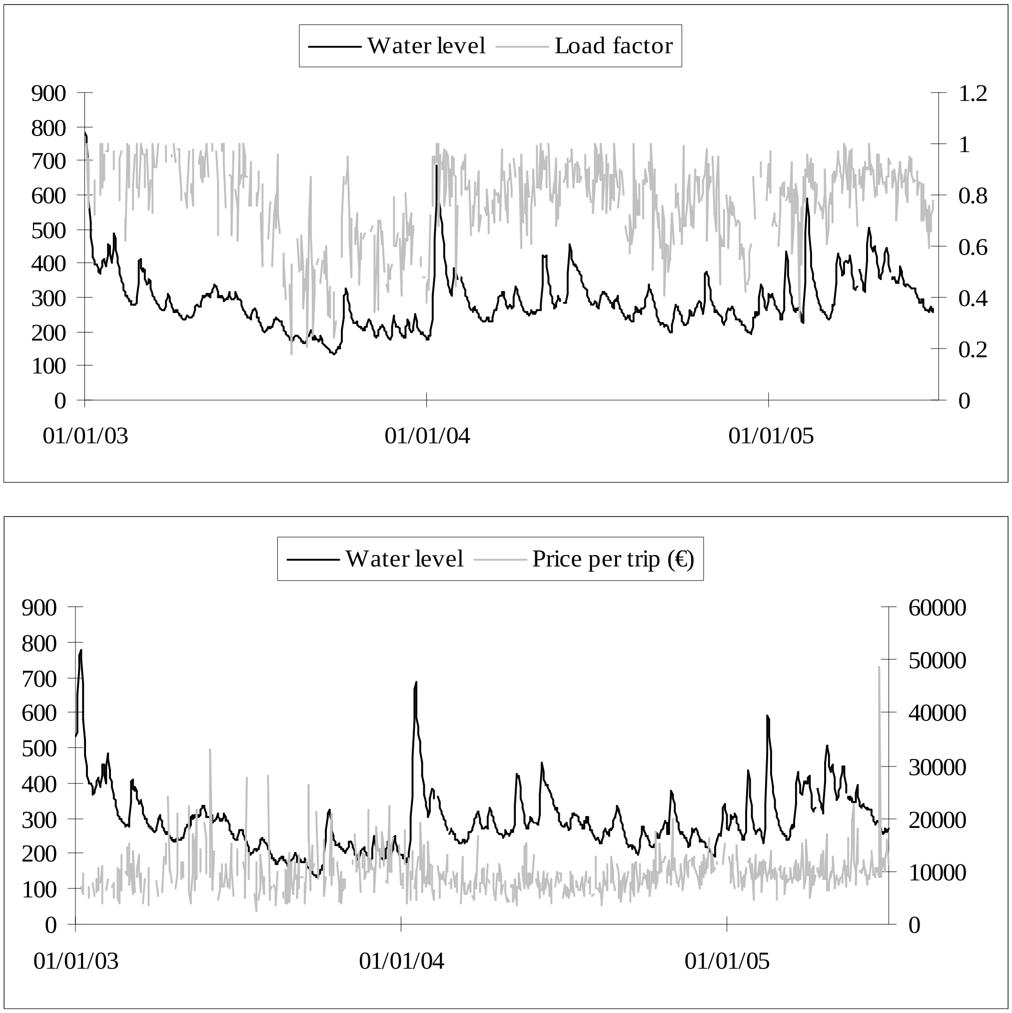


Figure 2.2: Relation between water level at Kaub and price per tonne, load factor and price per trip

Source: The Vaart!Vrachtindicator, 2003 – 2005.

Finally, the figure does not show a clear relationship between water level and price per trip. Note that also this finding is in line with the assumption of a competitive market. In the next section, we will examine these relationships using multivariate techniques.

2.4 Multiple regression analysis

We assess the impact of water level on the logarithms of transport price per tonne, load factor and price per trip using a regression analysis. We use the following explanatory variables in each regression: a time trend; trip distance in logarithm (see McCann, 2001); ship size (4 dummy variables), which allows for economies of vessel size; cargo type (41 dummy variables), because of differences in the mass per volume of each cargo type; and navigation direction, to correct for imbalances in trade and because for upstream navigation more fuel is needed than for downstream navigation. Fuel price is not taken up as an explanatory variable as it highly correlates with the time trend.

The following additional two explanatory variables need extra attention. The water level variable is measured by means of nine dummy variables to allow for a flexible functional form of this variable. Each dummy represents a water level interval of 10 centimetres. The reference-category is the group where water levels exceed 260 cm, which measures the threshold level. We have performed a sensitivity analysis and it appears that the effect of water level is absent when water levels exceed 260 cm at Kaub.

We included a dummy variable for each month (29 dummies) to control for unobserved monthly changes in supply and demand factors. The estimated effect of water level is then unlikely to be spurious because unobserved changes in demand and supply factors within short periods such as a month are likely to be small.[15] In addition, unobserved changes that occur within a short period are unlikely to be correlated with water level. Note that the choice of the number of the time dummies (for example, weekly, monthly, seasonal) affects the estimated effect of water level. The more time dummy variables, the less likely it is that the estimated effect is spurious. The consequence is however that some variation in the dependent variable may not be attributed to the effect of water level as it is captured by the time dummies. Therefore the water level effect may be somewhat underestimated.

One may analyse the data at the level of trips or days. Both analyses have their advantages. Employing the day average data enables us to model serial correlation of (unobserved components of) the dependent variables using regression models with lagged variables. The disadvantage of such an approach, however, is that by employing day averages, information on variation of variables within the same day is ignored. Using the trip data, it is straightforward to control for factors that refer to a specific trip (for instance, the distance). The drawback of the trip data is that modelling correlation of unobserved factors between and within days is less straightforward. It is not clear whether the analysis of one data type is superior to the other. It turns out however that the results of both data

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[15] Figure 2.2 shows that there is sufficient variation *within* months to identify a separate effect of water level controlling for monthly variation.

types generate very similar results. Tables 2.3 and 2.4 show the estimated coefficients for both trip and day data.

Table 2.3: Estimation results for trip data

Variable	**Price per tonne**		**Load factor**		**Price per trip**	
	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
Water level, 9 dummies						
> 261	Reference		Reference		Reference	
251 - 260	0.029	0.023	- 0.065	0.018	- 0.022	0.024
241 – 250	0.088	0.025	- 0.137	0.019	- 0.003	0.027
231 – 240	0.075	0.021	- 0.125	0.017	- 0.048	0.023
221 – 230	0.146	0.026	- 0.170	0.021	- 0.005	0.028
211 – 220	0.156	0.030	- 0.244	0.023	- 0.074	0.032
201 – 210	0.225	0.040	- 0.287	0.034	- 0.031	0.045
191 – 200	0.316	0.035	- 0.367	0.028	- 0.024	0.039
181 – 190	0.289	0.037	- 0.464	0.032	- 0.180	0.042
≤ 180	0.553	0.036	- 0.529	0.031	0.058	0.041
Distance log(kilometres)	0.501	0.016	0.010	0.013	0.536	0.017
Vessel size, 4 dummies						
0 – 1000 tonnes	0.253	0.017	0.240	0.013	- 0.744	0.018
1000 – 1500 tonnes	0.117	0.012	0.223	0.011	- 0.444	0.014
1500 – 2000 tonnes	0.080	0.014	0.128	0.011	- 0.292	0.015
2000 – 2500 tonnes	0.038	0.019	0.092	0.015	- 0.092	0.020
> 2500 tonnes	Reference		Reference		Reference	
Navigation direction, and backhaul						
Trips upstream on Rhine	0.323	0.015	0.009	0.012	0.310	0.016
Trips upstream on Rhine, to Danube	0.596	0.028	0.011	0.022	0.524	0.031
Trips downstream on Rhine, from Danube	0.224	0.029	- 0.068	0.024	0.186	0.033
Trips downstream on Rhine	Reference		Reference		Reference	
Cargo type, 41 dummies	Included		Included		Included	
Time trend, divided by 1000	0.378	0.192	0.062	0.149	0.735	0.208
Time dummies, 29 months	Included		Included		Included	
Model performance: R^2	0.79		0.59		0.76	

The results are based on data from the Vaart!Vrachtindicator, 2003 – 2005. The dependent variables are measured in logarithm.

To examine the validity of our regression models we performed diagnostic tests to check serial correlation and heteroskedasticity. Based on such analysis we transformed the dependent variables by taking the natural logarithm to reduce heteroskedasticity. Scatter plots show that, after this transformation, the variance of the residuals is close to constant. Three tests, employing the *day data*, indicate that serial correlation of the residuals is present in the regressions with load factor and price per trip as dependent variables but not in case of the dependent variable price per tonne. We employ the Ljung-Box test (or Qstatistic), the Durbin-Watson test, which is only indicative due to missing values (Gujarati, 2003), and we tested if the (partial) correlations differ significantly from zero.

Table 2.4: Estimation results for day data

Variable	**Price per tonne**		**Load factor**		**Price per trip**	
	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
Water level, 9 dummies						
> 261	Reference		Reference		Reference	
251 - 260	0.040	0.030	- 0.040	0.026	0.019	0.034
241 – 250	0.122	0.034	- 0.146	0.030	0.015	0.038
231 – 240	0.089	0.032	- 0.153	0.030	- 0.083	0.036
221 – 230	0.145	0.038	- 0.153	0.036	- 0.035	0.042
211 – 220	0.209	0.041	- 0.268	0.038	- 0.080	0.045
201 – 210	0.293	0.050	- 0.351	0.046	0.036	0.057
191 – 200	0.337	0.050	- 0.416	0.047	- 0.055	0.055
181 – 190	0.316	0.048	- 0.467	0.047	- 0.238	0.054
≤ 180	0.505	0.051	- 0.541	0.051	0.008	0.057
Distance log(kilometres)	0.431	0.037	-0.028	0.031	0.469	0.045
Vessel size, 4 dummies						
0 – 1000 tonnes	0.241	0.038	0.229	0.032	- 0.632	0.045
1000 – 1500 tonnes	0.120	0.028	0.251	0.024	- 0.297	0.034
1500 – 2000 tonnes	0.068	0.030	0.124	0.026	- 0.152	0.037
2000 – 2500 tonnes	0.019	0.051	0.083	0.042	0.010	0.061
> 2500 tonnes	Reference		Reference		Reference	
Navigation direction, and backhaul						
Trips upstream on Rhine	0.307	0.034	0.079	0.029	0.286	0.041
Trips upstream on Rhine, to Danube	0.722	0.072	0.125	0.060	0.642	0.085
Trips downstream on Rhine, from Danube	0.173	0.061	-0.033	0.053	0.159	0.073
Trips downstream on Rhine	Reference		Reference		Reference	
Cargo type, 41 dummies	Included		Included		Included	
Time trend, divided by 1000	0.241	0.286	0.006	0.977	0.518	0.335
Time dummies, 29 months	Included		Included		Included	
Lagged values dependent variable						
AR1	-	-	0.128	0.045	- 0.169	0.041
AR2	-	-	0.109	0.044	-	-
Model performance						
R^2	0.83		-		-	
Log likelihood	-		-2993.02		-3323.58	

The results are based on data from the Vaart!Vrachtindicator, 2003 – 2005. The dependent variables are measured in logarithm.

To eliminate the serial correlation, we estimated several regression models with lagged values of the concerning explained variables. On the basis of information criteria (AIC and SIC) and LR-tests, models are selected. Evaluation of these criteria on the different models is shown in Appendix A.

The best models turned out to be those with one lagged value in case of the model with dependent variable price per trip and two lagged values in case of the model with dependent variable load factor. The size of the two coefficients of the lagged load factors are 0.13 (AR1) and 0.11 (AR2) and the value of the coefficient of the lagged price per trip is – 0.17 (AR1). Why the latter value is negative remains a bit of a puzzle. Because the sum of the absolute value of the AR-coefficients is smaller than 1 in both AR processes, these processes are stationary.

Our main result is that the water level has a strong, statistical significant, negative effect on the price per tonne, a strong positive effect on the load factor and no (systematic) effect on the price per trip. These results are the basis of the welfare analysis in the next section. The latter finding indicates that the inland waterway transport market can be considered as a competitive market as assumed in the theoretical section. Bishop and Thompson (1992) apply a similar approach to show that their theoretical assumption of a competitive market is plausible.

By definition, the price per trip is equal to the price per tonne times the number of tonnes transported. Hence, when trip prices do not depend on water levels, the sum of the effects of water levels on the logarithm of price per tonne and the logarithm of load factor will be zero, controlling for the vessel size. This is confirmed by our results.

The results are also in line with figures derived from the IVTB (VBW, 1999). This document determines rights and obligations of inland waterway transport enterprises and shippers in the European market. It serves as a kind of guideline for both parties for setting up short- and long term contracts and for low water surcharges which can be used in negotiations. The IVTB state that usually at a water level of 250 or 240 cm at Kaub, low water surcharges can be charged.

The effect of water level on the price per tonne is the opposite of the effect on load factor. Note that the drop in load factor, as presented in Tables 2.3 and 2.4, is relative to the situation of ‘normal’ water levels, which we defined as water levels higher than 260 cm at Kaub.

Given normal water levels, the average load factor is 84 per cent. The drop in load factor has to be regarded relative to this percentage.

In Table 2.5 we derived the average prices per tonne, load factors and prices per trip for an average ship at the different water level intervals based on the estimates reported in Table 2.3. We see that in the lowest water level interval an average ship uses less than

50 per cent of its capacity. The estimated effect on the price per tonne more or less offsets the reduction in load factor, as we can see in the column for price per trip.

Table 2.5: Estimated prices per tonne, load factors and prices per trip

Water depth Kaub (cm)	**Estimated price per tonne in € (trip data)**	**Estimated load factor (trip data)**	**Estimated price per trip in € (trip data)**
> 260	7.53	84%	9626
251 - 260	7.75	78.8%	9414
241 – 250	8.22	73.2%	9597
231 – 240	8.11	74.1%	9173
221 – 230	8.71	70.9%	9577
211 – 220	8.80	65.8%	8943
201 – 210	9.43	63.0%	9337
191 – 200	10.33	58.2%	9395
181 – 190	10.05	52.8%	8037
≤ 180	13.09	49.5%	10193

The results are based on data from the Vaart!Vrachtindicator, 2003 – 2005.

We will shortly discuss the effect of the control variables. We find that distance has a positive effect on price per tonne and price per trip but does not affect the load factor. The effect of vessel size on price per tonne decreases as the vessel size increases, which suggests the existence of economies of vessel size in inland waterway transport. As discussed in Section 2, this is not inconsistent with the assumption of perfect elastic supply. Further, the coefficients indicate that smaller inland waterway vessels navigate with higher load factors. The trip data show that the time trend has a slightly positive effect on the price per tonne and price per trip while there is no change in load factor over time. The day data show no significant effect of the trend at all. The variable that controls for navigation direction and imbalances in trade indicates that trips upstream on the Rhine with destinations at the Danube have a relatively large increase in price per tonne and price per trip. The explanation is the longer duration of the trip: in particular inland vessels that navigate to and from the Danube have to pass many locks.

Because it is plausible that the change in the dependent variables for large ships is larger than for small ships when the water level drops, as smaller ships are less affected by low water levels, we tested for the presence of an interaction effect between the water level and the size of the ship. Water level is measured as a continuous variable and ship size is measured as a continuous logarithmic variable. Above a certain water level, it is plausible that the marginal effect of water level on the load factor and therefore on the price per tonne is zero because the load factor is at its maximum. Water level values above 260 cm are therefore fixed at 260 cm, in line with findings reported in Tables 2.3 and 2.4.

Let us define α as the logarithm of the vessel size in tonnes. The marginal effect of water level on the logarithmic price per tonne is equal to $0.004113 - 0.001330\alpha$, on the logarithmic load factor $-0.010294 + 0.002221\alpha$ and on the logarithmic price per trip $-0.011687 + 0.001597\alpha$. Table 2.6 gives the marginal effects of water level for several ship sizes. Given a *decrease* in water level, for small ships, the increase in price per tonne is less than for large ships. For large ships the increase in price per tonne less than offsets the reduction in load factor as for small ships we observe the opposite. Hence, given a decrease in water level, the price per trip decreases for large ships but increases for small ships. Observing Table 2.6, a decrease of water level with one centimetre leads to an increase of 0.654 per cent of the price per tonne for vessels of 3000 tonnes. For a ship size of 1507 tonnes, the increase in price per tonne exactly offsets the reduction in load factor. The interaction effects will be ignored in the welfare analysis as these are secondary.

Table 2.6: Marginal effect of water level on dependent variables

Dependent variable in logarithm	**Ship size (in tonnes)**			
	500	**1000**	**3000**	**5000**
Price per tonne	-0.00415	-0.00507	-0.00654	-0.00721
Load factor	0.00351	0.00505	0.00749	0.00862
Price per trip	-0.00176	-0.00066	0.00110	0.00191

The results are based on data from the Vaart!Vrachtindicator, 2003 – 2005.

Another potentially important aspect we addressed is the time lag between the moment of reporting a trip and the moment of passing Kaub by a ship. Usually one or two days are in between those moments. We have investigated what the effect of forecasted water levels is on the dependent variables. If we re-estimate the same model as in Table 2.4, but measuring the water level variable as a continuous variable, measuring values above 260 cm as 260 cm and we also include the first, second or both leading values of the water level variable, we find results as summarized in Table 2.7.

Table 2.7: Significance of coefficients for lead values of water level at the 5 per cent level

Dependent variable	**Water level**	**Water level + 1st lead value of water level**		**Water level + 2nd lead value of water level**		**Water level + 1st + 2nd lead value of water level**		
		Water level	*1st lead value*	*Water level*	*2nd lead value*	*Water level*	*1st lead value*	*2nd lead value*
Price per tonne	Sign.	Sign.	Insign.	Sign.	Insign.	Sign.	Insign.	Insign.
Load factor	Sign.	Sign.	Sign.	Sign.	Sign.	Sign.	Insign.	Sign.
Price per trip	Insign.	Insign.	Insign.	Insign.	Insign.	Insign.	Insign.	Insign.

The results are based on data from the Vaart!Vrachtindicator, 2003 – 2005.

The results in Table 2.7 suggest that bargemen take into account future water levels when determining the load factor of their ships in periods of low water levels.

However, future water levels do not seem to play a role in determining the price per tonne. We find that the total effect of water level (the sum of the different water level effects) in the estimations underlying Table 2.7 is about the same as in Tables 2.3 and 2.4. This finding makes sense considering the high correlations between water level and its first (0.98) and second (0.94) lead value.

The selection mentioned in Section 2.3 implies that our estimate of the welfare loss only refers to trips passing the bottleneck Kaub. Trips that do not pass Kaub encounter other low-water bottlenecks which impose less severe restrictions on the load factor of inland ships and thus have a weaker effect on the transport price per tonne. Furthermore, in non-Kaub areas, transport prices per tonne might be indirectly affected by water level restrictions at Kaub in the short run, because the demand for ships in the Kaub market will attract inland ships from the non-Kaub markets. We have estimated similar models as in this paper for areas where low water levels are less severe (the canals in North Germany). Although the number of observations is limited, it appears that a smaller (but statistically significant) effect of water level at Kaub on the price per tonne of trips in North Germany can be observed.[16]

2.5 Welfare analysis

We use equation (1) to estimate the welfare loss in the years 1986 to 2004. For this period we have daily water levels at Kaub and the annual transported quantity via Kaub at our disposal. The value of q_0 is based on yearly aggregate data (CCNR, 2005; 2002; 2000; 1998 and PINE, 2004) presented in Appendix B, presuming that q_0 is large as the number of days with water levels below 260 cm at Kaub in a year is large.

Estimation of the prices p_0 and p_1 is based on the data set that contains trips of inland waterway vessels between beginning 2003 and mid 2005. The average price per tonne of all trips made at normal water levels is € 7.53 and at low water levels € 9.39. The coefficients in Table 2.3 (trip data) are used to calculate the price increase at each water level interval.

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[16] This is probably a scarcity effect: because higher prices are being paid in the Kaub-related market, inland ships are pulled away from adjacent regions, such as from North Germany.

Estimates of the price elasticity of demand (ε) for inland waterway transport are mainly found in North-American literature. Table 2.8 gives an overview. The estimates found in the literature concern yearly price elasticities of demand for inland waterway transport and have a median value of about – 1.0. For a number of reasons it is plausible that demand for inland waterway transport may be more inelastic. First, the price for transportation by inland waterway vessel for most bulk goods is substantially lower than transport by another mode. Consequently, the price per tonne has to rise substantially before other transport modes become competitive and modal shift effects are expected to be small.

Table 2.8: Literature on price elasticities of demand in inland waterway transport

Paper	Estimated elasticity	Details
Yu and Fuller (2003)	[-0.5, -0.2]	Concerns grain transport, -0.5 for the Mississippi River and -0.2 for Illinois River.
Dager et al. (2005)	[-0.7, -0.3]	Concerns corn shipments on Mississippi and Illinois Rivers.
Oum (1979)	-0.7	Intercity freight transport in Canada for period 1945 – 1970.
Train and Wilson (2005)	[-1.4, -0.7]	Revealed and stated preference data to analyse both mode and O-D changes as a result of an increase in the barge rate for grain shipments.
Henrickson and Wilson (2005)	[-1.9, -1.4]	Concerns grain transport on Mississippi and accounts for spatial characteristics of the shippers.
Beuthe et al. (2001)	[-10.0, -0.2]	Estimated elasticities for 10 different commodities of cargo based on a multimodal network model of Belgian freight transports.

Second, inland waterway vessels transport such large quantities that other modes of transport by far do not have enough capacity to transport all cargo originally transported by inland waterway vessels. Third, and more fundamentally, shippers aim to prevent their production process from costly interruptions and costs of inland waterway transport are only a small part of total production costs. Harris (1997) mentions that for most low value goods like coal and steel inland waterway transport is about 2 per cent of total production costs. Thus, paying more for inland waterway transport in periods of low water levels is more cost-effective than having interruptions in the production process. So, demand for inland waterway transport is thought to be more inelastic in the long run (measured in weeks). In the short-run (measured in days) the demand may be more elastic because shippers are able to postpone transport and rely on their stocks for example.[17]

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[17] In the very long run (that is, decades), it is likely that demand will be more elastic, as shippers may shift location.

To examine the short-run demand elasticity for inland waterway transport, we estimated the demand elasticity using daily data and a standard instrument variable approach. Hence, we regressed the logarithm of the *daily* quantity transported on the logarithm of the mean *daily* price per tonne controlling for a number of explanatory variables. A Hausman test showed that the logarithm of the daily price per tonne is endogenous. In one regression we employ water level as an instrument and in another regression we employ water level *and* distance as instruments. It is very probable that the water level variable instrument is valid, because it is exogenous, will strongly affect the transport costs and consequently the supply function, and will *not* directly affect the demand for freight. If we only use water level as an instrument we are not able to test the validity of this instrument. Distance is also likely to be valid as an instrument, as it is not clear there is any systematic relation with temporal variations in quantity, whereas it has a direct and strong effect on the price. The joint validity of the instruments water level and distance is empirically confirmed by a Sargan test. We have experimented with a range of control variables, and the results are quite insensitive to the inclusion of control variables.

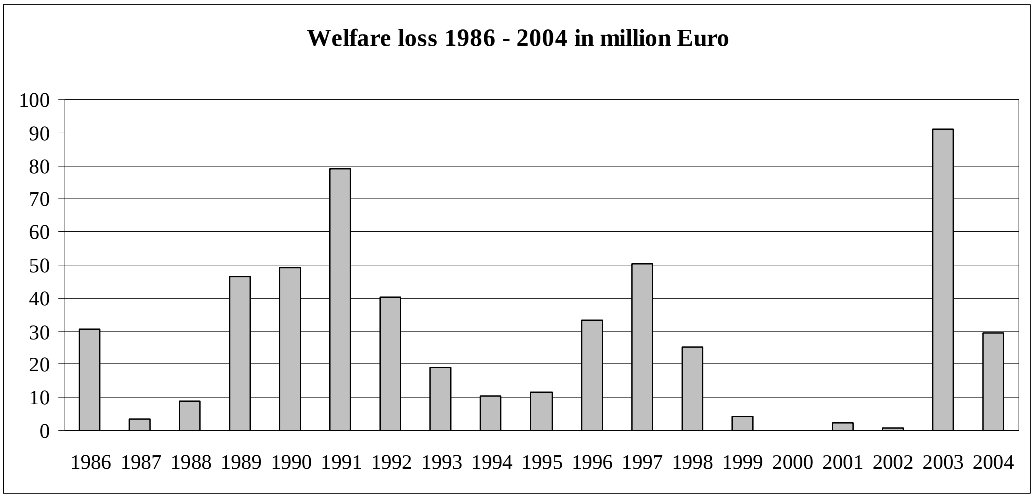

Figure 2.3: Welfare loss due to low water levels affecting inland waterway transport via Kaub

Note: the results are based on data from the Vaart!Vrachtindicator, 2003 - 2005 and CCNR, 2005; 2002; 2000.

When we include as control variables a trend variable (to control for a trend in the number of observations in the survey), 11 month dummies (to control for seasonal variation due to monthly changes in demand and supply) and the logarithm of the size of the inland waterway vessels, we find that the point estimate of the demand elasticity is equal to -0.60 with a standard error equal to 0.27 for the model with one instrument. Re-estimating the same model, but now with two instruments gives a demand elasticity equal to -0.40 with a standard error equal to 0.13. Statistically the -0.60 and -0.40 estimates are equal. Not controlling for the size of the inland waterway vessels, the demand is only slightly more elastic. Figure 2.3 shows the annual welfare loss for the period of 1986 to 2004 using an elasticity of -0.6.

The current study is the first to focus on transport prices in inland waterway transport in relation to water levels. The estimated average annual welfare loss is € 28 million in the period under investigation. In a few specific years the welfare loss was relatively high. In 2003 the loss amounted to € 91 million, and in 1991 the welfare loss also was considerable with € 79 million. Compared with the annual turnover in the Kaub-related Rhine market of about € 640 million the welfare loss in 2003 is about 14 per cent.[18]

Because we know the size of the Kaub-related Rhine market and the total Rhine market in terms of tonnes transported, we are able to roughly estimate the size of the welfare loss in the total Rhine market. In 2003, about 75 million tonnes were transported in the Kaub-related Rhine market and 187 million tonnes in the total Rhine market (CCNR, 2005).[19] Assuming: (1) that the increase in transport price for trips in the total Rhine market is equal to the increase in transport price for trips in the Kaub market and, (2) that the number of days with low water levels per year in the total Rhine market is equal to the number of days with low water levels per year in the Kaub market, the welfare loss in the total Rhine market in 2003 is equal to (187/75) times € 91 million = € 227 million. Note that this is an overestimation as it is very likely that the increase in transport price due to low water levels is less severe and the number of days with low water levels is lower in locations other than Kaub. The welfare loss interval for the total Rhine market for 2003 is then [91, 227].

Our results are in line with another study which uses a different methodology. RIZA et al. (2005) estimated the costs of low water levels for domestic inland waterway

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[18] The annual amount of cargo transported through the Kaub-related Rhine market is about 75 million tonnes. The average price per tonne for all journeys in the data set that pass Kaub is about € 8.50.

[19] The total Rhine market includes transport of goods which took totally or partly place on the Rhine between Rheinfelden (close to Basle in Figure 1.1) and the Dutch-German border, including Dutch-German border-crossing transport. Excluded is transport between Dutch (inland) ports and Dutch (inland) ports and Belgian and French ports.

transport in the Netherlands based on assumptions about additional costs of low water levels. These extra costs concern the increase in the number of trips, in handling costs and costs as a result of longer waiting times at the locks and amounted € 111 million for the year 2003. The annual amount transported in the Dutch domestic market (100 million tonnes) is comparable to that of the Kaub-related market (80 million tonnes). Other attempts to estimate the costs for inland waterway transport due to low water levels can be found in a few North American studies. Marchand et al. (1988) use a climate model, a hydrological model and an economic model, all models being dedicated to the Great Lakes basin. The authors considered an annual market of about 180 million tonnes. In a climate scenario in which a doubling of carbon dioxide levels by the year 2035 is assumed, it is expected that lake levels are reduced impeding navigation. Together with an economic growth scenario for 2035, the mean annual shipping costs may increase with about $65 million. An estimation by Millerd (1996), also for the Great lakes region and also assuming a doubling of atmospheric carbon dioxide concentration, shows an amount of only $2 million. Millerd (2005) uses more recent climate scenarios, more recent shipment data and an improved simulation model compared with the previous studies. He finds that the same increase in carbon dioxide concentration could increase total shipping costs by 29%, or $75 million in an inland waterway transport market of about 70 million tonnes annually, indicating that his previous finding is an underestimation. Finally, Olsen et al. (2005) calculate the economic consequences of changes in inland waterway transport system in terms of low and high flows on the Middle Mississippi River on which about 120 million tonnes are transported annually. They report an increase of transport costs of $118 million in case of the most extreme climate scenario. We emphasize that the current study is based on observed prices in the market and not on difficult to observe costs.

Our welfare analysis is based on the assumption that the demand elasticity is -0.6 (in line with our point estimate). Because one may argue that this assumption is inaccurate, we also estimated the welfare loss for another value of ε. If we would have used an elasticity of -1.0, the welfare loss would have been only 11 per cent less and amount € 81 million. This indicates that the size of the welfare loss is rather insensitive to the chosen elasticity.

A demand elasticity of -0.6 implies that some cargo is shifted to other transport modes in periods with low water levels. Transportation by those modes in periods with low water levels is likely to be more expensive than transportation by barge in periods with normal water levels. This welfare effect is ignored in our calculations.

Note that the estimated welfare loss is likely to be a minimum. Due to the large number of time dummies, the estimated water level effect may be somewhat underestimated, as argued above. As a sensitivity analysis we have reduced the number of time dummies. If we employ 9 seasonal time dummies in our regression the welfare loss amounts to € 113 million and if we employ no time dummies at all the welfare loss leads to a welfare loss of € 146 million in 2003. Hence, the welfare loss in 2003 is somewhere between € 81 and € 146 million.

Another possible cause for the underestimation of the welfare loss may be that we control for distance. Controlling for distance implies that the separate effect of detour-kilometres as a result of low water levels on prices is ignored. However, regressing distance on water level and a range of control variables indicated an insignificant, and even positive, effect of water level on the trip distance, so that it is unlikely that detour kilometres add to the costs during periods of low water levels.

Also note that the welfare loss cannot be assigned to a certain geographical area, because the welfare loss is caused by all trips that pass Kaub. These trips have origins and destinations all over North West Europe. This also implies that there are other locations at the Rhine where welfare losses occur.[20] So, the welfare loss estimated in this study concerns the Kaub-related Rhine market, which is only part of a larger welfare loss related to the total Rhine market.

One reason why the estimated welfare loss may be an overestimation is that we do not have full insight in the number of trips of the inland ships, which means that the absence of a producer surplus is not guaranteed. It may be the case that in periods with low water levels, inland ships make more trips than in periods with normal water levels due to less waiting- and (un)loading time or less empty trips. Given the presence of fixed costs (for example, interest on capital), there are profits in years with many days with seriously low water levels.[21] This implies the existence of a positive producer surplus that reduces the welfare loss presented here. In an empirical analysis not shown here, it appears however that the number of empty kilometres does not relate to low water levels. We do

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[20] For instance, inland waterway vessels that navigate from Rotterdam to Andernach, situated north of Kaub, may suffer from load factor restrictions caused at Cologne.

[21] In the long run (several years) profits are zero. But in a certain year profits may be positive or negative. Presumably, in years with many days with seriously low water levels, not enough inland ships enter the Kaub-related inland waterway transport market to sufficiently cut down the price per tonne, and thus the producer surplus is positive.

not have information about waiting and loading times so the impact of these factors cannot be analysed.

2.6 Conclusion

In this chapter, we studied the effect of low water levels in the river Rhine on welfare. For our estimation, several characteristics of inland waterway transport on the river Rhine were taken into account. The effect of the water level on the transport price per tonne was found to be negative. The effect on the load factor is positive and on the transport price per trip no effect was found. We derived an annual average welfare loss of € 28 million for the period of 1986 to 2004 for all waterway transports that passed the bottleneck Kaub. As not all trips on the Rhine pass Kaub, the welfare loss concerns a part of the Rhine market. The welfare loss in 2003 of € 91 million was much higher due to a very dry summer. In the light of the observation that: (1) demand for transport will grow and, (2) dry summers like in 2003 are expected to occur more often in the future due to climate change, annual welfare losses as a result of low water levels via the inland waterway transport sector will rise.

Appendix A: Evaluation of different models

Table A.1: Criteria for models with dependent variable price per trip

Lags included	**AIC**	**SIC**	**Log likelihood**
AR(1)	6827.15	7243.80	-3323.58
AR(2)	6828.94	7250.21	-3323.47
ARMA(1,1)	6828.58	7249.85	-3323.29

Likelihood ratio-tests show that there is no difference in log likelihood between the model specifications. We choose the model with the lowest AIC (Akaike information criterion) and SIC (Schwarz information criterion). Then the model with one included AR term is preferred above the model with one AR and one MA term. Because the models with one AR and two AR terms are nested the AIC and SIC are weak criteria. However, the 2nd AR term is insignificant in the model with two AR terms so the model with AR(1) is the preferred model.

Table A.2: Criteria for models with dependent variable load factor

Lags included	**AIC**	**SIC**	**Log likelihood**
AR(1)	6171.52	6586.48	-2995.76
AR(2)	6168.04	6587.61	-2993.02
ARMA(1,1)	6168.84	6588.41	-2993.42

Likelihood ratio-tests show that the log likelihood of the model with two AR terms is significantly higher than the model with one AR term. The model with two AR terms shows a lower SIC and AIC than the model with one AR and one MA term so the model with AR(2) is the preferred model.

Appendix B: Annual amount of cargo that passes Kaub (x 1000)

Year	Tonnes along Kaub
2004	83527
2003	75536
2002	85917
2001	87217
2000	87456
1999	82459
1998	84866
1997	82941
1996	79642
1995	82584
1994	82844
1993	77567
1992	81466
1991	82130
1990	84635
1989	85105
1988	82673
1987	79431
1986	81052

Source: CCNR, 2005; 2002, 2000, 1998, PINE, 2004.

Note: The figures for 1986 – 1996 are approximated using an index for the transported annual amount of tonnes on the Rhine. The figures for 1997 – 2004 come from CCNR, 2002, 2000, 1998.

CHAPTER 3

THE EFFECT OF CLIMATE CHANGE ON THE COMPETITIVE POSITION OF INLAND WATERWAY TRANSPORT IN THE RIVER RHINE AREA[22]

3.1 Introduction

This chapter focuses on the potential effects of climate change on modal split in countries where inland water transport is an important transport mode. In Europe, this holds true for countries such as Germany and the Netherlands, where the river Rhine is used for the transport of large amounts of bulk products and containers.

An obvious problem with studies on the effects of climate change is that we do not know exactly how the climate will be in the future. Therefore, we will use the KNMI'06 climate scenario's as described in Section 1.1 as a starting point. As a result of climate change, it is expected that in summer water levels in the Rhine will be lower, implying more days with load factor restrictions for inland waterway transport (Middelkoop et al., 2000, Middelkoop et al., 2001). A consequence of load factor restrictions for barges is that the costs per tonne transported rise. We know from the previous chapter that the inland waterway transport market can be characterized as a perfectly competitive market. Therefore, the increase in costs per tonne is assumed to be equal to the increase in price per tonne. Increased transport prices for inland waterway transport imply that other modes become more competitive and take over a certain amount of cargo originally transported by barge.

We model the effect of low water levels on modal split using a Geographical Information System- (GIS-)based software model called NODUS which provides a tool for the detailed analysis of freight transportation over extensive multimodal networks. It is built around the systematic use of the concept of "virtual links" which enables the development of a network analysis covering all transport operations by different modes, means and routes, including all interface services in nodal platforms and terminals. Cost functions are attributed to every operation (loading, unloading, moving, waiting and/or

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[22] This chapter has been based on Jonkeren et al. (2009).

transit, transshipping) in the virtual network. It is then possible to minimize the corresponding total cost of freight transportation with respect to the choices of modes, means and routes, with intermodal combinations included in the choice set. Hence, we assess the impact of low water levels on the cost functions for inland waterway transport between combinations of origins and destinations under several climate scenarios.

Like in the previous chapter, the area (the set of origins and destinations) under research covers the Kaub-related Rhine market. Recall that Kaub is chosen as a reference point, because it is here that restrictions related to low water levels are most severe.[23] The Kaub-related Rhine market is a geographical market area and is formed by all regions that are the origin or destination of a trip made by barge that passes Kaub. Consequently, all trips made by road and rail between those origins and destinations also belong to the Kaub-related Rhine market.

The purpose of this chapter is to gain insight into the effect of climate change on modal split. One effect may be that a loss in quantity transported by inland waterways results in an increase in quantity transported by rail and road, which could possibly lead to higher levels of congestion for these modes. In addition, an increase in CO_2 emissions may be expected because inland waterway transport is a more environmental friendly mode than road transport. These consequences would be highly undesirable from the viewpoint of the European Commission transport policy, which is aimed at reducing the emission of greenhouse gasses and shifting freight from road to rail, inland waterways, and short sea shipping (European Communities, 2006).

3.2 Modelling freight transport

Freight transport demand models can be classified in a number of different ways. A common classification is the one that distinguishes between aggregate and disaggregate models where the distinction lies in the nature of the data used; in the aggregate studies, the data consist of information on total flows by modes at the regional or national level, while in disaggregate studies, the data concern individual shipments (Winston, 1983; Zlatoper and Austrian, 1989). García-Menéndez et al. (2004) define aggregate models as models that are used to forecast the behaviour of an entire transport system, and disaggregate models as models that can predict the behaviour of individual agents within a

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[23] See Section 2.1 and Figure 2.1 for a more profound explanation of the location Kaub.

specific transport system. Recent examples of studies that use aggregate models are Ham et al. (2005) who use data on the commodity level (in tonnes) to predict the weight (again in tonnes) of network flows, and Ohashi et al. (2005) who use air cargo traffic flow data to identify the critical factors influencing air cargo transshipment route choice decisions. Recent disaggregate models can be found in García-Menéndez et al. (2004) and Beuthe and Bouffioux (2008), which are both studies that investigate the determinants of mode choice on the individual shipper level using surveys.

A distinction between econometric and non-econometric studies is another classification possibility. In Smith (1974) and de Jong et al. (2004), a survey of mainly non-econometric models can be found, while Zlatoper and Austrian (1989), or more recently, Bhat et al. (2008) deal with econometric models. An econometric technique that nowadays is very often used in behavioural freight transport modelling is discrete choice analysis.

The Four-Step Model offers a third way to classify freight transport demand models. Models can be specified as being a generation, a distribution, a mode choice, or a route choice model, or a combination of these types. Note that, in a route choice model, a confrontation of demand and supply takes place, so we cannot speak of a freight *demand* model. Examples of a distribution model and a simultaneous mode- and- route choice model can be found in chapters 5 and 6 in Tavasszy (1996). Reviews of the Four-Step Model are given in McNally (2008), de Jong et al. (2004) and Rietveld and Nijkamp (2003).

Finally, freight demand models can be categorized as urban or non-urban. The concept of urban freight modelling is explained in D'Este (2008). A broader review of freight transport demand models can be found in for example Ortúzar and Willumsen (2001), Chapter 13.

According to the classifications made above, the freight transport model used in the current study can be classified as a non-econometric, non-urban, aggregate, combined mode choice/ route choice model. In fact, our model can be described as a strategic freight network planning model. Such models are not meant for use in managing the moment-to-moment or day-to-day operations of freight companies. Rather, they are employed primarily to forecast months or years into the future (Friesz and Kwon, 2008). Examples of the literature on network planning models are Friesz (1985) and Friesz and Harker (1985), while Kresge and Roberts (1971) are generally considered to be the creators of the first freight network planning model. A useful overview can also be found in Crainic and Laporte (1997).

We apply a static GIS-based strategic freight network planning model called NODUS[24]. It provides a tool for the detailed analysis of freight transportation over extensive multimodal networks. The limitations of the model are discussed in Section 3.5.2. An advantage of NODUS is that mode-and-route choice are modelled in an integrated way. Other strengths are the very detailed spatial character of the model and the fact that it allows for multimodal solutions. Dueker and Ton (2000) state that GIS concepts and technologies are valuable aids in transportation planning and operations. They provide an overview of the possible application levels of a GIS in these disciplines. Other GIS-based models for freight transportation analysis can be found in, for example, Cheung et al. (2003) and Cairns (1998).

3.3 Freight transport modelling with NODUS

3.3.1 The concept of the virtual network

NODUS is a tool for the detailed analysis of freight transportation over extensive multimodal networks. It contains the transport networks of road, rail, inland waterways and short sea shipping covering the geographical area of the whole of Europe. The networks of each mode are constructed from links and nodes. On the links (roads, railways, waterways, ferry lines), moving operations take place and, in the nodes, operations such as loading, unloading, transhipping and transiting, are carried out at terminals or logistic platforms. Costs are attributed to the different operations on the infrastructure network. However, infrastructures can be used in different ways. For example, small and large trucks have different operating costs but they can use the same road. A simple geographic network does not provide an adequate basis for the detailed analysis of transport operations where the same infrastructure is used in different ways. Therefore, NODUS decomposes all transport operations that take place on the "real" multimodal network into a virtual network.[25] This concept of the virtual network was initially proposed by Harker (1987). By

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[24] Other studies based on NODUS are Jourquin and Beuthe (1996), Geerts and Jourquin (2001), Beuthe et al. (2001), and Beuthe et al. (2002).

[25] In Figure 2.1, the "real" network for inland waterways is visualized. The "real" networks of rail and road are omitted from the figure to keep it comprehensible.

creating a virtual network, a transportation problem with all its alternative solutions and operating dimensions can be properly analysed by identifying and separating each transport operation. So, all successive operations in the geographic space concerned are linked in a systematic way. We use Figure 3.1 to visualize a virtual network.

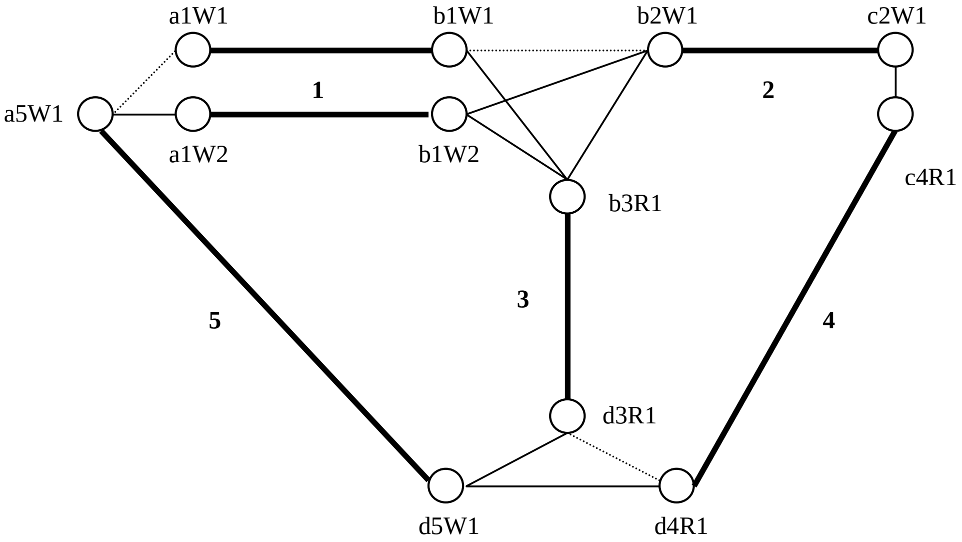

Figure 3.1: Virtual network

Note: for virtual node ‘a1W2’, ‘a’ represents the node, ‘1’ the link, ‘W’ the mode (in this case inland ship) and ‘2’ the means (the type of inland ship). An ‘R’ stands for railways and the bold numbers stand for the link-numbers. The thin continuous lines represent transhipment operations, the dotted lines transit operations, and the bold lines the links of the real network, possibly split up, depending on how many different means of a certain mode can be carried on the link. For instance, between node ‘a’ and node ’b’, link ‘1’ can carry two types of inland ships: small ones (W1) and large ones (W2), so the real link is split into two separate virtual links. What holds for a link, also holds for a node. Node ‘b’ for example is present in the label of four virtual nodes; it is a starting or end point of the links ‘1’, ‘2’ and ‘3’, where starting or end point ‘b1’ is represented twice because it is the starting or end point of two different types of inland ships. These four virtual nodes are also interconnected in order to represent transit and transhipment operations.

However, the virtual network in Figure 3.1 is still not complete, as it does not contain virtual nodes for entry and exit (loading and unloading). In addition, the costs of going one way on a link are usually not equal to going the other way on that link, so every link should be represented by two arrows, indicating the direction of the flow. The final virtual network (now focusing on node ‘b’) can be seen in Figure 3.2. The ‘+’ sign indicates that cargo is unloaded at a certain virtual node and a ‘–’ sign indicates a loading activity. X_k^{jtm} defines a virtual node k, with link number j, mode t and means (or mode type) m. Virtual node $-X_b^{000}$ indicates an entry point in the virtual network. For a more detailed explanation of virtual networks, we refer to Jourquin and Beuthe (1996).

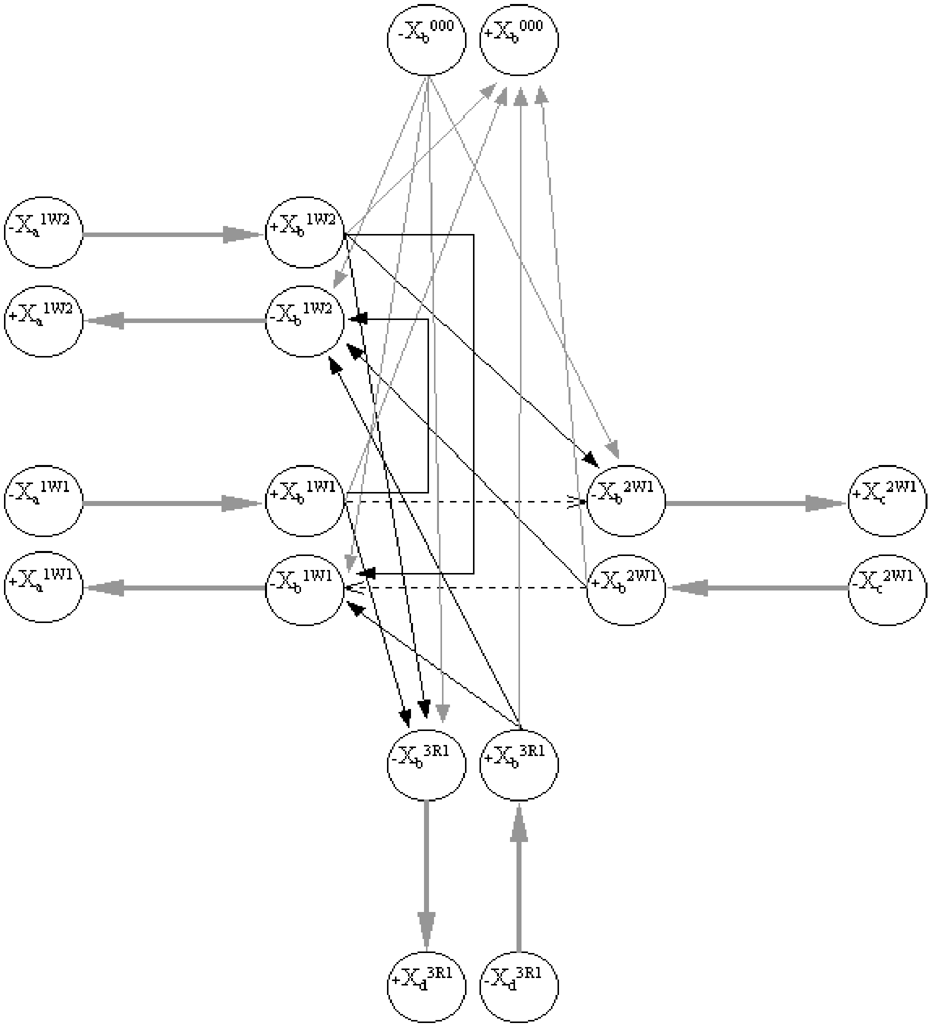

Figure 3.2: Final virtual network at node b

3.3.2 Assignment method: the Multi-Flow approach

NODUS confronts supply (the infrastructure networks of several modes, and the costs associated with the several types of vehicles that can be used) with demand (the given mode's specific flows), according to a chosen assignment method. Several assignment methods can be applied. In some earlier studies (Jourquin and Beuthe, 1996; Beuthe et al., 2001) with NODUS, the All-or-Nothing method was applied to mode choice and route choice. With this method, the flow is assumed to be transported on the minimum cost path for each OD pair.

With the equilibrium method, NODUS can determine how the flow between each OD pair is distributed over various routes and modes, taking into account the variation of the transportation costs according to the assigned flows. Jourquin and Limbourg (2006) focus on equilibrium algorithms. However, from their study, it turned out that within the NODUS context this methodology was of little use, in the sense that the modal split per OD pair does not differ much from the All-or-Nothing result. This is mainly explained by the aggregation level of the demand matrices[26], and the static nature of the assignment[27].

A better solution can be found in the multi-flow approach (Jourquin, 2006). This method can compute a set of realistic alternative routes (and modes), over which the flow can be spread. For every mode type, (small barge, large truck, etc.) if possible, at least one path is computed, between every OD combination. Thus one can generate a set of credible alternative paths between OD pairs that also includes a set of alternative transportation modes. Compared with the above-mentioned assignment methods, the multi-flow method leads to a better prediction of the modal split *per OD combination* (Jourquin and Limbourg, 2007).

Summarizing, the All-or-Nothing procedure only includes generalized costs as the explanatory variable for route/mode choice, while the equilibrium algorithms also include capacity constraints (in combination with flow), and the multi-flow method allows for other, unknown explanatory variables like unknown features of routes and modes.

The distribution of the demand over the different identified paths is the last step that must be performed with the multi-flow method. The basic idea that is used here is that the modal split is computed on the basis of the cost of the cheapest path for each mode. In a second step, the quantities are spread over the different routes/means within the same mode, according to their relative weight. This procedure is similar to a nested logit model. The modal split (in tonnes) remains independent of the number of alternative routes computed for a certain mode/means combination (iterations). Tests with the multi-flow

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[26] The OD matrices contain total quantities on an annual basis, so it is difficult to estimate what is transported at a given time of a day.

[27] As distances are long, a single trip often occurs during different periods of the day, including peak hours, so travel times are not constant over time. However, as NODUS is a static model, it is not able to deal with this aspect.

assignment procedure in the context of the NODUS model can be found in Jourquin (2006).

3.4 The reference scenario

In the reference scenario we want to analyse how many tonnes are transported by barge in the Kaub-related Rhine market in a year under current climate conditions. The freight flows from the OD matrix are assigned on the detailed network, where the assignment is based on cost functions. Figure 3.3 shows how NODUS works schematically.

Demand is formed by the European OD matrix containing flows in the year 2000, kindly provided by NEA. The origins and destinations are defined at the level of NUTS II (Nomenclature of Territorial Units for Statistics) regions, each NUTS II region having a centroid representing a gravity point of demand within the region.

So, we work with aggregate demand data for a number of pre-specified NUTS II regions. The OD matrices contain those combinations of origins and destinations that would logically make use of the Kaub link in a situation of normal water levels if the mode inland waterway transport were to be used. Our geographical study area is of this size because we want to focus our analysis on the Kaub-related Rhine market. We will come back to this issue in the next section.

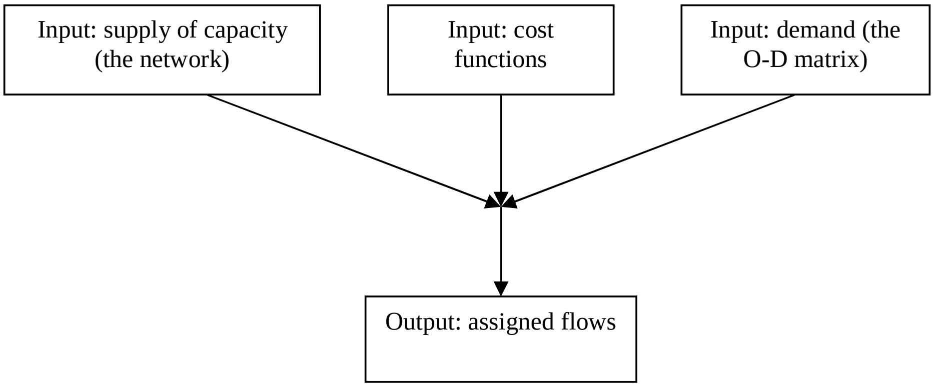

Figure 3.3: Inputs for NODUS

Our cost functions are based on detailed cost data from NEA (2005). NEA has calculated the costs for loading, unloading, waiting and transportation for several types of trucks, trains and barges[28]. The costs take into account that vehicles are not always fully loaded or may even be empty and that different cargo types are transported. Indeed, transporting 10 tonnes of live animals costs more than transporting 10 tonnes of coal. Moreover, costs for transhipment between trucks and barges and trucks and trains for commodity NSTR 9 are defined because this commodity includes containers[29]. The standard cost functions take into account an average speed for each mode, but the assignments are based on costs that integrate the real speed defined for each link of the digitized network.

External costs are not taken into account. Apart from costs, qualitative factors like reliability and safety also determine the mode and route choice. These factors are not included explicitly, but through the calibration of the model.

We split the OD matrix into three equal sub-matrices (in terms of tonnes) according to distance. So, the first OD matrix contains flows that are transported over less than 308 kilometres; the second, flows that are transported over more than 308 kilometres but less than 473 kilometres; and the third, flows that are transported over more than 473 kilometres. Distinguishing these three “distance-markets” enables us to calibrate in such a way that a change in costs in the operations of one of the modes leads to a correct shift in market shares.

Calibration is required because there is a lack of information (e.g. we do not have information on the behaviour of shippers). So, not all the ideally needed information is incorporated into the cost functions, resulting in a modal split that is not necessarily in line with the observed one. To overcome this problem calibration factors are introduced into the cost functions. The result is that we approximate the observed modal split for the area under research. In our model we distinguish two types of calibration factors, those for fixed costs and those for variable costs.

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[28] Only the time costs of loading and unloading are included, not the handling costs. We refer to Appendix A for an overview of the different types of modes (and the various means) we use in our study.

[29] The NSTR nomenclature can be found in Appendix B.

In interviews, experts stated that transhipment of bulk cargo between trucks and trains is quite exceptional. Transhipping bulk cargo between trucks and barges happens more often, but the majority of bulk transport by barge is also point-to-point transport. Shippers of bulk cargo are often very large and have their own railway or inland waterway connection to the railway or waterway network which facilitates point-to-point transportation by train and barge. Transhipment of containers (included in NSTR 9) happens much more often between trains and trucks or barges and trucks. Therefore, these transhipment costs are taken into account.

Focusing on Figure 3.4, an adjustment in the calibration factor for the variable costs of one of the modes results in a change of the slope of one of the curves, while an adjustment in the calibration factor for fixed costs results in a change of the intercept of the curve of the particular mode.

Every OD combination of our OD matrix can be placed somewhere on the horizontal axis of Figure 3.4. For an OD combination with distance A, the transport costs for each mode are given by the intersection of the mode-specific cost curves and the vertical dotted curve through A. The market shares for each mode are then based on their relative costs, so road gets the largest share, inland waterway transport the smallest share, and rail a share in-between the other two. For an OD combination with a longer distance (for example, distance B), the cost levels, and thus the market shares are different.

Now, calibration in the form of a change in the intercept or slope of one curve, changes the share of every mode, for every distance. In this way we are able to calibrate the model in such a way so that the modal split in the three different distance markets is approximated.

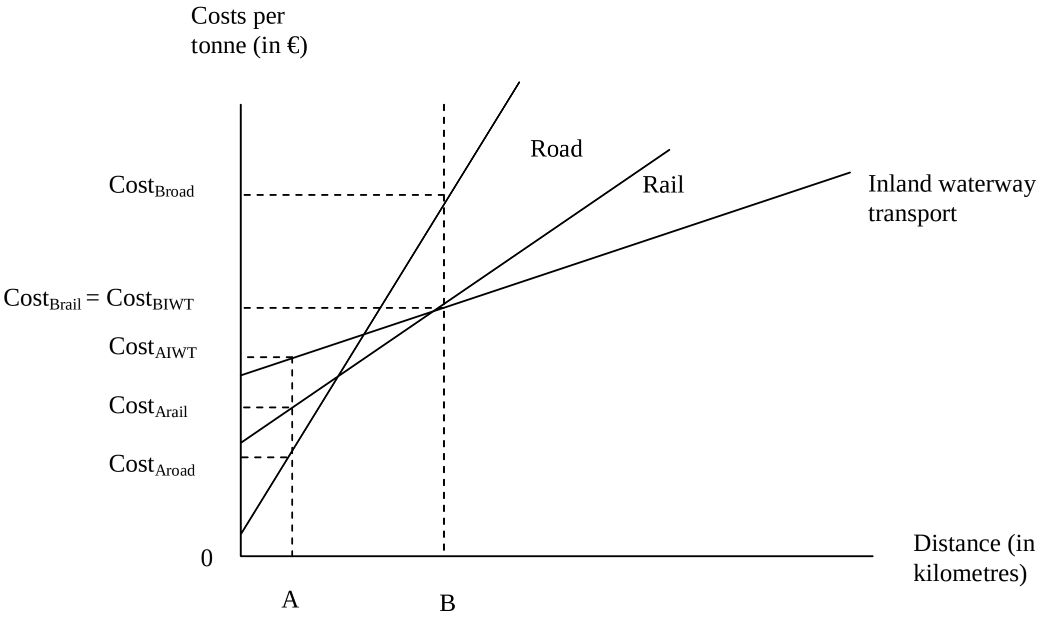

Figure 3.4: Transport costs, distance and modal choice

Table 3.1: Comparison of the 2000 statistics and assigned flows in the river Rhine area, measured in tonnes per NSTR group for the total distance market

NSTR group	**2000 statistics (NEA)**			**Assigned flows**		
	% Water	% Rail	% Road	% Water	% Rail	% Road
0-9	16.1%	11.9%	71.9%	15.3%	13.5%	71.3%
0	7.9%	8.3%	83.8%	7.8%	12.4%	79.8%
1	9.8%	1.6%	88.6%	9.8%	4.0%	86.2%
2	43.5%	40.8%	15.7%	41.8%	40.8%	17.4%
3	61.2%	15.3%	23.5%	56.3%	18.7%	25.0%
4	20.7%	29.9%	49.4%	24.6%	31.0%	44.4%
5	6.6%	23.3%	70.1%	4.5%	25.5%	70.0%
6	12.1%	4.6%	83.3%	9.8%	6.5%	83.8%
7	35.4%	25.4%	39.3%	35.5%	21.7%	42.7%
8	16.1%	15.4%	68.6%	17.5%	11.7%	70.8%
9	4.4%	11.4%	84.2%	4.5%	13.1%	82.4%

Source: NEA, 2000 and own computation, 2009.

The obtained modal split after calibration for every NSTR group in the river Rhine area in the base scenario for the total market is presented in Table 3.1. Table 3.2 shows the number of tonnes transported past Kaub by barge in the base scenario for each NSTR commodity type and distance market.

Table 3.2: Relative (in modal split) and absolute (in thousands of tonnes) volumes transported by inland waterway transport past Kaub in the base scenario, year 2000, per NSTR group, for each distance market (short, medium and long)

NSTR group	$Q_{0Kaubtotal}$		$Q_{0Kaubshort}$		$Q_{0Kaubmedium}$		$Q_{0Kaublong}$	
	Absolute	%	Absolute	%	Absolute	%	Absolute	%
0-9	52 424	15.3%	9677	8.5%	18 976	16.7%	23 770	20.5%
0	2368	7.8%	400	3.6%	552	5.8%	1415	14.8%
1	3538	9.8%	513	4.1%	719	6.7%	2305	17.7%
2	5344	41.8%	540	20.5%	2422	43.9%	2381	51.2%
3	18 993	56.3%	3766	44.5%	10 363	58.0%	4862	65.7%
4	2271	24.6%	223	7.0%	5268	24.9%	1521	38.6%
5	825	4.5%	95	3.0%	189	3.1%	540	6.0%
6	6716	9.8%	2312	5.9%	1163	6.5%	3240	27.9%
7	2012	35.5%	354	17.0%	795	41.6%	862	51.8%
8	6144	17.5%	768	8.9%	1274	10.8%	4101	27.9%
9	4210	4.5%	702	3.1%	966	3.2%	2540	6.3%

Source: Own computation, 2009.

Commodity type 3 (petroleum products) is by far the biggest group. In total, about 52 million tonnes was transported past Kaub in the year 2000, and this is used as the base scenario. The distance-market-specific columns show that for almost every NSTR commodity the amount transported by inland waterways increases with the distance covered.

3.5 Alternative scenarios

3.5.1 The effect of climate change on the market share of inland waterway transport

In the alternative scenarios we study the effect of climate change on the amount of goods transported by each mode in the Kaub-related Rhine market.

Te Linde (2007) assessed the effect of climate change on the discharge of the river Rhine at several locations, including Kaub, using hydrological models. In that study, for every climate scenario daily discharges were estimated for the years 1961 to 1995[30]. By means of what is known as the Q-h (discharge – water level) relationship for the location of Kaub, the daily discharges were transformed into daily water levels for Kaub for the period of 1986 to 1995[31]. Daily water levels at Kaub under a certain threshold level imply an increase in transport prices for trips that passes Kaub. These price increases have a one-to-one relationship with cost increases via changes in load factors, under the assumption of perfect competition in the inland waterway transport market.[32] In periods of low water levels, inland ships sometimes have to navigate with a load factor of 50% (or even lower) leading to severe increases in the transport price per tonne. The height of the price increases is based on Table 2.5 in Chapter 2. The percentages presented in the table are price increases per tonne corrected for a large number of factors. Since the distance of the trips is given, they can be interpreted as price increases per tonne-kilometre.

The price increases are only valid for the Kaub-related inland waterway trips. After all, barges that do not pass Kaub, are not restricted in their load factor by the water level at

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[30] Although we have the *observed* daily water levels in the base scenario at our disposal, we use the *modelled* daily water levels in the base scenario so that a possible systematic error in modelling water levels is present in the base scenario as well as in the alternative scenarios.

[31] Because our water level data ranges from 1986 to 2007, in order to translate discharges into water levels we can only use the overlapping years in the discharge series and the water level series.

[32] The inland waterway transport market in the river Rhine basin may be characterised as a competitive market because inland waterway transport carriers offer an almost homogenous product (transport of different types of bulk cargo), there are many suppliers, shippers may easily (without much costs) switch from one inland waterway transport enterprise to another and it is relatively simple to enter the Rhine market out of adjacent geographical markets.

Kaub, but by the water level at another location. Compared with other locations, the water level at Kaub has the most severe effect on the load factor of inland ships. This is also the reason why we focus our study on the Kaub-related Rhine market and not on the total inland waterway transport market in Europe. If we were to apply the price increases only valid for the Kaub-related Rhine market to the whole market, the effect of low water levels on the change of tonnes transported by barge would be overestimated.

Table 3.3 gives an overview of the average percentage increase in price per tonne during the low water period and the length of the low water period in days in the cases of the base scenario, the four climate scenarios, and the year 2003, in comparison with a year without low water levels. The figures in Table 3.3 are averages, based on a series of ten years between 1986 and 1995. We include the year 2003 because Beniston (2004) states that the summer of 2003 can be used as an example for future summers in the coming decades in climate-impact and policy studies.

Table 3.3: Effect of climate scenarios on the length of the low water period and on the costs of inland waterway transport in the low water period

Climate scenario	**Base period (1987 – 1995)**	**M (2050)**	**M+ (2050)**	**W (2050)**	**W+ (2050)**	**2003**
Average annual number of days low water (less than 260 cm)	103	99	140	95	182	198
Average % cost increase in low water period compared with situation without low water	17.8%	18.0%	21.9%	17.9%	27.0%	27.2%

Source: Te Linde, 2007.

The length of the low water period is equal to the number of days with a water level lower than 260 cm at Kaub.

To model the effect of climate change on modal split, we have to model the difference between the climate scenarios and the base scenario. The percentage cost increase in an alternative scenario is thus based on this difference.

Because of lack of information, we had to assume that the demand for inland waterway transport for each NSTR group is constant over a year. In the alternative scenarios, the costs for the transportation activities by barge are raised according to the respective climate scenarios. Table 3.3 shows that, in climate scenarios M and W, the cost effect of climate change is close to zero, as water levels drop in summer and autumn, but only marginally, thus not affecting costs. The 2003 scenario is very similar to the W+

scenario. In the remainder of this study, we will therefore only assess the effect of climate scenarios M+ and W+ on modal split.

Table 3.4 shows the percentage of tonnes that inland waterway transport loses in the Kaub-related Rhine market in both climate scenarios. The absolute figures are presented in Appendix C.

Table 3.4: Relative loss of tonnes transported by inland waterways in both climate scenarios compared with the base scenario per NSTR group in the river Rhine area

NSTR group	**M+ scenario**	**W+ scenario**
0-9	-2.3%	-5.4%
0	-2.4%	-5.8%
1	-2.0%	-4.9%
2	-1.9%	-4.7%
3	-1.4%	-3.3%
4	-3.4%	-8.3%
5	-2.7%	-6.3%
6	-3.1%	-6.7%
7	-2.1%	-4.9%
8	-4.2%	-10.2%
9	-2.1%	-5.1%

Source: Own computation, 2009.

In the W+ scenario, total demand (in terms of tonnes transported) for inland waterway transport drops by about 5.4 per cent (2.8 million tonnes) because of an average price increase of 16.9 per cent during 182 days in a year. In the M+ scenario total demand for inland waterway transport drops by about 2.3 per cent (1.2 million tonnes) because of an average price increase of 8.8 per cent during 140 days in a year[33]. In the total transport market (in the area under consideration), transport performance, road traffic performance and the level of CO_2 emissions change in the W+ scenario compared with the base scenario. On an annual basis, the total volume of tonne-kilometres decreases by 0.5 per cent because the tonnes that are shifted to road and rail in the low water level period are transported over shorter distances. The total volume of vehicle kilometres increases by 0.98 per cent because the carrying capacity of a train or (especially) a truck is lower than

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[33] W+: during 103 days a price increase of 9.2 per cent (27.0 - 17.8 per cent) and during 79 days (182 – 103) a price increase of 27.0 per cent. Weighted average price increase is then 16.9 per cent. M+: during 103 days a price increase of 4.1 per cent (21.9 - 17.8 per cent) and during 37 days (140 – 103) a price increase of 21.9 per cent. Weighted average price increase is then 8.8 per cent. Note that an elasticity may not be derived from these changes in p and q. The change in q is based on the low water periods of 140 (M+) and 182 (W+) days, while the q_0 is based on the whole year.

that of a barge and the annual volume of *truck* vehicle-kilometres increases by 1.0 per cent. The total volume of annual CO_2 emissions increase by 1.1 per cent because the CO_2 emission per truck tonne-kilometre is higher than per barge tonne-kilometre and because the load factor of barges is lower in the W+ scenario due to lower water levels. Because the trend in freight transport related CO_2 emission in the EU15 (shown in Table 3.5) demonstrates a stabilization since 2004, the estimated increase in CO_2 emission is clearly undesirable from a European Commission transport policy point of view.

Table 3.5: Index for CO_2 emission due to freight transport by road, rail and inland waterways in the EU15

Year	2000	2001	2002	2003	2004	2005	2006
CO_2 index	100	101.4	102.7	103.5	105.0	104.2	104.7

Source: Eurostat, 2008

Table 3.6 shows that the road transport sector profits most from low water levels. About 70 per cent is taken over by this mode, the rest by rail.[34] On an already congested road network, like in North West Europe, an increase in the amount of road traffic leads to a disproportionate increase in congestion (Small and Verhoef, 2007). Note that, within the context of the model, total demand for transport is perfectly inelastic. This implies that the absolute number of tonnes that is shifted from inland waterway transport to road and rail is somewhat overestimated. Indeed, the amount that is shifted to road and rail also contains those shipments that were not to be transported due to elastic demand for total transport.

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[34] Road is a dominant transport mode in terms of tonnes for most OD combinations for most NSTR groups. This implies that on average (seen over all NSTR groups and OD combinations), road has the lowest relative costs in each distance market and as a result most of the tonnes lost by inland waterways are taken over by road. Note that qualitative factors that determine mode choice are included in the relative costs through the calibration of the model.

Table 3.6: Distribution of the loss of freight of inland waterways over rail and road in percentages per NSTR group in climate scenarios M+ and W+

NSTR group	**Rail**	**Road**	**Rail**	**Road**
	M+		**W+**	
0-9	28.0%	72.0%	28.4%	71.6%
0	16.0%	84.0%	16.0%	84.0%
1	4.8%	95.2%	4.9%	95.1%
2	68.0%	32.0%	68.0%	32.0%
3	43.1%	56.9%	43.1%	56.9%
4	43.8%	56.2%	42.8%	57.2%
5	27.4%	72.6%	27.4%	72.6%
6	9.7%	90.3%	9.4%	90.6%
7	34.5%	65.5%	34.2%	65.8%
8	19.5%	80.5%	19.9%	80.1%
9	14.9%	85.1%	15.0%	85.0%

Source: Own computation, 2009.

Our methodology can also be used to study price (or cost) elasticities of demand for inland waterway transport in the context of intermodal competition. The results of this analysis are shown in Table 3.7. Note that these are long-run elasticities, based on yearly demand data. The main conclusion is that the demand for inland waterway transport is rather inelastic with almost all values lying between -1 and 0. These results are close to the value of the elasticity of demand for inland waterway transport of about -0.50, estimated in Chapter 2, which is based on data on volumes and prices. However, these elasticities are only partly comparable. The present estimate is based on the assumption that mode change can take place without additional costs or capacity constraints.

Table 3.7: Cost elasticities for inland waterway transport in the Kaub-related Rhine market per NSTR chapter

NSTR group	**ε Kaub market, M+**	**ε Kaub market, W+**
0-9	-0.67	-0.64
0	-0.71	-0.69
1	-0.60	-0.58
2	-0.57	-0.55
3	-0.41	-0.40
4	-1.01	-0.98
5	-0.80	-0.75
6	-0.90	-0.79
7	-0.63	-0.58
8	-1.25	-1.21
9	-0.63	-0.60

Source: Own computation, 2009.

This is, of course, a strong assumption: transport by barge is often characterized by large volumes, so that in the short run, other modes are not able to take over a part of the volume transported by barge. Therefore, it is no surprise that we find that the overall elasticity (for NSTR 0-9) obtained here is slightly higher than the one in Chapter 2 which is based on observed flows.

3.5.2 Drawbacks and limitations

Some drawbacks of our research should be mentioned. Demand for total transport is assumed to be perfectly inelastic, while it is plausible that, in the case of low water levels leading to higher prices, some cargo will not be transported by any mode due to elastic overall demand. Second, costs are assumed to be equal to prices in all the three transport markets under consideration. The markets for inland waterway transport and road transport could be characterized as perfectly competitive markets. The rail freight transport market used to be a monopoly, however as a result of liberalization the number of railway operators has increased since 1998. In the Netherlands, 13 commercial railway freight operators were active in 2007 (KIM, 2007) whereas before 1998 there was only one operator. Furthermore, NODUS is a strategic model with which day-to-day operations can be modelled only in an implicit way. Moreover, it is assumed that no technological improvements will be made in infrastructure and the fleet of inland waterway vessels in the future. Next, we assume that transportation costs are linear with distance, while they are probably concave (McCann, 2001). However, by distinguishing three different “distance-markets”, this limitation is partly overcome. Also, the demand for inland waterway transport is assumed to be equally distributed over the year, while signs from the market indicate that the peak demand for inland waterway transport lies in those months when low water levels occur relatively often. In addition, it is assumed that shippers do not have switching costs when choosing for another transport mode. Then, the estimated absolute modal shift effect is based on flows in the year 2000. It is likely however, that the demand for transport will grow in the future. Last, remember that the loss of cargo for inland waterway transport only applies to the Kaub-related Rhine market. Trips that do not pass Kaub, but pass other locations that impose load factor restrictions on barges, are not considered here.

3.6 Conclusion

In this chapter we have studied the effect of climate change on modal split in the river Rhine area. Climate change is likely to affect inland waterway transport prices via low water levels which may lead to a deterioration of the competitive position of inland waterway transport compared with rail and road transport. We studied this issue using NODUS, a GIS-based strategic freight network planning model that combines supply, demand and cost functions to assign flows on a multi-modal network. At first, a base scenario was created describing a fictitious year with average daily water levels, as modelled from 1986 to 1995. The alternative scenarios were based on several climate scenarios which implied increases in the costs for inland waterway transport as a result of low water levels. Relative to the base scenario, we estimated the reduction in the annual quantity transported by barge to be about 2.3 per cent (1.2 million tonnes) in the case of climate scenario M+, and about 5.4 per cent (2.8 million tonnes) in the case of scenario W+, in the Kaub-related Rhine market.[35] As a result, the volume of road vehicle kilometres and the volume of CO_2 emission increase with about 1 per cent.

Note that, in other markets, where the load factor of inland ships is determined by other locations than Kaub, inland waterway transport will also be confronted with a reduction in the quantity transported. However, the effect of low water levels in those locations on transport prices, and thus also on the transported quantity, is less severe than in the Kaub location. If we consider the total Rhine market, which is larger than the Kaub-related Rhine market, and assume that the effect of low water levels on transport prices in all locations where the water level is measured is equal to the effect in Kaub, an upper limit for the decrease in tonnes transported by inland waterways would be about 16 million tonnes annually in the case of climate scenario W+.

We conclude that, under the given climate scenarios the effect of climate change on modal split in the Rhine area is limited. However, in the light of the policy goal of the European Commission to shift cargo from road to other transport modes and to reduce the emission of greenhouse gasses, this predicted change in model split is undesirable.

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[35] The climate in North West Europe in the year 2003 can be considered as representative for the climate scenario W+.

Appendix A: Transport means considered in NODUS

Road	Rail	Inland waterway transport
Truck 12-20 tonnes	Electric train	Barge < 400 tonnes
Truck > 20 tonnes	Diesel train	Barge 400 – 650 tonnes
		Barge 650 – 1000 tonnes
		Barge 1000 – 1500 tonnes
		Barge 1500 – 3000 tonnes

Appendix B: Description of the NSTR commodity groups

NSTR group	Description
0	Agricultural products and life animals
1	Foodstuffs and animal fodder
2	Solid mineral fuels
3	Petroleum products
4	Ores and metal waste
5	Metal products
6	Crude and manufactured minerals, building materials
7	Fertilizers
8	Chemicals
9	Machinery, transport equipment, etc.

Appendix C: Absolute loss of transported volume (in thousands of tonnes) by inland waterways in both climate scenarios compared with the base scenario per NSTR group in the river Rhine area

NSTR group	M+ scenario	W+ scenario
0-9	1190	2818
0	57	137
1	71	171
2	102	249
3	262	633
4	77	187
5	22	52
6	205	447
7	43	98
8	258	626
9	90	213

Source: Own computation, 2009.

Note: the results are based on transport flows in the year 2000.

CHAPTER 4

THE EFFECT OF AN IMBALANCE IN TRANSPORT FLOWS ON INLAND WATERWAY TRANSPORT PRICES[36]

4.1 Introduction

Transport costs play a fundamental role in the determination of the location of regional economic activities (see, e.g., Krugman, 1991, 1998; Ottaviano and Puga, 1998; Neary, 2001). A characteristic assumption in studies of regional activities is that transport costs are exogenous. However, recently, a number of studies in the new economic geography literature have emphasized that transport costs may be *endogenous*. In particular, we refer to the recent studies by Behrens and co-authors (Behrens and Gaigné, 2006; Behrens et al., 2006; Behrens et al., 2009). For example, Behrens et al. (2006) introduced the presence of density economies into a new economic geography model by assuming that unit shipping costs decrease with the aggregate volume of trade. Endogeneity of the transport costs is clearly also important for studies on international trade. For example, Anderson and van Wincoop (2004) stress the need to deal with this issue in studies of trade. [37]

There are a number of reasons why transport costs may be endogenous (for recent studies which discuss this issue, see Duranton and Storper, 2008, and Anderson, 2008). One reason is that the unit shipping costs decrease with the volume of trade due to the presence of density economies (e.g. Behrens et al., 2006). Another reason is that transport markets are not competitive and that industry location is endogenous (see, Behrens et al., 2009). This chapter emphasizes, however, that the endogeneity of transport costs is more fundamental and also an issue in competitive transport markets, as is prominently featured

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[36] This chapter has been based on Jonkeren et al. (2008).

[37] Note that, although transport costs, i.e. the physical costs of a shipment, are only a share of trade costs, i.e. the sum of all the costs incurred to deliver a good to its user (Duranton and Storper, 2008), transport costs are generally thought to be the most important trade cost *within* countries and one of the most important components of trade costs *between* countries**.** This certainly applies to trade within the EU where artificial trade barriers are absent or limited. According to Sánchez et al. (2003) and Limão and Venables (2001), artificial trade barriers are reduced to low levels as a result of trade liberalization. Therefore, it is plausible that the relative importance of transport costs in total trade costs has increased in recent decades.

in transport economic textbooks such as Boyer (1998). The main reason is that, at least theoretically, an imbalance in terms of trade volumes between two regions causes the transport price in one direction to exceed the price in the opposite direction when *a positive proportion of carriers are required to return without paid cargo*.[38] One of the implications is that, ceteris paribus, unit shipping costs increase with the relative volume of trade between regions, implying that the transport costs increase with trade. It is therefore theoretically ambiguous what the net effect is of a change in the traded volume on trade costs as it depends on what type of effect dominates. In one market, the net effect may be negative while for other markets it may be positive.

The effect of imbalance on freight prices may potentially be very large. For example, the freight price for a 1 TEU container of plastic bags from Shanghai to San Francisco is $ 2,065, whereas its backhaul price is $ 1,111. So the backhaul price is roughly 50% less than the fronthaul price.[39] Likely, the main explanation for this observation is that the imbalance between merchandise goods flows from China to the U.S. is much larger than the other way around (in value terms, the flow from China to the U.S. is four times that of the return flow).

In the current chapter, we focus on price formation in the inland waterway transport network in North West Europe. This market is highly competitive with thousands of small carriers. In this network, imbalances in transport flows are frequently observed. Imbalances are caused by regional differences in demand and supply for transport. For example, in Europe, most seaports, such as Rotterdam and Hamburg, are import ports of, in particular, bulk goods such as oil, coal, etc. This implies that more cargo is transported from the seaports to the hinterland than in the opposite direction, which causes an imbalance in trade flows.

This chapter is not the first empirical study to focus on endogenous transport prices.[40] We are aware of four studies in which the effect of an imbalance in transport flows on maritime shipping prices has been examined empirically (Blonigen and Wilson, 2008; Wilmsmeier et al., 2006; Márquez-Ramos et al., 2005; Clark et al., 2004). However,

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[38] For an early discussion of this phenomenon, usually called the “backhaul problem”, see Pigou (1913).

[39] This kind of information is publicly available on freight price websites such as www.freight-calculator.com. The exact figures given apply to November 2007.

[40] There is some literature, mainly focusing on maritime transport, in which the determinants of transport prices are analysed, but imbalances in transport flows are usually ignored.

in these studies, the imbalance is assumed to be exogenous, which is at odds with theory.[41] Furthermore, the maritime shipping industry is characterized by a high degree of collusion, with a few large firms with market power, so the assumption of a competitive market may not apply (Sjostrom, 2004). Hence, it is not clear whether the empirical results of these four studies may be interpreted only in the light of predictions of competitive theories.

We estimate the marginal effect of an imbalance in transport flows on the unit transport price of a trip between two locations (regions) in the inland waterway transport market in North West Europe. Some major differences between the current study and the four transport price studies mentioned above must be mentioned. First, these studies only use information on imbalances of bilateral routes, while we also take into account characteristics of the whole network.[42] Hence, we are able to employ a standard and a sophisticated measure of imbalance. Second, to our knowledge, we are the first to consider imbalance as a possible endogenous variable. Third, we empirically capture density economies in a different, and arguably more fundamental, way than Clark et al. (2004) and Márquez-Ramos et al. (2005). According to theory (see, for example, Brueckner et al., 1992), density economies arise because a higher traffic density on a route allows the carrier to use larger vessels and to operate this equipment more intensively (at higher load factors). In addition, higher traffic densities on a route allow for a more intensive and efficient use of the port facilities that serve that route implying lower time costs per unit handled. As we have a very rich data set, we are able to capture density economies more directly by three trip-specific control variables: vessel size; load factor; and travel time.[43] Fourth, our study concerns the inland waterway transport market, which comes close to the 'ideal' standard perfect competitive market, while previous studies focus on the maritime transport sector, where market power of carriers is an important issue.

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[41] Clark et al. (2004) and Márquez-Ramos et al. (2005) allow for density economies by including aggregate trade volume as an explanatory variable and treat trade volume as an endogenous variable.

[42] More specifically, we measure imbalance as the ratio of the number of trips departing from a region to the number of trips arriving in a region and spatially weight this measure. The use of a spatially-weighted region imbalance measure is in line with other economic applications of spatial problems (see, for example, Boarnet, 1994a, 1994b; Rice et al. 2006). By spatially weighting, the network characteristics are taken into account. Weights are based on information about the number of inland waterway trips *without cargo* between regions.

[43] The travel time of a trip includes the time of loading, transporting, and unloading the cargo. As higher volumes are usually handled in large ports with more efficient handling facilities, this implies relatively short (un)loading times, leading to shorter travel times.

The importance of inland waterway transport as part of the overall transport sector for the regional economy is determined by geographical constraints. Only in those regions in the world where the natural infrastructure offers sufficient opportunities does inland waterway transport play a significant role in inland transport. Examples of such regions include parts of Europe (the rivers Rhine, Danube, and their tributaries), the US (the Great Lakes area and the Mississippi river) and China (the Yangtze and the Pearl river).

The river Rhine is the most important trade waterway in Europe as it connects large economically important areas within and between the Netherlands and Germany.[44] This river has its source in Switzerland in the Alps and runs through the Ruhr area, one of the most industrialized areas in Germany, to Rotterdam, in the Netherlands, one of the world's major seaports, where it flows into the North Sea. In 2005, 58 per cent of all bilateral inland trade, measured in tonnes, from the Netherlands to Germany, was transported by inland waterways. In the opposite direction, inland waterway transport accounted for 41 per cent (CBS, 2008; TLN, 2007).[45] Hence, trade costs between the Netherlands and Germany strongly depend on inland waterway transport prices. So, an understanding of price formation in the inland waterway transport market is fundamental to understand the endogeneity of transport costs between the Netherlands and Germany.

Next, in Section 2, we review the textbook theory on transport price formation when imbalance in transport flows is present in a perfectly competitive environment. Section 3 describes the data and formulates the model. Section 4 presents the results, and, finally Section 5 makes some concluding remarks.

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[44] The Netherlands and Germany are neighbouring countries, with a population of 16 million and 82 million, respectively. Trade between these countries is intensive. In 2005, Germany was the most important export country for the Netherlands, and the Netherlands was the fifth export country for Germany. Note that data on levels of trade between two countries differ from levels of transport flows because of *transit* flows (as trade between two countries may be directed via a third country). See for example Statistics Netherlands (2008).

[45] In 2005, 127 million tonnes were transported from the Netherlands to Germany, and 73 million tonnes were transported from Germany to the Netherlands by road, rail and inland waterways. This implies an overall imbalance proportion of 73/127 = 0.57. If we only focus on inland waterway transport, 74 million tonnes were transported from the Netherlands to Germany and 30 million tonnes in the opposite direction, so the imbalance proportion that concerns only inland waterway transport is equal to 30/74 = 0.41. For the survey data used here, we find an imbalance proportion of 0.49 for inland waterway transport between the Netherlands and Germany, indicating that our data is quite representative for the whole market.

4.2. Review of textbook theory on transport price formation

The textbook explanation that prices depend on imbalances in transport flows is straightforward (e.g. Boyer, 1998, p. 253).[46] It presumes a competitive transport market (with a perfectly elastic supply curve) in a two-region economy. Suppose there is demand for transport between regions A and B. The inverse (downward-sloping) demand function is denoted as p_{ij} (x_{ij}), where x_{ij} denotes the demand in region j for goods from region i (i,j = A, B; $i \neq j$). Goods are transported by carriers. The number of tonnes transported by a carrier is standardized to 1 (so the load factor is either 0 or 1). In this network, each carrier must make a return trip, and hence, in equilibrium, under perfect competition, the following condition must hold:

$$p_{AB}(x_{AB}) + p_{BA}(x_{BA}) = 2c,$$

where c denotes the one-way cost of transporting between regions for a carrier. In the context of transport, it is reasonable to assume that the inverse demand function drops to zero for a quantity $x_{ij}*$.[47] This means that there exists a finite quantity $x_{ij}*$ for which $p_{ij}(x_{ij}*) = 0$, so given the assumptions, it follows that, in equilibrium, there are three possible regimes with positive trade flows in both directions[48]:

$$x_{AB} > x_{BA} = x_{BA}*;\; p_{AB}(x_{AB}) = 2c;\; p_{BA}(x_{BA}) = 0,$$

or

$$x_{BA} > x_{AB} = x_{AB}*;\; p_{AB}(x_{AB}) = 0;\; p_{BA}(x_{BA}) = 2c,$$

or

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[46] It focuses on price formation for the physical activity of transporting goods between regions, ignoring other relevant costs such as loading costs, insurance, etc, which are exogenous in this setting.

[47] This assumption is reasonable because the demand for transport is a derived demand for goods. So, the customers for the good still have to pay a positive price for the good. For example, when the transport price of, say, coal drops to zero, then the demand for coal will still be finite.

[48] Other regimes can be shown to be inconsistent. For example, $x_{BA} > x_{AB} \geq x_{BA}*$ does not exist.

$$x = x_{AB} = x_{BA}; \; p_{AB}(x) + p_{BA}(x) = 2c; \; 0 < p_{AB}(x) < 2c \, ; \; 0 < p_{BA}(x) < 2c.$$

Hence, it immediately follows that the imbalance, defined as the ratio of the trade flow from j to i to the trade flow from i to j, negatively affects the transport price p_{ij}.[49] This result is, of course, intuitive. It just formalizes the idea that, given *joint* costs of transport between regions, one-way transport prices are *not* equal to one-way transport cost, c, and one-way transport prices depend on the *relative* demand for transport between regions.

4.3. Methodology and data

4.3.1 Methodology

Our aim is to estimate the effect of an imbalance in transport flows on the transport price in a spatial network. In a multi-region network, one may measure imbalance for a trip between two regions at the level of the *route* (for example, for each route one can calculate the ratio of the size of the flow in one direction to the size in the other direction*)* or at the level of the *region (*for example, for each region one can calculate the ratio of the size of the outgoing flow to the size of the incoming flow*).* In the current study, we will measure imbalance at the level of routes, as well as of regions.

At the *route level*, imbalance is measured bilaterally, so on every route the imbalance is measured by the ratio of the number of trips with cargo in one direction to the number of trips with cargo in the opposite direction.[50] Hence:

$$M_{ij} = T_{ji}/T_{ij}, \qquad (1)$$

where M_{ij} is the *route imbalance* for the route from region i to region j; T_{ji} is the number of trips with cargo from j to i, and T_{ij} is the number of trips with cargo from i to j. In our

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[49] To be more specific, the model makes the rather extreme prediction that, if the transport flow in one direction exceeds the transport flow in the other direction, then one of the one-way transport prices will exactly cover the two-way transport costs, whereas the other one-way transport price will be zero.

[50] Imbalance may be measured in terms of either the tonnes transported or the number of trips with cargo between regions. In our empirical application, these measures are almost identical. In the current chapter, we will report results for the imbalance variable on the basis of the number of trips. Our data does not contain trips without cargo.

application, we will use the logarithm of M_{ij}.

In a multi-region network, carriers will not move back and forth between two regions but will make more complicated journeys.[51] Measuring imbalance in a multi-region network is not standard. Therefore, measuring imbalance at the level of *routes* will generally not adequately capture the effect of imbalances on prices in a multi-region network, when carriers do not move back and forth between the same two regions. It is straightforward to give relevant examples.

An illuminating example is when carriers transport goods from A to B, but a positive proportion of these carriers move from B to C (possibly without goods), and then transport goods from C to A. In this example, the transport price from A to B depends not only on the demand from A to B, as well as the demand from B to A, but also on the cost and demand characteristics of the B to C and C to A routes.[52] Measuring imbalance at the level of routes implies that only the demand from A to B, as well as the demand from B to A, is used in order to explain the price from A to B. It follows that an empirical analysis of the effect of imbalance on transport prices in multi-region networks which only includes measures of route imbalance is likely to underestimate the importance of the effect of imbalance on transport prices, because the route imbalance does not adequately capture imbalance.[53] This implies that it is important to measure imbalance taking network characteristics into account.

At the *regional level*, imbalance will be measured as the number of trips with cargo originating from region *i* divided by the number of trips with cargo arriving in region *i*, taking into account the spatial dimension of the network. Within a spatial network, carriers navigate without cargo to other, usually adjacent regions, to pick up freight.

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[51] We have examined this for a randomly-selected sample of carriers in our data, which will be discussed later on. It appears that only 1 out of 50 carriers immediately travels back to the region of origin.

[52] Another straightforward example is to presume that there exists demand for transport from region B to C (but not from C to A). The transport price from A to B then depends not only positively on the demand for transport from A to B and negatively on the demand for transport from B to A, but also negatively on the demand for transport from region B to C.

[53] To be more precise, if the route imbalance variable is a proxy variable for the theoretically appropriate imbalance variable, and the difference between the route imbalance and the theoretically appropriate imbalance travel is random error, then the estimated effect of the route imbalance variable underestimates the effect of imbalance (Verbeek, 2000, p. 120).

To take this into account, we construct a spatially-weighted imbalance variable, I_i, which is defined as follows:

$$I_i = \frac{\sum_j w_{ij} O_j}{\sum_j w_{ij} D_j} \;, \qquad (2)$$

where O_j is the number of trips with cargo departing from region j; D_j is the number of trips with cargo arriving in region j; and w_{ij} is a weighting factor. One may define w_{ij} in several ways. For example, if $w_{ii} = 1$ and $w_{ij} = 0$ for $i \neq j$ then regions other than i do not play a role in the determination of the imbalance in region i, so $I_i = O_i/D_i$. In our empirical specification, we define w_{ij} as follows:

$$w_{ij} = \frac{F(d_{ij})}{\sum_j F(d_{ij})}, \quad \text{so} \quad \sum_j w_{ij} = 1. \qquad (3)$$

We will use $F(d_{ij}) = e^{-\gamma d_{ij}}$, so F can be interpreted as an exponential-decay factor; d_{ij} is the distance between regions i and j; and γ is a decay parameter.[54] This parameter γ will be estimated using information about the distance navigated without cargo by carriers before starting a new paid trip. The weight w_{ij} may thus be interpreted as an inverse indicator of economic distance: the shorter the distance between the region where a carrier is located (i) and a neighbouring region (j), the higher the weight of that neighbouring region, and the higher the probability that empty trips will be made to collect cargo in that neighbouring region.

In multi-region networks, transport prices are expected to depend negatively on the imbalance in the region of *destination*, as well as positively on the imbalance in the region of *origin*. So, it may be necessary to use *two* indicators of region imbalance.[55] As every trip has an origin and a destination region, we are able to estimate the effect of the imbalance in the ‘origin’ and ‘destination’ region on the transport price. Later on, we will show that, after a logarithmic transformation, these two imbalance variables have exactly opposite

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[54] The use of the distance-decay principle is not new. For example, Hojman and Szeidl (2008) recently constructed a model of network formation in which benefits from connections decay with distance.

[55] In a two-region network, imbalance can be measured by a *single* indicator, for example the ratio of the size of the outgoing flow to the size of the ingoing flow in one of the regions. In this context, there is no distinction between measuring at the level of the region or at the level of the route.

effects. Therefore, we will use a more parsimonious and intuitive measure of the pair of regions i and j, I_{ij}, which we will call the *region imbalance* and which is defined by the ratio of the imbalance in the destination region and the imbalance in the origin region:

$$I_{ij} = I_j/I_i. \tag{4}$$

In our application, we will use the logarithm of region imbalance I_{ij}, which can be interpreted as a measure of the (relative) difference in the imbalance between two regions.[56]

4.3.2 Data

We employ an extended version of the data set that we used in Chapter 2. Recall that the Vaart!Vrachtindicator contains detailed information about trips made by inland waterway transport carriers in North West Europe. The carriers report information (via the Internet) about their trips, such as the transport price, region and date of (un)loading, capacity of the ship, number of tonnes transported, type of cargo, etc. We distinguish between trips from and towards 20 regions.[57] The data set contains information on inland waterway transport trips that occur in the spot market where the price for transport is negotiated per trip.[58] In our application we use the logarithm of the price per tonne.

The extended data set contains 21,865 observations of trips in North West Europe, reported between January 2003 and January 2007. Observations with missing information, a few extreme outliers, and observations that concern container transport were excluded.[59]

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[56] We will demonstrate later on that to measure imbalance as the ratio of imbalance between two regions gives the same result as to measure imbalance separately for both regions. We use the natural logarithm of I_{ij} in the regression analysis later on. Note that $\log(I_{ij}) = \log(I_j) - \log(I_i)$, so that we model the effect of the difference in imbalance between the origin and destination region on the transport price.

[57] More detailed information on the 20 regions used can be found in Appendix A.

[58] Inland waterway transport enterprises that operate in the long-term market (and work under contract) are not included in the data set. Note that the data covers only a limited part of the whole inland waterway transport market, but, descriptives of the imbalance variable between the Netherlands and Germany suggest that the sample is representative in terms of imbalance variables.

[59] We exclude observations referring to container transport because the price for container transport depends on the number of containers transported rather than on the weight of the freight which is the measure used here. We have information on the weight of the freight, but not on the number of containers.

Further, we excluded a limited number of observations for which the measurement of the route imbalance is unreliable. Ultimately, 16,583 observations remained.[60]

The decay parameter γ has been estimated on basis of the carriers' distribution of distances navigated without cargo before starting a trip (see Appendix B).[61] Frequently, after a carrier has been unloaded, it travels a certain distance without cargo to arrive at a location from where the next trip starts. For example, it appears that in one out of three trips, carriers navigate more than 100 kilometres without cargo before starting a new trip. In one out of nine trips, carriers navigate even more than 200 kilometres without cargo. The average distance navigated without cargo is 90.12 kilometres, which is substantial compared with the average distance navigated with cargo (514 kilometres, see Table 4.1). We have estimated γ presuming an exponential distribution of distances without cargo. This assumption fits the data well (see Appendix B). Given the exponential assumption, the estimated γ equals the inverse of the mean distance navigated without cargo (see, for example, Lancaster, 1990). Hence $\hat{\gamma} = 0.011$.

The descriptives of key variables used in the analysis are shown in Table 4.1. Note that the average trip (including loading and unloading time) takes five days. The average price per tonne is € 7.48.

Table 4.1: Descriptives of key variables

Variable	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
M_{ij}	0.01	100.00	7.16	14.91
$\log(M_{ij})$	-4.61	4.61	0.94	1.40
I_{ij}	0.36	2.76	0.97	0.55
$\log(I_{ij})$	-1.02	1.02	-0.21	0.55
Price per tonne (in €)	0.85	54.55	7.48	5.06
Travel time (in days)	1.00	31.00	5.01	2.45
Distance trip (in km)	12.00	4000.00	514	286
Distance navigated without cargo (in km)	0.00	908.00	90.12	96.11

Source: The Vaart!Vrachtindicator, 2003 – 2007.

As an illustration of the effects we aim to capture, it may be useful to focus on the Rotterdam port area. Transport prices for trips originating from Rotterdam are 32 per cent

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[60] The route imbalance, M_{ij}, may contain substantial measurement error if the number of trips between two regions is small. Therefore, in our empirical application, we select only those observations for which the sum of the number of trips in both directions between two regions exceeds 25.

[61] For the exponential distribution, the mean is equal to the standard deviation. As can be seen in Table 4.1, this restriction holds almost perfectly in the data.

higher than prices for trips arriving in Rotterdam, whereas the (weighted) number of trips with cargo departing from the port of Rotterdam is about two times higher than the (weighted) number of trips with cargo arriving in the port of Rotterdam.

Although only suggestive, it seems that the effect of imbalance on transport prices may be substantial. We will examine the effect of imbalance on transport prices, using a number of regression approaches. In addition to the two imbalance measures mentioned above (log(M_{ij}) and log(I_{ij})), we include a large number of control variables in the price equation. These control variables include: a time trend; travel time[62] and distance, both in logarithms; ship size (categorized by 4 dummy variables); 47 cargo dummies (e.g. coal, gravel, fertilizer, wheat, corn, soya), the fuel price in logarithm and the load factor, defined as the ratio of the tonnes transported and the capacity of the inland vessel, also in logarithm. Furthermore, we include the water level as an explanatory variable by means of 9 dummies. As shown in Chapter 2, water levels have strong effects on prices, as low water levels impose restrictions on the load factors of inland waterway vessels. Water level is measured at Kaub because Kaub is the critical bottleneck in the Rhine river basin, which determines the maximum load factor of many inland ships. As not all trips pass Kaub, we make a distinction between the effect of the water level for trips that pass Kaub and that for trips that do not pass Kaub. Finally, we include a dummy variable for each month (11 dummies) to control for unobserved monthly changes in supply and demand factors. A discussion of the results of our analysis will be presented in Section 4.

4.4. Results

We examine the impact of an imbalance in transport flows on the transport price per tonne. In Section 4.3.1, we explained how to construct two different measures for imbalance. As the effects of these two imbalance variables may be difficult to identify separately, we have also estimated models including only one measure for imbalance.

The first model includes only the route imbalance variable, the second model includes only the region imbalance variable, whereas the third model includes both types of imbalance variables. These models have been estimated using ordinary least squares.

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[62] For 76 per cent of the observations we have the trip-specific travel time. For the other observations this variable is not reported, so we use the region-to-region specific *average* travel time. This introduces some measurement error in this variable.

Table 4.2: Estimation results for the transport price in the inland waterway transport market

	(1)		(2)		(3)	
Explanatory Variables	***Coefficient***	***Std. Error***	***Coefficient***	***Std. Error***	***Coefficient***	***Std. Error***
Region imbalance, log(I_{ij})	-	-	-.186	.029	-.201	.028
Route imbalance, log(M_{ij})	-.016	.014	-		.012	.006
Log(travel time)	.207	.024	.166	.015	.164	.016
Log(distance)	.468	.035	.493	.027	.493	.027
Time trend/1000	.265	.023	.272	.025	.272	.025
Log(fuelprice)	.032	.043	.029	.047	.031	.047
Log(loadfactor)	-.406	.076	-.431	.071	-.429	.071
Vessel size						
0 – 1000 tonnes	.318	.022	.320	.020	.323	.020
1000 – 1500 tonnes	.225	.020	.230	.019	.232	.019
1500 – 2000 tonnes	.122	.016	.130	.016	.131	.016
2000 – 2500 tonnes	.084	.013	.086	.012	.086	.012
> 2500 tonnes	Reference		Reference		Reference	
Water level, trips via Kaub						
< 180	.422	.045	.406	.042	.408	.041
181 – 190	.319	.043	.305	.043	.306	.043
191 – 200	.295	.032	.281	.030	.282	.030
201 – 210	.229	.032	.214	.031	.215	.031
211 – 220	.141	.034	.126	.032	.126	.032
221 – 230	.134	.026	.124	.025	.124	.025
231 – 240	.094	.022	.084	.021	.085	.020
241 – 250	.066	.019	.058	.017	.059	.017
251 – 260	.027	.012	.024	.012	.025	.012
≥ 261	Reference		Reference		Reference	
Water level, trips not via Kaub						
< 180	.168	.064	.168	.058	.169	.057
181 – 190	.124	.055	.119	.048	.122	.047
191 – 200	.022	.052	.023	.045	.023	.044
201 – 210	.025	.056	.021	.049	.021	.047
211 – 220	-.046	.049	-.042	.042	-.041	.041
221 – 230	-.086	.042	-.084	.040	-.082	.039
231 – 240	-.071	.047	-.067	.042	-.066	.041
241 – 250	-.086	.041	-.082	.039	-.080	.038
251 – 260	-.087	.036	-.087	.036	-.085	.035
≥ 261	-.118	.038	-.112	.037	-.110	.036
Month dummies						
January	Reference		Reference		Reference	
February	-.057	.012	-.062	.012	-.062	.012
March	-.116	.013	-.116	.012	-.117	.012
April	-.089	.011	-.090	.010	-.089	.009
May	-.075	.014	-.077	.014	-.077	.014
June	-.063	.018	-.067	.017	-.067	.016
July	-.039	.020	-.041	.018	-.041	.018
August	-.116	.017	-.114	.016	-.115	.016
September	-.036	.018	-.039	.016	-.041	.016
October	.039	.015	.041	.015	.041	.015
November	.070	.016	.075	.015	.075	.015
December	.149	.017	.154	.016	.155	.016
Cargo dummies, 46	Included		Included		Included	
R^2	0.806		0.822		0.823	

Note: The dependent variable is the logarithm of the price per tonne.

So, for now, endogeneity of imbalance will be ignored. Later on, in Section 4.5.2, this issue will be elaborated on. As the imbalance variables are aggregate measures, we allow for clustering on the basis of the region of destination. This prevents the standard errors to be biased downward (Moulton, 1990).[63] Table 4.2 presents the regression results for the three models.

Let us first focus on the results when the two types of imbalance variables, $\log(M_{ij})$ and $\log(I_{ij})$, are separately included in the model. In line with theory, we find that both imbalance variables negatively affect the transport price. If we focus on the route imbalance effect, however, we must conclude that its impact on the transport price is rather limited in size and statistically insignificant.[64] In contrast, the effect of the region imbalance is quite strong and statistically very significant. To be more precise, the effect of an increase of one standard deviation of the region imbalance measure is about *five* times larger than the effect of an increase of one standard deviation of the route imbalance measure.

If we now focus on the model where both imbalance variables are included (the partial correlation between these two variables is 0.40), we find that the estimated effect of the region imbalance measure is almost the same, whereas the effect of the route imbalance measure remains small and statistically insignificant, and even becomes positive. This strongly suggests that the region measure is the superior measure. Therefore, in the remainder of the paper, we will continue employing the region imbalance measure only. This not only improves the interpretation of the results, but also simplifies the other statistical analyses, for example when we deal with endogeneity issues later on.

Recall that I_{ij} is defined as I_j/I_i, and we use the logarithm of this variable. Our main result is that the elasticity of I_{ij} is statistically significant and equal to -0.186. To understand the size of the effect, it is also useful to consider a one standard deviation increase in the region imbalance, I_{ij} (0.55). Suppose that we compare the transport prices of a trip from region A to B with those of A to C, assuming that the region imbalance between A and B is one standard deviation greater than the region imbalance between A and C, which is equal to the mean region imbalance in the network ($I_{ij} = 0.97$). In this case,

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[63] Clustering on the basis of region of origin or on the basis of routes generates almost identical results. However, as clustering on the basis of the region of destination is the more conservative, in the sense that the standard errors are larger, we opt to report this way of clustering. Not allowing for clustering results in standard errors which are about four times smaller for some variables.

[64] If we cluster on the basis of the region of origin or on the basis of routes, then the route imbalance variable is just significant.

the transport price from A to B will be 8.0 per cent lower than from A to C.[65] It is also interesting to compare the effect of the region imbalance in an extreme case: making a trip from the Rotterdam port area to the Neckar area instead of the other way around. In the Neckar area, the (weighted) number of trips with cargo leaving the region is 34 per cent fewer than those arriving whereas the (weighted) number of trips with cargo leaving the Rotterdam port area is 81 per cent higher than those arriving. Making a trip from the Rotterdam port area to the Neckar area (I_{ij} = 0.656/ 1.81 = 0.362) instead of the other way around (I_{ij} = 1.81/ 0.656 = 2.761) implies a transport price difference of 46 per cent.

We will now briefly discuss the results for the control variables. It appears that the travel time elasticity is about 0.17, and the distance elasticity is about 0.49. The sum of these elasticities is less than 1, suggesting economies of scale in terms of the length of the trip. We find that low water levels increase the transport costs for water levels lower than 260 cm, in line with the findings in Chapter 2. We find that the effect is stronger for trips that pass Kaub than for trips that do not pass Kaub. The load factor elasticity is estimated to be about -0.40, implying lower prices per tonne at higher load factors. Further, we find that the price decreases as the vessel size increases, indicating economies of vessel size. The December dummy shows higher transport prices confirming a phenomenon which is well known in this sector.[66] The barge-fuel price effect is not statistically significant even at the 10 per cent level.[67]

4.5 Sensitivity analyses

In this section, we test for the robustness of the reported imbalance variable effect. To be more specific, we examine the sensitivity of the results with respect to the assumption that the effect of the logarithm of the imbalance variable for the origin region is equal in value (but with opposite signs) to the effect of the logarithm of the imbalance variable for the destination region (4.5.1), endogeneity of imbalance (4.5.2), controls for cargo type (4.5.3),

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[65] This has been calculated by $((0.97 + 0.55)/0.97)^{-0.186} - 1 = -0.080$. As the transport price includes the costs of navigation plus the time costs of loading and unloading (the handling costs of loading and unloading are paid for by the shipper), the calculated decrease applies to this “full” transport price.

[66] Many inland waterway transport enterprises do not work at the end of the year for holiday reasons, and because they put their inland ship in maintenance. As a result, supply falls and transport prices rise.

[67] Note that we control for a time trend, and that, during the period analysed, fuel prices strongly correlate with this time trend, so this effect is difficult to identify.

the number of empty kilometres navigated before a trip starts (4.5.4), unobserved route-specific factors (4.5.5), the value of the decay parameter γ (4.5.6) and controls for navigation direction (4.5.7).

4.5.1 Measuring imbalance: distinguishing between origin and destination regions

The region imbalance variable is measured as the difference between the natural logarithm of the origin-and-destination region imbalances. However, it could be argued that this specification is too restrictive, so we allow here for a separate impact of the origin-and destination-imbalance variables on the transport price. We find that the effect of the origin-imbalance variable, $\log(I_i)$, is 0.151 (s.e. 0.039), and the destination-imbalance variable, $\log(I_j)$, -0.220 (s.e. 0.042). In line with theory, the effect of the origin variable is positive, whereas the effect is negative for the destination imbalance variable. Furthermore, it appears that the sum of the coefficients is not statistically different from zero (the sum equals -0.069 with a standard error equal to 0.055) justifying the use of $\log(I_{ij})$.[68] Moreover, it turns out that using the effect of the measure of the region imbalance as reported in Table 4.2, $\log(I_{ij})$, leads to only a slightly different predicted effect of imbalance on the transport price than when the effects of both measures ($\log(I_i)$ and $\log(I_j)$) are used.[69]

4.5.2 Endogeneity of imbalance

Another reason why our estimate of imbalance in Table 4.2 may be biased is due to endogeneity of the region imbalance variable. As emphasized in Section 2, transport prices and transport flows are simultaneously determined as the demand for transport, and therefore the imbalance, depends on the price. Hence, shippers in regions with a, for them, favourable imbalance (i.e. in regions where supply of carriers is relatively large) will increase their demand for inland waterway transport because the transport price for trips that depart from that region is low. Note that, in the case of inland waterway transport, the

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[68] The standard error of the sum of the coefficients is calculated using standard covariance rules.

[69] For example, employing the measure of region imbalance as reported in Table 4.2, for a carrier going from the Rotterdam port area to the Neckar river area instead of from the Neckar river area to the Rotterdam port area, the price per tonne increases by 46 per cent. Employing the separate measures of imbalance, the effect of a change in region imbalance on the price per tonne in this extreme case is equal to 42 per cent.

endogeneity of imbalance with respect to the price per tonne may be potentially important, as the inland waterway transport sector competes with the rail and road sectors for the same cargo. On the other hand, one may think that endogeneity is not an issue, as, especially over long distances, the cost advantage of using inland waterway transport instead of alternative transport modes is greater. Furthermore, as the inland waterway transport costs are only a small part of the overall production costs of the goods, it may be thought that demand for transport is quite inelastic with respect to the unit price of transport. In Table 2.8 we refer to a number of studies which almost all demonstrate that demand for inland waterway transport is inelastic. In addition, in Chapter 2 we find that the demand elasticity is about -0.5.

We use an instrumental variable approach to test for the presence of, and to solve for, endogeneity. Our instrument is a dummy variable that is equal to 1 if I_{ij} exceeds 1, and zero otherwise. This instrument can be argued to be exogenous with respect to the unit transport price, because, although the price plausibly affects the imbalance, it is unlikely to affect whether the ratio of the number of departing trips with cargo over the number of arriving trips with cargo in the destination region exceeds the ratio of the number of departing trips with cargo over the number of arriving trips with cargo in the origin region. That is, if I_j exceeds I_i, then a change in prices is unlikely to result in a situation where I_i exceeds I_j. We believe that this is plausible. The imbalance dummy is also a strong predictor of the region imbalance variable and therefore believed to be an appropriate instrument.[70]

We perform IV estimation with the same control variables as presented in Table 4.2, using the imbalance dummy as an instrument. The estimated elasticity is now -0.177 (s.e. 0.033), only slightly weaker than the elasticity of the OLS estimation (-0.186). A Hausman t-statistic (t = 0.571) tells us that we must not reject the null hypothesis of exogeneity at the 95 per cent confidence level, indicating that the OLS estimates are consistent (see Wooldridge, 2002, p.120).

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[70] This claim has been examined by regressing the logarithm of the imbalance variable on the control variables of the transport price and the instrumental variable. It turns out that the instrumental variable is highly significant, with a t-value of 10.23 (allowing for clustering).

4.5.3 Controls for cargo type

In the previous section, we have shown that our measure of the region imbalance in transport flows has a strong negative effect on the transport price. We have controlled for cargo type, as it may be argued that the cargo transported affects the unit costs via the density (mass per volume) of the cargo. In addition, there is correlation between region imbalance and cargo type so, the cargo type is a relevant control variable.[71] However, one may argue that the effect of the type of good transported, and therefore the imbalance effect, is biased because the type of good transported may be endogenous. For example, because of a decrease in transport prices, it may become profitable to transport certain goods that otherwise would not have been profitable (e.g. bricks). A counterargument would be that demand for inland waterway transport is price inelastic as discussed above. In this case, it is not very likely that the cargo type is endogenous with respect to the transport price.

In a sensitivity analysis we have excluded the 47 dummy controls for cargo. The region imbalance effect is then equal to -0.202 (s.e. 0.024).[72] Hence, our results are robust with respect to controlling for cargo type, indicating that this is a minor issue in the market analysed.[73]

4.5.4 Controlling for the distance navigated without cargo before starting a trip

We have argued above that due to imbalance differences between regions, it will be frequently beneficial for carriers to navigate without cargo to a region with a more favourable imbalance. Therefore, trips that start from regions with an imbalance that is favourable for the carriers are likely to be preceded by a relatively long distance navigated without cargo.[74]

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[71] Imbalance is region-specific but also the production of certain goods and raw materials is region-specific.

[72] Note that, in this analysis, the imbalance parameter may also be biased because of omitted-variable bias.

[73] Note that this issue is likely to be relevant in the maritime transport market. For example, most of the goods shipped from the Netherlands to China appear to consist of used paper, which is transported at bottom transport prices.

[74] This conjecture is confirmed by a weak negative correlation between the natural logarithm of the empty kilometres variable and the natural logarithm of the region imbalance variable.

In a perfectly competitive transport market,[75] the distance navigated without cargo before starting a paid trip should not have any effect when controlling for imbalance factors, but, in a market with substantial imperfections (e.g. market power of carriers), the bargaining position of carriers may depend on this distance, and therefore affect the bargained transport price. It appears that controlling for distance navigated without cargo in the regression hardly affects the region imbalance coefficient (which is equal to -0.178 with an s.e. equal to 0.028). We find that the effect of distance navigated without cargo on the transport price is small with an elasticity of only 0.02.

4.5.5 Bilateral route fixed effects

As there may be unobserved, route-specific, factors that are correlated with imbalance, the coefficient of the imbalance variable may be biased. In particular, it may be imagined that we do not sufficiently control for the characteristics of the network. To deal with this potential bias, we have included bilateral route dummies (131 dummies).[76] So, for each transport route between two regions (independent of the direction of the trip), we have included a dummy.

We now find that the region imbalance elasticity is equal to -0.235 (s.e. 0.013). Therefore, we may conclude that the reported elasticity of -0.186 in Table 4.2 can be considered as an underestimate.

4.5.6 Different values for the decay parameter

Recall that the value of the decay parameter γ has been estimated assuming an exponential distribution, and is therefore equal to the inverse of the average distance navigated without cargo before starting a trip, which is slightly more than 90 kilometres. We have examined the robustness of our results by assuming that the distance navigated without cargo is 70 or

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[75] In a perfectly competitive market, the effect of the number of empty kilometres made before starting a trip on the price for that trip must be absent. A shipper will choose the inland waterway transport company that offers the lowest price, so an inland waterway transport company cannot ask a higher price if it has to navigate empty to the place of loading for a particular trip.

[76] If the trips in our data set covered all routes, the total number of dummies would be ((20 * 20)/2 =) 200. However, because there is no transport between some of the regions, the number of bilateral route dummies is equal to 131.

110 kilometres, implying a γ of 1/70 and 1/110 respectively. We find that the results and, in particular, the effect of the region imbalance on the transport price remain essentially unaltered for these other values for γ. An increase of one standard deviation in the region imbalance variable now results in a decrease of 7.3 per cent and 8.8 per cent of the transport price, respectively.[77]

4.5.7 Controlling for navigation direction

For upstream navigation more fuel is consumed than for downstream navigation. As for many trips, the high demand transport direction coincides with upstream navigation, it may be that the region imbalance variable also captures a fuel consumption effect and as a result the elasticity may be biased. Unfortunately, the fuel consumption per trip is unknown.

To be able to gain some insight into this problem a navigation direction dummy is included in the regression equation. A selection of trips (4826) was made in such a way that for each trip it could be determined if it took place upstream of downstream. So, trips that took place partly upstream and partly downstream, or on canals are not included. Estimating the same equation as in specification 2, Table 4.2, resulted in a region imbalance elasticity of -0.184 (s.e. 0.040). Including the navigation direction dummy changes this elasticity into -0.099 (s.e. 0.043), the navigation direction variable showing an value of 0.235 which implies that navigating upstream instead of downstream results in a ($e^{0.235}$ =) 26% increase in transport price.

It is likely that this is an overestimation of the real navigation direction effect because the navigation direction dummy probably also captures the imbalance effect to some extent. Experts from the inland waterway transport market report that the share of fuel costs in total transport costs is about 15% in case of downstream navigation and about 25% in case of upstream navigation. This implies that due to the difference in fuel consumption, an upstream trip is about 13% more expensive than a downstream trip.[78]

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[77] More extreme values for γ lead to larger (+25% if γ is 1/170) or smaller (-60% if γ is infinite) effects of the region imbalance. However, very small values for γ imply that navigating without cargo is costless, whereas very large values for γ imply that navigating without cargo is prohibitively expensive. Both implications are unrealistic and inconsistent with the data. Thus, extreme values for γ are not realistic.

[78] Let us define the fuel costs as B and the transport price as X. Then $B_1 = 0.15X_1$ and $B_2 = 0.25X_2$. Solving for X_2 shows that $X_2 = 1.13X_1$.

Fixing the navigation direction dummy at 0.13 results in a region imbalance elasticity of -0.134 (s.e. 0.037) showing that maximally 27% of the region imbalance effect, reported in specification 2, Table 4.2 can be attributed to differences in navigation direction.[79]

4.6 Conclusion

In the extensive literature on (regional and international) trade and regional activity, it is common to assume that transport costs are exogenous, but recently a new literature has emerged which argues that these transport costs may be endogenous. For example, Behrens et al. (2006), Behrens and Gaigné, (2006) Behrens et al. (2009), make the assumption that unit transport prices negatively depend on trade volume using density economies arguments. In the current chapter, we also argue that transport costs are endogenous, but use an entirely different argument. Our argument is that, at least according to textbook transport economics theory, transport costs depend on imbalances in trade flows because carriers have to return to high demand regions without paid cargo. This implies that, ceteris paribus, unit transport prices positively depend on trade.

Here, we have studied this effect empirically using an ongoing survey for carriers in the inland waterway spot market in North West Europe, which covers mainly the Netherlands and Germany. Between these two countries, about 50 per cent of all physical trade is transported by inland waterways, so the price formation in the inland waterway transport market is fundamental to our understanding of the cost of trade between these two countries. The survey provides not only information about prices for each trip, but also detailed micro-information about a large number of control variables.

One important difference between the current chapter and existing empirical maritime transport studies is that the latter studies consider that transport costs vary with the imbalances because of density economies, whereas in our empirical application, which is novel, we control for density economies directly (e.g. by vessel size), and emphasize that transport costs are endogenous with respect to the imbalance in traded volumes between regions.

Although standard transport economic theory on pricing of transport services within a two-region setting motivates our study, we have argued that in the case of a multi-region network, the traditional measure of trade imbalances at the level of the route may be

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[79] (-0184 – 0.134)/ -0.184 = 0.27.

less appropriate than a measure of imbalances at the level of the region. In our empirical application we employ both measures.

Our main finding is that region imbalances play a much more prominent role than route imbalances in the determination of transport prices. We find that a one standard deviation increase in the region imbalance from region A to region B decreases the transport price from region A to region B by about 8 per cent. A range of sensitivity analyses show that this effect is robust.

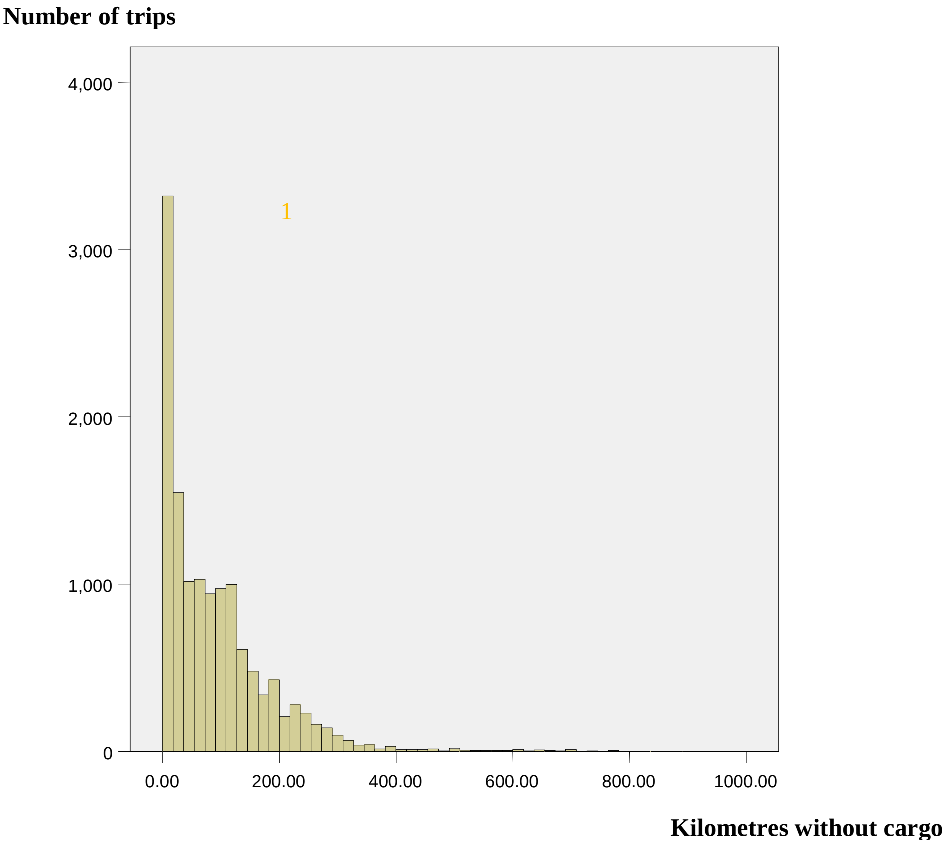
The inland waterway transport market we have studied covers ‘exporting’ regions (regions from which more trips with cargo depart than arrive) along the North Sea coast, and ‘importing’ regions in the hinterland. The exporting regions include the seaports of Hamburg, Amsterdam, Rotterdam and Antwerp. Most bulk cargo enters Europe via these ports and is then transported further to the hinterland making use of inland waterway transport. The hinterland regions do not export bulk goods on a large scale (they tend to export manufactured goods and services). Hence, the *physical* transport flow, and therefore the number of inland waterway trips, between seaports and hinterland is very unbalanced. One of the main consequences is that unit transport prices from the seaports to the hinterland are substantially higher than the other way round. For example, for trips from the Rotterdam port area to the Neckar area in Germany, transport prices are 37 per cent higher than in the opposite direction. Our results also have implications for (studies on) international trade. Our study makes a strong case that transport prices from the Netherlands to Germany are substantially higher than the other way round *because* the Netherlands transports much more to Germany than the other way around. In other words, we have emphasized that transport costs may be endogenous.

Appendix A: Imbalance by region, I_i

Region	I_i	log(I_i)
Rotterdam port area (NL)	1.811	0.594
Amsterdam port area (NL)	1.649	0.500
Netherlands, South (NL)	1.626	0.486
Northern France (F)	1.523	0.421
Antwerp port area (B)	1.409	0.343
Flanders (B)	1.230	0.207
Netherlands, Centre (NL)	1.154	0.143
Wallonia (B)	1.103	0.098
Netherlands, North (NL)	1.060	0.058
Meuse area (NL, B)	1.050	0.049
Upper Rhine area (D, F, CH)	1.002	0.002
Main and Danube (D, H)	0.960	-0.041
North German Canals (D)	0.923	-0.08
Ruhr area (D)	0.829	-0.187
Netherlands, East (NL)	0.811	-0.21
Middle Rhine area (D)	0.808	-0.213
Lower Rhine area (D)	0.761	-0.273
West German Canals (D)	0.746	-0.293
Moselle and Saar area (D, F)	0.742	-0.299
Neckar area (D)	0.656	-0.422

Note: NL = the Netherlands; B = Belgium; D = Germany; F = France; CH = Switzerland; H = Hungary.

Appendix B: Distribution of distance navigated without cargo before starting a paid trip



Note that the variable "kilometres without cargo" is missing for observations in the period up to June 2004 as it was not included in the first 18 months of the survey. Therefore, the number of observations for this variable is somewhat smaller and equal to 13,133.

CHAPTER 5

5 LOW WATER LEVELS AND TRADE IMBALANCES IN INLAND WATERWAY TRANSPORT REVISITED: INTERACTION EFFECTS ON TRANSPORT PRICES

5.1 Introduction

This chapter focuses on the *interaction* effect of an imbalance in trade flows and low water levels on transport prices in the inland waterway transport sector.[80]

In Chapter 2, the effect of climate change on inland waterway transport prices in the river Rhine basin was estimated employing detailed trip data reported by bargemen. In that chapter, it was explained that as a result of climate change, the temperature and the pattern of precipitation in the river Rhine basin will change, leading to a change in water levels over time. In periods with low water levels barges have to reduce their load factor in order not to hit the river ground. As a consequence, barge operators receive a low-water surcharge, a price mark-up per tonne transported, to be compensated for the reduction in load factor. It turns out that transport prices may increase up to 73 per cent in periods with low water levels compared with periods with normal water levels in the part of the Rhine market considered.[81]

Chapter 4 focuses on the effect of an imbalance in trade flows on transport prices in the inland waterway transport sector. According to economic theory, transport prices in the high demand direction exceed those in the low demand direction in order to attract carriers to return to the high demand region without cargo. Results show that imbalances in trade flows have substantial effects on transport prices and that a one standard deviation increase in the in Chapter 4 constructed region imbalance variable decreases the transport price by about 8 per cent.

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[80] Such an effect is present if the marginal effect of one variable (in this case: the water level) is sensitive to the level of another variable (in this case: imbalance in trade).

[81] Normal water levels are defined as water levels above a threshold level. Above this threshold level the water level effect is absent. Later on, in the empirical section, these threshold levels are identified for several locations at the Rhine where the water level is measured.

An interesting question that arises from these chapters is: will the effect of an exogenous change in transport costs on transport prices depend on the level of imbalance? In other words, do differences in imbalance in trade flows over space affect the size of the effect of an exogenous change in transport costs? This question is relevant from the perspective of economic theory, as a water level change can be interpreted as an exogenous change in costs. The question is also relevant in the light of climate change as it may be expected that an imbalance in trade flows can enforce or weaken the effect of low water levels on inland waterway transport prices.

According to theory, the effect of a change in transport costs on transport prices will vary with the imbalance in trade flows. In short, as long as carriers make round trips between two locations and some of the carriers navigate without being loaded on one of the two legs of the round trip, an increase in transport costs will be fully borne by the shippers who pay for transport in the high demand direction. This will be explained *theoretically* in the next section. In Section 5.3 we will *empirically* demonstrate that the effect of an increase in the transport price due to low water levels is stronger for transport in the high demand direction, than for transport in the low demand direction. Section 5.4 offers some concluding remarks.

5.2 Theory

Assume a market with a high and a low demand location. Carriers transport goods back and forth between those two locations. In Figure 5.1, the demand curves D_L, D_H, and D represent the demand for transport in the low demand direction, high demand direction and demand for round trips respectively.[82] Q denotes the number of round trips and P denotes the transport price per tonne. When the number of round trips exceeds Q*, the willingness to pay for transport in the low demand direction is zero. This implies that when Q exceeds Q*, some trips return without cargo from the low demand location to the high demand location and the price for transport in this direction is zero.

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[82] Figure 5.1 is based on Boyer (1998).

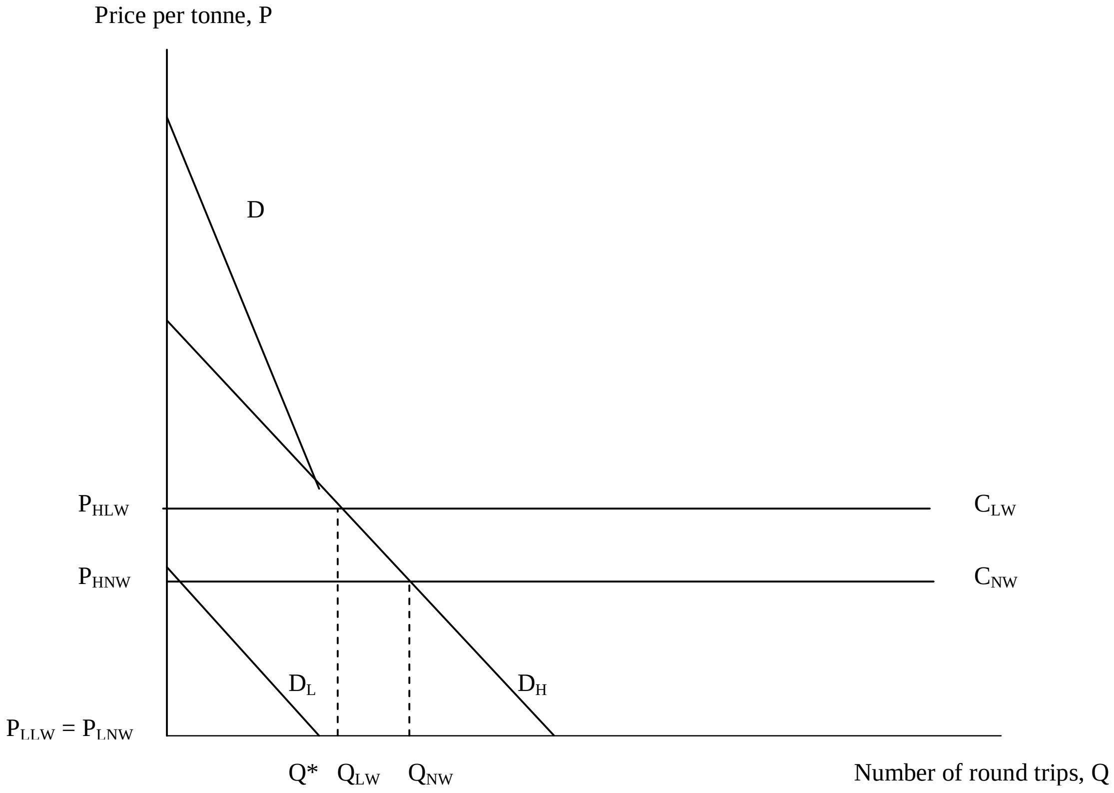

Figure 5.1: Imbalance in trade flows, transport costs and equilibrium transport prices

If Q is less than Q*, shippers in both directions are willing to pay a positive price for the use of the transport vessel. Now suppose we only have two water levels: normal and low water levels and that the cost (supply) curves are horizontal. The cost curves depend on the water level. Given low water levels, the round trip costs, denoted by C_{LW}, are high. Given normal water levels, the round trip costs C_{NW} are low. The demand for transport is assumed not to depend on the water level. This seems a reasonable assumption since the demand for goods typically transported by inland waterway carriers (e.g. agricultural products) does not directly depend on the water level.

We have now two equilibria (one for normal water levels; another for low water levels). Given normal water levels, P_{LNW}, the price in the low demand direction is zero, whereas P_{HNW}, the price in the high demand direction is positive. Now suppose that C_{NW} increases to C_{LW}. In this case, P_L, the price in the low demand direction, does *not* change because in case of low water there are still carriers that navigate without cargo in the low

demand direction so $P_L = P_{LNW} = P_{LLW}$.[83] The change in P_H, on the other hand, is equal to the vertical difference between P_{HNW} and P_{HLW}. Thus, the model in Figure 5.1 predicts that the impact of an increase in transport costs (due to low water levels) on transport prices depends on the direction of transport (D_L or D_H). In addition, the figure shows that the price gap between the two directions is larger when water levels are lower.[84]
We will empirically test for these predictions in the next section.

5.3 Analysis and results

5.3.1 Regression analysis

To investigate whether the marginal effect of transport costs on the transport price depends on the imbalance in trade flows, we test for the presence of an interaction effect between the water level and the imbalance in trade flows. We employ the same subset of the data set used in Chapter 4. In addition, we exclude trips that do not pass one of the three locations for which we have the exact daily water levels: Kaub, Duisburg and Koblenz (as indicated by the black spots in Figure 5.2). The daily water levels are publicly available on the internet (iidesk.nl, 2008). Given these selections, 14,937 observations remain for analysis. Again, we distinguish between trips from and towards 20 regions.[85] We use the logarithm of the transport price per tonne as the dependent variable.

The origin-destination combination of a particular trip determines the critical location in terms of the water level. In this respect Kaub is the critical location for transport between locations downstream of Kaub and locations in the Upper Rhine, Neckar and Danube/Main regions. This implies that if a trip passes Kaub, but also Duisburg and Koblenz, the water level at Kaub determines the load factor of the inland ship and therefore

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[83] The assumption that there is still a positive proportion of carriers which navigate without freight is reasonable, because our data show that carriers execute trips without cargo in periods with normal water levels as well as in periods with low water levels.

[84] Note that this result only holds when there is navigation without cargo in the low demand direction with and without the cost increase. For example, if C_{LW} increases much more than is considered in Figure 5.1, there would be no carriers that navigate without cargo and prices in both directions would be positive. So, our result may not always hold, as it depends on the level and shape of the supply and demand curves and the size of the cost increase.

[85] More detailed information on the 20 regions used can be found in Chapter 4.

the effect of the water level on the transport price. The water level at Koblenz is relevant for transport to and from the Moselle/Saar region (except for those trips that pass Kaub).

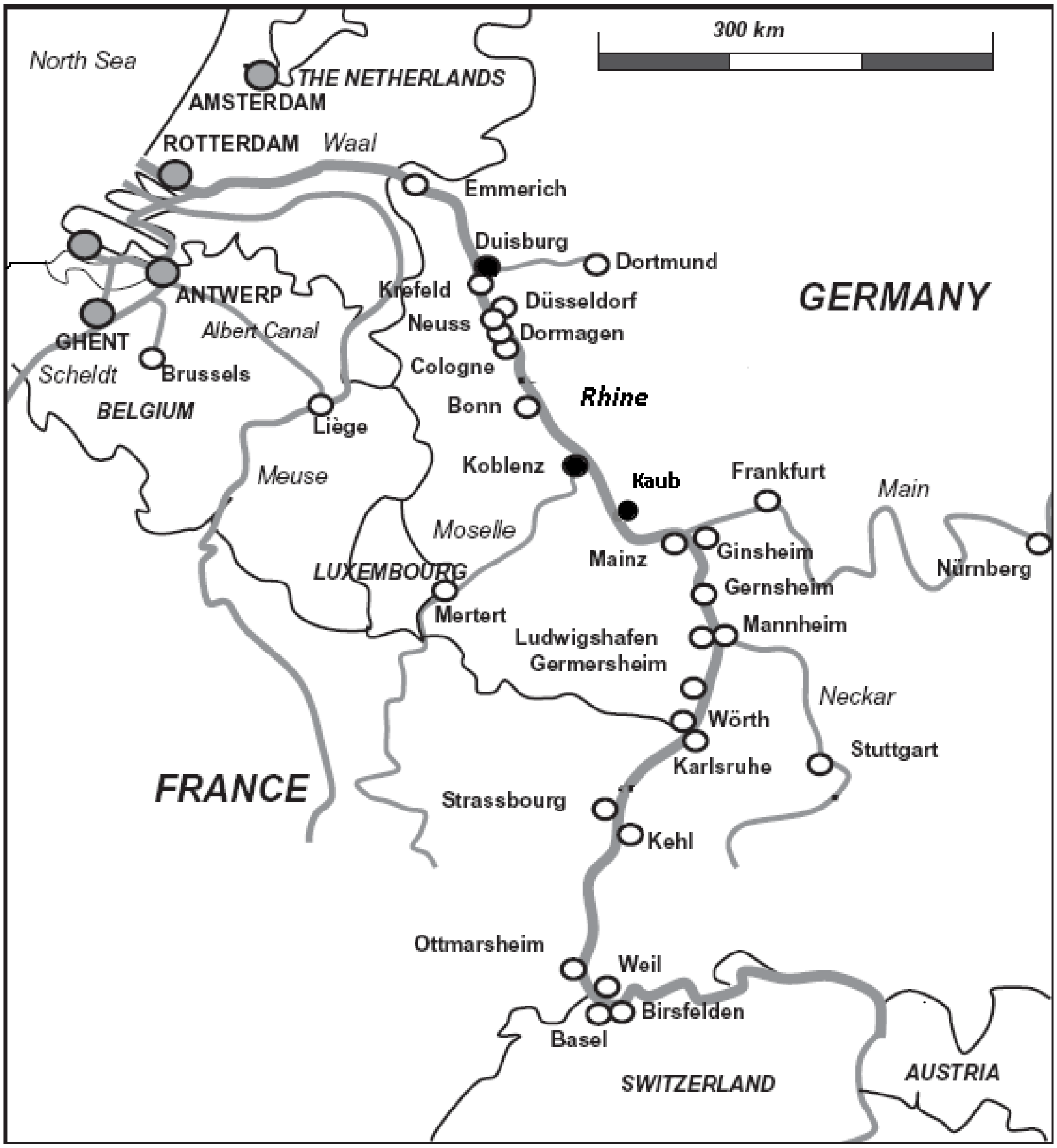

Figure 5.2: Map of the river Rhine area with locations Duisburg, Koblenz and Kaub

Finally, the water level at Duisburg is relevant for transport between locations downstream of Duisburg and locations in North and East Germany on the one hand, and locations in the area between Duisburg and Kaub on the other hand. .

For each location, above a certain water level threshold, the marginal effect of water level on the transport price is zero because the water level is sufficiently high to allow for the maximum load factor.[86] The three threshold levels are not exactly identical, which is due to differences in ship size: inland ships that pass Duisburg are on average larger.[87] Separate analyses show that for Kaub, the threshold is about 265 cm, for Koblenz it is about 275 cm and for Duisburg it is about 325 cm (see Appendix A). In the separate analyses, water level is measured using nine dummy variables. The marginal water level effect appears to be constant for water levels below the threshold. Therefore, water levels may be more conveniently measured by a continuous variable up to the threshold level.

Table 5.1 provides water level information concerning trips that pass one of the three critical locations. It shows, for example, that for Duisburg, out of 6,224 trips, 1,645 trips occurred during low water levels between 207 and 325 cm (the average water level for these trips is 290 cm). Recall that the trips that pass Kaub frequently also pass Duisburg (and/or Koblenz) but the critical location is Kaub.[88]

As explained in the previous section, we are interested to determine the effect of the water level on transport prices and the interaction with an imbalance in transport flows. Like in the previous chapter, the imbalance variable is measured between two regions i and j (I_{ij}) by the ratio of the imbalance in the destination region j (I_j) and the imbalance in the origin region i (I_i) and is called the region imbalance.

Table 5.1: Low water level descriptives

Critical location	**No. of trips per location**	**No. of trips per location during low water levels**	**% low water trips**	**Average water level for low water level trips**	**Range of low water levels**	**Threshold water level**
Duisburg	6,224	1,645	26%	290	207 – 325	325
Koblenz	1,876	644	34%	243	156 – 275	275
Kaub	6,837	2,825	41%	217	140 – 265	265

Source: Vaart!Vrachtindicator, 2003 – 2007 and iidesk.nl, 2008

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[86] Recall from Chapter 2 that the navigability of the Rhine river at a particular location in Germany is measured by the locations' Pegel. The Pegel is not the same as the actual water depth, which is the distance between the river soil and the water surface. Each Pegel has its own 0-point. Thus, with Pegel Kaub it is only possible to determine navigation depth in the surroundings of Kaub. For the sake of convenience we will employ water depths and regard water depth and water level as synonymous. The water depth at Kaub is about 105 cm higher than its Pegel, at Koblenz it is 125 cm and at Duisburg 35 cm higher.

[87] Because ships that pass Duisburg are on average larger, they will be confronted with a reduction in their load factor at a higher water level.

[88] Note that the average water level for each location is about 30 to 40 cm lower than the location's threshold level suggesting that the average degree to which load factors are restricted, given low water levels, is about equal for every location.

Table 5.2: Estimation results for transport price

Explanatory Variables	***Coefficient***	***Std. Error***	***Coefficient***	***Std. Error***	***Coefficient***	***Std. Error***
Model	1		2		3	
Region imbalance					-0.172	0.030
Region imbalance at Kaub	-0.158	0.048				
Region imbalance at Duisburg	-0.156	0.028				
Region imbalance at Koblenz	-0.299	0.043				
Water level					-6.081	0.342
Water level at Kaub	-6.695	0.240	-6.765	0.211		
Water level at Duisburg	-5.196	0.561	-5.381	0.404		
Water level at Koblenz	-5.353	0.256	-5.465	0.222		
Region imb. * Water level					1.397	0.401
Region imb. * Water level at Kaub	1.780	0.284	1.821	0.235		
Region imb. * Water level at Duisburg	0.620	0.808	0.472	0.722		
Region imb. * Water level at Koblenz	1.693	0.441	1.697	0.301		
Location Duisburg	-0.130	0.038			-0.157	0.045
Location Koblenz	-0.132	0.033			-0.125	0.050
Location Kaub	Reference		Reference		Reference	
Log(travel time)	0.134	0.011	0.083	0.008	0.131	0.011
Log(distance)	0.566	0.027	0.638	0.032	0.571	0.025
Time trend	0.258	0.021	0.257	0.017	0.265	0.020
Log(fuelprice)	0.124	0.050	0.125	0.038	0.120	0.049
Vessel size						
0 – 1000 tonnes	0.259	0.019	0.243	0.010	0.265	0.021
1000 – 1500 tonnes	0.147	0.009	0.128	0.008	0.152	0.010
1500 – 2000 tonnes	0.089	0.008	0.077	0.008	0.090	0.009
2000 – 2500 tonnes	0.057	0.007	0.051	0.008	0.058	0.008
> 2500 tonnes	Reference		Reference		Reference	
Month dummies						
January	Reference		Reference		Reference	
February	-0.085	0.011	-0.084	0.010	-0.092	0.010
March	-0.148	0.016	-0.145	0.012	-0.149	0.017
April	-0.136	0.015	-0.134	0.012	-0.137	0.015
May	-0.125	0.017	-0.122	0.010	-0.126	0.017
June	-0.107	0.021	-0.108	0.013	-0.108	0.020
July	-0.064	0.025	-0.072	0.014	-0.067	0.025
August	-0.151	0.021	-0.154	0.014	-0.155	0.020
September	-0.079	0.020	-0.076	0.013	-0.083	0.019
October	0.004	0.019	-0.001	0.013	0.003	0.019
November	0.059	0.015	0.052	0.012	0.054	0.016
December	0.160	0.017	0.162	0.014	0.162	0.017
Cargo dummies (46)	Included		Included		Included	
Route fixed effects (232)	Excluded		Included		Excluded	
R^2	0.834		0.863		0.830	

Note: the dependent variable is the logarithm of the price per tonne; the water level variable is in cm and divided by 1000; the time trend variable is in days and divided by 1000.

So, this variable measures the (relative) difference in imbalance between two regions. In the empirical application, we will use the logarithm of I_{ij}. The imbalances in the origin and destination regions (I_i and I_j) are measured by the ratio of the number of departing trips with cargo from the region and the number of arriving trips with cargo in the region during the period that is covered by the data set. Values for the imbalance in the regions can be found in Appendix A, Chapter 4.[89]

We estimate three specifications of which the results are presented in Table 5.2. We report standard errors that are robust because we allow for clustering and we cluster on the basis of the region of destination. In all analyses, we control for a large number of variables including whether the trip passes one of the three critical locations (Duisburg and Koblenz dummies), the logarithm of the trip travel time, the logarithm of the trip distance, a time trend, the logarithm of the fuel price, the logarithm of the load factor, the vessel size and 46 cargo type dummies. The control variables are included to correct for supply and demand factors other than water level and region imbalance. Descriptives of the most relevant variables can be found in Table 5.3. The average (one-way) trip (including loading and unloading time) takes about five days for about 550 kilometres. The average price per tonne is € 7.90.

Table 5.3: Descriptives of key variables

Variable	**Mean**	**Std. Deviation**	**Minimum**	**Maximum**
Price per tonne (in €)	7.90	5.01	0.85	54.55
Region imbalance, I_{ij}	0.96	0.58	0.36	2.76
Log(I_{ij})	-0.21	0.57	-1.02	1.02
Travel time (in days)	5.22	2.36	1.00	31.00
Distance trip (in km)	557	274	17.00	4000

Source: The Vaart!Vrachtindicator, 2003 – 2007.

So, we regress the logarithm of the transport price per tonne on the region imbalance, water level, their interaction effects and the mentioned control variables. In specification 1, we allow the effect of the region imbalance, water level and their interactions to be location-specific, where the location is defined by the critical water level location (Kaub, Koblenz or Duisburg). The specification shows that region imbalance has about the same negative effect for each critical location (for Kaub, -0.158, for Duisburg, -0.156).

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[89] As an example: the region imbalance for a trip from the Antwerp port area to the upper Rhine area is equal to 1.002/1.409 = 0.711.

The effect at Koblenz is somewhat stronger (-0.299).[90] This means that when the region imbalance (I_{ij}) increases with one standard deviation (0.58) from its mean (0.96) for a trip with critical location Koblenz, the transport price decreases with about 13 per cent. The results also show that the water level effects are roughly equal to each other at the different locations (for Kaub -6.695, for Duisburg -5.196, for Koblenz -5.353), although the effect at Kaub is somewhat stronger from a statistical perspective.[91] This means that a one centimetre decrease in water level at Kaub increases the transport price for trips that pass Kaub by 0.67 per cent if the water level is below the Kaub threshold value. Note that a decrease in water level increases the transport price by about the same degree at every location.

The *interaction* effects between region imbalance and water level are positive at all three locations, in line with theory (for Kaub 1.780, for Duisburg 0.620, for Koblenz 1.693).[92] The three interaction effects are statistically equal to each other. The precise interaction effect for Duisburg is difficult to determine due to its large standard error. The marginal effect of water level for a trip with critical location Kaub is equal to $-0.006695 + 0.00178(\log(I_{ij}))$. The location dummies for Duisburg and Koblenz have a negative sign which implies that there are unobserved factors at Kaub that lead to higher transport prices for trips that pass Kaub. The remaining variables show values which are similar to Table 4.2 in Chapter 4.

To check the robustness of the interaction effect between water level and imbalance, we estimate a second specification, in which we include route specific fixed effects. So, we include a dummy for every one-way route. Those fixed effects capture all spatial factors that affect the transport price. Consequently, the location dummies and the location-specific region imbalance variables are not identified. The results are similar to

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[90] Trips that have Koblenz as critical location have the Moselle/Saar area as an origin or destination. This is a non-typical region as it is a dead-end waterway region in which many industries are located. Shippers who pay for transportation out of this region are better able to play the barge operators off against each other than shippers in other regions and pay relatively low prices for transport out of this region. It is maybe therefore not without reason that the shippers in this region are characterized by the barge operators as the “Moselle mafia”.

[91] The water level effect applies to a ship of average size as no distinction is made (no interactions are estimated) with respect to ship size.

[92] Including the interaction effects between the ship size and the water level at the three locations, results in a 10 per cent decrease of the strength of the interaction effect between region imbalance and water level.

those in specification 1, so the estimated parameters are not biased due to omitted (unknown) variables with a spatial character.[93]

As the results in specification 1 indicate that the estimated effects of the water level, region imbalance and interaction effects hardly differ over the locations, in a third specification, we estimate the same model, except that we now do not allow the effects to be location-specific. For this specification it is more straightforward to interpret the results.

The results for this specification show that the marginal water level effect (in centimetres) is equal to -0.006081 + 0.001397(log(I_{ij})). The average log(I_{ij}) is -0.21 so the average effect is equal to -0.006374 implying a 0.63 per cent increase in the transport price when the water level drops by one centimetre.[94] Log(I_{ij}) ranges between -1.02 and 1.02. Given a decrease in water level, for routes in a high demand direction, the increase in transport price can be substantially larger than for routes in a low demand direction. Table 5.4 shows the marginal effect of water level for four different routes: from the Rotterdam port area to the Moselle/Saar area and vice versa and from the Upper Rhine area to the North German canals and vice versa.

Table 5.4: The relative change of the transport price when the water level increases by one centimetre.

Route	Rotterdam port area – Moselle/Saar area	Upper Rhine area – North German canals	North German canals – Upper Rhine area	Moselle/Saar area – Rotterdam port area
Region imbalance in logarithm	-0.893	-0.082	0.082	0.893
Marginal effect of an increase of water level of 1 centimetre	-0.733%	-0.619%	-0.597%	-0.433%

Note: by construction, the region imbalance for the trip “Rotterdam port area – Moselle/Saar area” is the negative of the region imbalance for the trip “Moselle/Saar area – Rotterdam port area” and the region imbalance for the trip “Upper Rhine area – North German canals” is the negative of the region imbalance for the trip “North German canals – Upper Rhine area”.

Table 5.4 shows that a decrease in water level of one centimetre leads to an increase in the transport price of about 0.7 per cent for a trip from the Rotterdam port area to the

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[93] The R^2 does not increase much suggesting that the location dummies and imbalance variables in specification 1 capture the aggregate of all spatial effects to a large extent.

[94] Note that the reported marginal effect of water level only applies when the water level is less than the threshold level.

Moselle/Saar area but for a trip in the opposite direction the transport price increases only by about 0.4 per cent. This is a large difference. It implies that, depending on the origin-destination combination, the marginal effect of an increase in costs in the high demand direction can be almost twice as large as in the low demand direction.

5.3.2 Re-estimation of the welfare loss

In Chapter 2 the interval [91, 227] for the size of the annual welfare loss in € in the total Rhine market as a result of low water levels was estimated for the year 2003 using eq. (1) from that chapter.[95] For convenience eq. (1) is repeated here:

$$WL = (p_1 - p_0)q_0(1 + \tfrac{1}{2}\varepsilon(p_1 - p_0)/p_0) \qquad (1)$$

where ε is the price elasticity of demand:

$$\varepsilon = [(q_0 - q_1)/q_0]/[(p_0 - p_1)/p_0] \qquad (2)$$

In both equations, q_0 is the number of days with low water levels multiplied by the average daily quantity transported during normal water levels in a year, p_0 is the average transport price per tonne on days with normal water levels,[96] p_1 is the average transport price per tonne on days with low water levels and ε is the assumed price elasticity of demand for inland waterway transport.

The lower bound value of the interval in Chapter 2 is equal to the size of the welfare loss in only the Kaub-related Rhine market. The upper bound value represents the welfare loss in the total Rhine market under the assumption that the increase in transport price per tonne for trips in times with low water levels in the total Rhine market is equal to the increase in transport price per tonne for trips in the Kaub market.[97] In addition, it is

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[95] Recall that the total Rhine market includes transport of goods which took totally or partly place on the Rhine between Rheinfelden (close to Basle in Figure 1.1) and the Dutch-German border, including Dutch-German border-crossing transport.

[96] On days with normal water levels means: on days with water levels above the threshold level.

[97] The size of the Kaub and total Rhine market in terms of tonnes transported in 2003 is 75 million and 187 million respectively.

assumed that the number of days with low water levels in the total Rhine market is equal to the number of days with low water levels in the Kaub market.

In the current chapter we are able to re-estimate the interval on the basis of new information. First, our knowledge on the effect of the water level is not restricted to the location Kaub only, so that the lower and upper bound values of the welfare loss comprise the joint markets of Kaub, Duisburg and Koblenz in terms of tonnes transported.[98] So, eq. (1) is applied three times; once with a q_0 for the Kaub market, once with a q_0 for the Duisburg market and once with a q_0 for the Koblenz market. Second, we have new water level dummy coefficients for the Kaub market that are based on a larger number of observations than in Chapter 2 (see Table A.1 in Appendix A of the current chapter) so that p_1 in eq. (1) for the Kaub market is estimated more accurately. The p_1 for the Duisburg and Koblenz markets are based on the water level dummy coefficients in Tables A.2 and A.3 of Appendix A. Third, we are able to compute the p_0 for the Duisburg and Koblenz markets. The p_0 for the Duisburg and Koblenz markets is equal to the average transport prices per tonne for trips that pass Duisburg and Koblenz respectively on days with normal water levels in 2003. The ε applied in this chapter is equal to its value in Chapter 2 (-0.6).[99]

CCNR (2005) and Vaart! (2008) show that 75 million tonnes transported by inland waterways have Kaub as critical location, 63 million tonnes have Duisburg as critical location and about 14 million tonnes have Koblenz as critical location in 2003. Using eq. (1) above the welfare losses for the Kaub market, the Duisburg market and the Koblenz market amount to € 148 million, € 29 million and € 17 million respectively in 2003. The lower bound value is then equal to € 194 million.

For the estimation of the new upper bound value it is assumed that the tonnes transported in the Rhine market but that did not pass Kaub, Duisburg or Koblenz (the residual Rhine market amounting 35 million tonnes) in 2003, are subject to the increase in transport price which is valid for the trips that passed Kaub on days with low water

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[98] Note that the welfare loss interval which is estimated in the current chapter comprises the total Rhine market *and* the Moselle market.

[99] The value of the demand elasticity of -0.6 in Chapter 2 implies that some cargo is shifted to other transport modes in periods with low water levels. Transportation by those modes in periods with low water levels is likely to be more expensive than transportation by barge in periods with normal water levels. This welfare effect is ignored in our calculations.

levels.[100] Using eq. (1) the welfare loss for the residual market is equal to € 69 million. The upper bound value is then € 263 million. The interval for the size of the welfare loss in € in the total Rhine market plus the Moselle market in the year 2003 as a result of low water levels is then [194, 263].

5.4 Conclusion

According to economic theory, carriers drive transport prices for a low demand direction for transport down to zero because they compete for the scarcely available cargo in this direction.[101] Theory on imbalance in trade flows suggests therefore, that an exogenous increase in transport costs will be fully borne by the high demand direction for transport, under the assumption that some carriers move without cargo in the low demand direction (both with, and without the exogenous increase in transport costs). This theoretical result implies that the strength of the effect of an exogenous change in transport costs on the transport price on a one-way leg, is sensitive to the level of the imbalance in trade flows.

In our empirical application we test this and we find indeed that an increase in the transport price due to an exogenous increase in transport costs is higher if the trip takes place in a high demand direction than if the trip takes place in a low demand direction. We even find that, in some extreme cases, the increase in transport price in the high demand direction may be almost twice the size of the increase in transport price in the low demand direction.

This result is relevant in the light of climate change and its impact on inland waterway transport as it is expected that in the future there will be more days with low water levels on the river Rhine, a major inland waterway transport axis in North West Europe. Low water levels imply an exogenous increase in transport costs due to a reduction of the load factor of the inland ships. Imbalances in transport flows will determine for which routes the increase in transport price will be severe and for which routes it will be moderate. In North West Europe, inland waterway transport is mainly

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[100] Using the increase in transport price which is valid for the trips that passed Kaub on days with low water levels for estimating the welfare loss in the residual of the total Rhine market, most probably leads to an overestimation of the welfare loss for this residual market. However, this choice is made to be on the save side of the line concerning the upper bound value.

[101] Note that in practice, prices in the low demand direction will not be zero, because carriers that do transport cargo in the low demand direction have to be compensated for, for example, costs of loading and unloading.

from regions in which large sea-ports are located (Amsterdam, Rotterdam and Antwerp) to the hinterland in the centre of Europe, because most bulk cargo enters Europe via the sea-ports. From these hinterlands, exports take predominantly place in the form of goods or services that are not transported by inland waterways. This means that the physical transport flow, and thus also the number of inland waterway transport trips from the regions with sea-ports to the hinterland is larger than in the opposite direction.

Our results indicate that for shippers located in the hinterland[102], (in for example Neckar, Moselle and Saar areas and also the Middle and Upper Rhine area) and who pay for transportation from the coastal regions to the German hinterland, the increase in transport prices as a result of low water levels will be higher than for shippers that pay for transportation in the opposite direction. As a result of climate change the difference in transport prices is likely to become larger in the future. Further research might evaluate to what extent these shippers in the hinterland may for example relocate to more attractive (in terms of imbalance) regions.

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[102] These shippers pay for transportation in the direction from sea-port to hinterland. Note that in competitive markets the burden of the higher transport costs is shifted to the final consumer who may live in another part of the world.

Appendix A: Analyses of the water level effect

Table A.1: Estimation results for trips that have Kaub as critical location

Explanatory Variables	*Coefficient*	*Std. Error*
Region imbalance	-0.160	0.043
Water level		
140 – 185	0.662	0.036
186 – 195	0.537	0.038
196 – 205	0.436	0.020
206 –215	0.376	0.026
216 – 225	0.252	0.018
226 – 235	0.224	0.025
236 – 245	0.176	0.014
246 – 255	0.116	0.014
256 - 265	0.061	0.007
≥ 266	Reference	
Log(travel time)	0.141	0.020
Log(distance)	0.573	0.051
Time trend	0.212	0.031
Log(fuelprice)	0.196	0.091
Vessel size		
0 – 1000 tonnes	0.259	0.022
1000 – 1500 tonnes	0.135	0.013
1500 – 2000 tonnes	0.090	0.009
2000 – 2500 tonnes	0.057	0.008
> 2500 tonnes	Reference	
Month dummies		
January	Reference	
February	-0.077	0.015
March	-0.159	0.021
April	-0.152	0.017
May	-0.131	0.019
June	-0.122	0.026
July	-0.076	0.033
August	-0.164	0.030
September	-0.063	0.030
October	0.013	0.028
November	0.047	0.020
December	0.122	0.022
Cargo dummies, 46	Included	
R^2	0.797	
n	6837	

Note: the dependent variable is the logarithm of the price per tonne; the time trend variable is in days and divided by 1000; standard errors are clustered robust.

Table A.2: Estimation results for trips that have Duisburg as critical location

Explanatory Variables	*Coefficient*	*Std. Error*
Region imbalance	-0.205	0.019
Water level		
207 – 255	0.499	0.062
256 – 265	0.418	0.039
266 – 275	0.318	0.037
276 –285	0.294	0.028
286 – 295	0.242	0.041
296 – 305	0.172	0.040
306 – 315	0.152	0.032
316 – 325	0.109	0.018
326 – 335	0.027	0.024
≥ 336	Reference	
Log(travel time)	0.097	0.011
Log(distance)	0.585	0.038
Time trend	0.327	0.023
Log(fuelprice)	-0.039	0.049
Vessel size		
0 – 1000 tonnes	0.237	0.026
1000 – 1500 tonnes	0.146	0.016
1500 – 2000 tonnes	0.081	0.021
2000 – 2500 tonnes	0.053	0.009
> 2500 tonnes	Reference	
Month dummies		
January	Reference	
February	-0.083	0.016
March	-0.122	0.015
April	-0.096	0.018
May	-0.096	0.013
June	-0.069	0.016
July	-0.040	0.019
August	-0.116	0.017
September	-0.057	0.016
October	0.037	0.016
November	0.083	0.017
December	0.219	0.018
Cargo dummies, 46	Included	
R^2	0.756	
n	6252	

Note: the dependent variable is the logarithm of the price per tonne; the time trend variable is in days and divided by 1000; standard errors are clustered robust.

Table A.3: Estimation results for trips that have Koblenz as critical location

Explanatory Variables	*Coefficient*	*Std. Error*
Region imbalance	-0.262	0.038
Water level		
156 – 205	0.549	0.022
206 – 215	0.417	0.057
216 – 225	0.369	0.030
226 –235	0.274	0.036
236 – 245	0.156	0.029
246 – 255	0.175	0.026
256 – 265	0.134	0.028
266 – 275	0.034	0.022
276 – 285	0.004	0.013
≥ 286	Reference	
Log(travel time)	0.171	0.017
Log(distance)	0.440	0.108
Time trend	0.203	0.026
Log(fuelprice)	0.288	0.065
Vessel size		
0 – 1000 tonnes	0.226	0.047
1000 – 1500 tonnes	0.137	0.026
1500 – 2000 tonnes	0.078	0.012
2000 – 2500 tonnes	0.032	0.004
> 2500 tonnes	Reference	
Month dummies		
January	Reference	
February	-0.097	0.029
March	-0.197	0.023
April	-0.172	0.012
May	-0.157	0.043
June	-0.164	0.037
July	-0.110	0.058
August	-0.247	0.026
September	-0.156	0.017
October	-0.085	0.018
November	0.005	0.018
December	0.096	0.018
Cargo dummies, 46	Included	
R^2	0.769	
n	1886	

Note: the dependent variable is the logarithm of the price per tonne; the time trend variable is in days and divided by 1000, standard errors are clustered robust.

CHAPTER 6

TRANSPORT PRICES, NAVIGATION SPEED AND CLIMATE CHANGE

6.1 Introduction

The functioning of a (freight) transportation system depends to a large extent on the transportation speed. If links are congested, speed is low and as a result the transport system is not performing optimally. Shippers may find speed an important factor when deciding which transport mode to use for transporting their goods. Examples of studies that, among other determinants, discuss the importance of speed (or equivalently ”transport time or travel time”) as a determinant of mode choice in freight transport are García-Menéndez et al. (2004) and Beuthe and Bouffioux (2008).[103]

Also in the trade literature speed is considered to be an important factor, because transport time can be seen as a trade barrier. For example, lengthy ocean shipping times impose inventory-holding and depreciation costs on shippers (Hummels, 2001). He demonstrates that each day of increased ocean transit time between two countries reduces the probability of trade by 1 to 1.5 per cent. It appears that the time costs amount an average costs *per day* of 0.5 per cent of the value of the goods. Limão and Venables (2001) estimate the impact of infrastructure on trade volumes and transport costs where (the quality of) infrastructure can be regarded as a proxy for the transport time. They show that a deterioration in infrastructure from that of the median country to the 75th percentile decreases trade volumes by 28 per cent. The impact of this deterioration in infrastructure raises transport costs by an amount equivalent to 3,466 km of sea travel or 419 km of overland travel. Anderson and van Wincoop (2004) mention that for US trade, the time-in transit costs are equal to an average 9 per cent tariff equivalent.

The literature on the valuation of travel time should be mentioned as another field of literature in which speed has a central position. The majority of the work in this branch of literature focuses on valuation of person travel times. There are however a few studies

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[103] Other determinants on which shippers base their choice for a particular transport mode are for example transport costs, reliability, frequency and safety (probability of damage).

that consider valuation of travel time in freight transport. For recent examples see Wigan et al. (2000) and Fowkes et al. (2004). De Jong (2000) provides an overview of empirical studies.

Finally, within the maritime transport literature speed is considered to be an important factor, because it affects total supply in the market (Stopford, 2009). The capacity of the fleet is not fixed in size, because the fleet can change its navigation speed, which adds an element of flexibility to total supply in the market. It is also shown that navigation speed changes when freight rates change: when freight rates go up, a higher fuel consumption level is justified and ships increase navigation speed (Stopford, 2009).

In this chapter we will study if a similar relationship between transport prices and navigation speed is observed in the inland waterway transport sector in North West Europe. Studying this relationship is interesting from the perspective of climate change.

Due to climate change, periods with high transport prices are likely to occur more often in the future. Climate change expresses itself in both, a higher number of days with low water levels per year, and more severe low water levels. As a result, inland ships are restricted in their load factor implying a reduction of cargo hold supply in the market and therefore an increase in transport prices.[104] Higher transport prices in their turn may result in higher navigation speeds leading to more fuel consumption and thus in a higher emission of greenhouse gasses. This is undesirable from a climate mitigation point of view.

In addition, this chapter contributes to the above mentioned water transport literature by answering the question: does the relationship between transport prices and navigation speed, as it exists in the maritime transport sector, also exist in the inland waterway transport sector? Two other issues which will be addressed in Section 4 of this chapter are the elasticity of the transport price with respect to the fuel price and spatial competition in inland waterway transport.

For estimating the effect of higher transport prices on navigation speed we apply an econometric approach using the same micro data on inland waterway transport trips like in the previous chapters.

The remainder of Chapter 6 is organized as follows. Section 2 describes the literature on speed in relation to transport prices. In that section we will focus on the maritime transport sector because this sector shows similarities with the inland waterway

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[104] Note that there may exist several other causes for high transport prices.

transport sector. In Section 3 we present the data and we will describe the analysis. Section 4 discusses the empirical results while Section 5 concludes.

6.2 Literature

In maritime transport, an increase in navigation speed implies that a sea vessel's fuel consumption will shift closer to the right of the fuel consumption/speed curve meaning a disproportionate increase in fuel consumption due to increased resistance of water (see Figure 6.1). At speeds where the curve is relatively flat, operating speed can be increased with very little penalty. At speeds where the curve is steep marginal costs may be substantial. Preferred operating speeds are at those points where it starts to become considerably steeper. Operating at a higher speed is only profitable where transport rates are high enough to compensate for the extra fuel costs. If one replaces the fuel consumption on the vertical axis in Figure 6.1 by the transport costs per tonne and the speed on the horizontal axis by the quantity transported per unit of time, then the line can be regarded as a supply curve of an individual ship (Stopford, 2009).

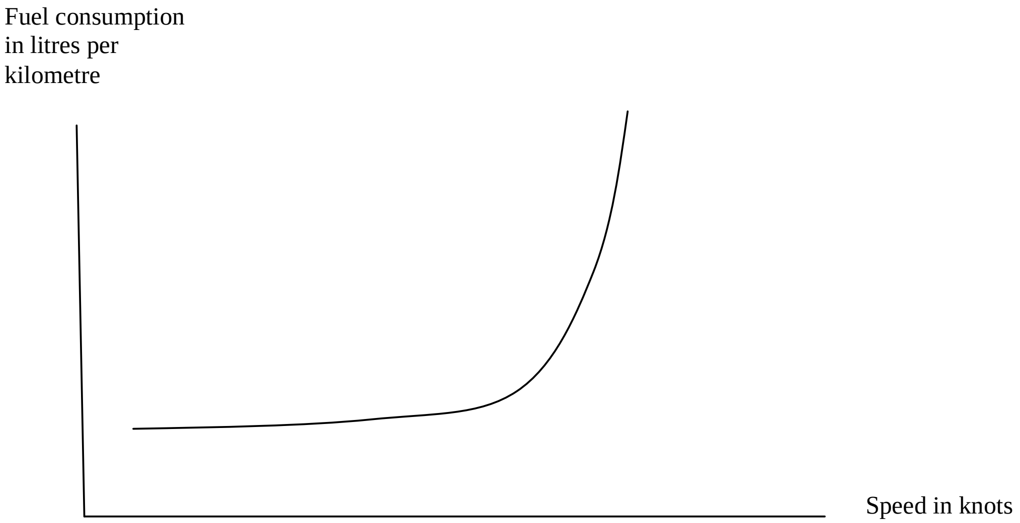

Figure 6.1: Relation between fuel consumption and navigation speed

The boundary on the right represents then the maximum amount the ship can transport in one unit of time navigating at maximum speed. If a liner shipping company holds the number of ships in service constant, increasing navigation speed has the additional benefit that a higher service frequency gives the possibility of charging higher transport prices. Note that this implies that the causal direction is not clear as higher speeds can also result in higher transport prices.[105] Improvement of the (un)loading speed in ports is also a possible way to achieve economies of speed, as explained by Laine and Vepsäläinen (1994). Note that the effect of increasing speed in both segments of the travel time (navigation and (un)loading) is heavily dependent on the ship size and the trip distance.

Instead of offering a higher service frequency to customers by increasing navigation speed, a liner shipper may also reduce the number of vessels in service, keeping the service frequency equal (see for example Becker et al., (2004)). Ronen (1982) focuses on the tradeoff between benefits in fuel consumption due to slower navigation on the one hand and losses due to longer trip duration on the other hand in order to determine the optimal speed of ships. Because fuel costs and time costs move in opposite directions as speed changes, small variations in speed for a given ship size do not have a significant impact on the overall cost per mile (Cullinane and Khanna, 1999), in particular not when the speed is close to its optimal level.

Our study differs from the existing literature on several points. First of all we focus on inland waterway transport, whereas the studies mentioned above concern maritime transport. Second, the causal direction of the relationship analysed in our study is different. Most studies focus on the effect of navigation speed on transport costs/ rates, whereas in the current study we are concerned with the effect of the transport price on speed.

6.3 The data

We employ the same data set as was used in Chapters 2, 4 and 5, the Vaart!Vrachtindicator. In this chapter, the data set can be regarded as an unbalanced panel data set where for each barge several trips are observed.[106]

The data set contains 21,865 observations of trips made in North West Europe, reported between January 2003 and January 2007. Observations with missing information

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[105] An example from which it becomes clear that the reverse effect may also exist in the inland waterway transport sector is in the case of expected cold weather. If cold weather, and thus frozen, non-navigable, waterways, are forecasted, the fleet may temporarily speed up on request of the shippers who want to increase their stocks. As a result, the carriers ask higher transport prices.

[106] The Vaart!Vrachtindicator does not contain every trip of all participants in the period 2003 – 2007 because the inland waterway carriers are not obliged to report every trip they make.

for the variable speed, a few outliers and observations that concern container transport are excluded so that 13,061 trips of 709 ships remain.[107] Descriptives of key variables used in the analysis, are shown in Table 6.1. The reported speed is based on the total travel time which includes the time of loading and unloading. The average speed is about 100 kilometres per day and the average price per trip is about € 8,600.[108]

Table 6.1: Descriptives of key variables

Variable	Minimum	Maximum	Mean	Std. Deviation
Speed (Km per day)	14.23	321.68	102.09	37.12
Price per trip (€)	520	45,340	8,620	5,368
Distance (Km)	77.00	4,000.00	505.91	256.55
Fuel price (€ per 100 liter)	26.55	57.13	47.00	7.57

Source: The Vaart!Vrachtindicator, 2003 – 2007.

In the analysis, the logarithm of speed is the dependent variable, which will be explained using the logarithm of the transport price per trip and a large number of control variables. These control variables include the logarithm of the fuel price, the logarithm of the shipment size, the logarithm of the trip distance, the square of the logarithm of the trip distance, 4 year dummies, 9 water level dummies, 38 region dummies and 709 ship fixed effects.

6.4 Analysis and results

6.4.1 Econometric approach

We aim to estimate the effect of transport prices on navigation speed. We have argued that high transport prices imply a situation of supply scarcity and as a result inland ships may speed up therefore increasing effective supply. However, the reverse effect may also exist, as described in Section 2. We address this endogeneity issue by means of an instrumental variable approach.

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[107] We exclude observations referring to container transport, because the price for container transport depends on the number of containers transported instead of the weight of the freight which is the measure used here. We have information on the weight of the freight, but not on the number of containers.

[108] We prefer a specification using the transport price per trip rather than the transport price per *tonne* because load factors vary per trip.

According to an OLS specification, the effect of the transport price on navigation speed is negative (with an elasticity of -0.042 (s.e. 0.006)) implying a decrease in navigation speed when the transport price increases. This finding is opposite to what one would expect on the basis of theory and likely to be caused by endogeneity problems.

Therefore, we employ two types of variables to instrument the transport price. The instruments are 9 water level dummy variables for non-Rhine trips and 11 month dummy variables. The water level instruments need some more clarification. We distinguish between two types of water level dummies. First, we use a set of dummies that measure the effect of low water levels in the Rhine area on the speed of trips that take place *within* this area. These variables will be used as control variables because low water levels may imply lower speeds because of safety measures. Second, we apply a set of dummies which measure the effect of low water levels in the Rhine area on the price of trips that take place *outside* this area. These water level dummies will be used as instruments. So, the water level instruments measure the effect of the water level at Kaub (a town located within the Rhine area) on the price of trips that take place on routes where water level changes are small or absent (outside the Rhine area).[109] Because the scarcity effect of low water levels within the Rhine area may seep into other, adjacent geographical markets, this instrument is likely to be correlated with the transport price of trips in those adjacent markets. At the same time, it is not very likely that the water level at Kaub will have a direct effect on the speed of trips in the non-Rhine area.

The month dummies are correlated with the transport price because changes in supply and demand over time affect transport prices over time. However, it is not likely that there exists a direct effect (so *not* via the transport price) of seasonality on navigation speed. We will test the validity of the instruments later on.

6.4.2 First step: estimation of the effect of the instruments on the transport price

In Table 6.2, the first step of the IV estimations, in which the transport price is regressed on the instrument matrix, are shown. We will discuss the results of two different specifications with different sets of instruments.

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[109] The water level is measured at Kaub because this location is most restrictive with respect to the load factor of inland ships that pass Kaub during low water levels. The water level at other locations in the Rhine area is highly correlated with the water level at Kaub. For the exact location of Kaub we refer to Figure 2.1.

Table 6.2: First step IV, estimation of specifications to explain the price per trip by barge

	OLS (1)		OLS (2)	
Explanatory Variables	***Coefficient***	***Std. Error***	***Coefficient***	***Std. Error***
Constant	6.583	0.216	6.605	0.216
Log(Fuel price)	0.227	0.026	0.239	0.026
Log(Shipment size)	0.243	0.007	0.242	0.007
Log(Distance)	-0.866	0.066	-0.880	0.066
(Logdistance)^2	0.124	0.006	0.125	0.006
Year dummies				
2003	Reference		Reference	
2004	0.071	0.013	0.063	0.013
2005	0.157	0.017	0.148	0.017
2006	0.301	0.020	0.288	0.020
2007	0.389	0.025	0.371	0.024
Water level, trips in Rhine area				
≤ 180	0.191	0.009	0.183	0.009
181 – 190	0.149	0.013	0.141	0.012
191 – 200	0.104	0.010	0.098	0.010
201 – 210	0.097	0.012	0.091	0.012
211 – 220	0.035	0.012	0.030	0.012
221 – 230	0.003	0.010	-0.001	0.010
231 – 240	0.013	0.009	0.009	0.009
241 – 250	0.016	0.010	0.014	0.010
251 – 260	0.006	0.008	0.004	0.008
≥ 261	Reference		Reference	
Water level, trips outside Rhine area				
≤ 180	0.119	0.020	-	-
181 – 190	0.067	0.038	-	-
191 – 200	0.035	0.026	-	-
201 – 210	0.038	0.029	-	-
211 – 220	-0.024	0.028	-	-
221 – 230	0.000	0.024	-	-
231 – 240	0.011	0.024	-	-
241 – 250	-0.003	0.029	-	-
251 – 260	0.018	0.021	-	-
≥ 261	Reference		Reference	
Month dummies				
January	Reference		Reference	
February	-0.058	0.009	-0.057	0.009
March	-0.086	0.012	-0.091	0.012
April	-0.094	0.010	-0.102	0.010
May	-0.063	0.010	-0.071	0.009
June	-0.044	0.010	-0.052	0.010
July	0.006	0.010	-0.001	0.010
August	-0.043	0.011	-0.050	0.011
September	0.012	0.010	0.005	0.010
October	0.085	0.011	0.079	0.010
November	0.153	0.009	0.154	0.009
December	0.263	0.010	0.261	0.010
Region of departure dummies	Included		Included	
Region of arrival dummies (19)	Included		Included	
709 ship fixed effects	Included		Included	
R^2	0.9135		0.9133	
Instruments	Water level dummies, trips outside Rhine + Month dummies		Month dummies	

Note: The dependent variable is the logarithm of the price per trip. Specification (1): the non-Rhine water level dummies and the month dummies are instruments. Specification (2): only the month dummies are instruments.

We are especially interested in the parameters of the water level and seasonal instruments as their size and standard errors give an indication of the strength of these instruments.

In the first specification, both instrument types are used, whereas in the second specification only the month dummies are the instruments.[110] The effect of the month dummies is strong but the strength of the (joint) effect of the 9 non-Rhine water level dummies is less obvious, because only the dummy which represents extreme low water levels identifies a significant effect. Therefore, we test the strength of the instruments with several F-tests.

The tests show that the instruments are strong in specifications 1 and 2 where the F-statistics are 114 and 183 respectively. These values are larger than 10, which is usually argued to be a minimum value for the F-test.[111]

Specifications 1 and 2 both offer some other interesting results. For example, the elasticity of fuel costs with respect to the transport price is equal to 0.23. This estimate matches with the estimate of fuel-related freight costs for ocean shipping in Hummels (2007) who found exactly the same elasticity. Lundgren (1996) reports an elasticity of 0.39.

Another interesting result is that in periods with low water levels inland waterway carriers receive a higher price implying that they earn some profits.[112] In addition, the effect of the water level in the Rhine area on prices for transport *within* the Rhine area is larger than the effect of the water level in the Rhine area on prices for transport *outside* the Rhine area.[113] An economic interpretation of this result is that inland ships do not distribute themselves over the spatial inland waterway transport area in such a way that the equilibrium between supply and demand for inland waterway transport leads to the same increase in trip prices in all geographical submarkets. The obvious reason is that the carriers would have to make transaction costs to move from one submarket to the other.

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[110] In the third specification, which is not presented in Table 6.2, only the water level dummies are the instruments. Many parameters in this specification are biased due to correlation with the month dummies which are excluded in this specification. In other words, specification 3 turns out to be misspecified.

[111] This is a rule of thumb test to test whether there might be a weak instrument problem, proposed by Stock and Watson (2003). For specification 3, the F-test reports a value of 3.15, indicating that the water level instruments are weak and therefore bad predictors of the transport price per trip.

[112] In Chapter 2 we found that trip prices in periods with low water levels are equal to trip prices in periods with normal water levels. However, the result in the current chapter is based on more data and shows that inland waterway carriers do earn some profits during periods with low water levels.

[113] Note that only at very low water levels the effect is present outside the Rhine area.

6.4.3 Main results

Table 6.3 contains the second step of the IV approach for the two specifications. Considering the difference in the effect of the transport price in the OLS estimate (-0.042) and the IV estimates in Table 6.3 (0.030 and 0.023) it is likely that endogeneity is present so that the OLS estimate is biased, assuming that at least one of the two IV specifications is well specified. Both specifications will be evaluated below.

Table 6.3: Estimation results for IV specifications explaining navigation speed.

Explanatory Variables	IV (1)		IV (2)	
	Coefficient	***Std. Error***	***Coefficient***	***Std. Error***
Constant	1.711	0.170	1.758	0.169
Log(Price per trip)	0.030	0.014	0.023	0.014
Log(Fuel price)	-0.009	0.014	-0.006	0.014
Log(Shipment size)	-0.006	0.006	-0.003	0.006
Log(distance)	0.384	0.047	0.378	0.047
(Logdistance)^2	0.022	0.004	0.023	0.004
Year dummies				
2003	Reference		Reference	
2004	-0.007	0.008	-0.007	0.008
2005	-0.005	0.009	-0.004	0.009
2006	-0.002	0.011	-0.001	0.011
2007	-0.017	0.012	-0.015	0.012
Water level, trips in Rhine area				
≤ 180	-0.027	0.007	-0.025	0.007
181 – 190	-0.029	0.009	-0.027	0.009
191 – 200	-0.029	0.007	-0.027	0.007
201 – 210	-0.027	0.008	-0.025	0.008
211 – 220	-0.028	0.008	-0.027	0.008
221 – 230	-0.020	0.007	-0.019	0.007
231 – 240	-0.011	0.006	-0.010	0.006
241 – 250	-0.020	0.007	-0.019	0.007
251 – 260	-0.014	0.005	-0.014	0.005
≥ 261	Reference		Reference	
Region of departure dummies (19)	Included		Included	
Region of arrival dummies (19)	Included		Included	
709 ship fixed effects	Included		Included	
R^2	0.8895		0.8894	

Note: the dependent variable is the logarithm of the speed. Specification (1): the non-Rhine water level dummies and the month dummies are instruments. Specification (2): only the month dummies are instruments.

In the case of two types of instrumental variables (specification 1), we find a significant and positive but small effect of the transport price on navigation speed. A 10 per cent increase in the transport price results in a 0.3 per cent increase in speed. However, a Sargan test rejects the validity of the instruments, so we must conclude that the effect is biased. In the model with only the month dummies as instruments (specification 2), the effect of the transport price on navigation speed is absent or so small that it cannot be identified (elasticity is equal to 0.023 (s.e. 0.014)). Here, a Sargan test accepts the null hypothesis of exogeneity of the month dummies as instruments.[114] Considering the F-tests and Sargan test, the second specification performs best and is the preferred specification. Concerning the control variables in this preferred specification, the effect of the year dummies, fuel price and shipment size on speed seems to be absent.[115] As the shipment size variable is positively correlated with the transport price and negatively correlated with the speed, not including this variable would lead to a downward biased effect of the transport price on speed. The squared distance is included in the specification because on long distances an increase in trip length may have a smaller or larger effect on navigation speed than on short distances.[116]

The region dummies control for up-or-downstream navigation and all kinds of unknown spatial factors that affect speed. The ship fixed effects control for all inland ship related factors that affect speed such as hull-design. Finally, the water level dummies show that at low water levels barges reduce their navigation speed slightly which is probably done to maintain safe navigation.[117] Note that this direct effect of the water level in the Rhine area on the speed of trips that take place in the Rhine area justifies our choice for the other water level dummies as potential instruments, although they turn out to be weak and invalid.

6.4.4 Sensitivity analysis

In this section we will firstly test if the effect of the transport price on navigation speed is sensitive for replacing the origin-and-destination region dummies by route dummies. In a second sensitivity analysis we replace the logarithm of the transport price per trip by the logarithm of the transport price of the next trip.

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[114] A Hausman t-test confirms that the transport price per trip is endogenous (t-value is equal to 4.82).

[115] Using yearly dummies instead of a time trend allows for non-linearity in estimating the effect of time on speed.

[116] For $\log(S) = 0.38\log(D) + 0.022(\log(D))^2$ the first derivative of S with respect to D is always larger than 0 and the second derivative is always smaller than 0 for every $D > 0$, implying a concave relationship between distance (on x-axis) and speed (on y-axis).

[117] In addition, in canals locks open less frequently during periods with low water levels to keep as much water as possible in the waterway. This results in longer waiting times in front of locks and thus longer travel times.

Including route dummies

Route-related factors that affect navigation speed might better be captured by route dummies instead of region of origin-and-destination dummies. Therefore, we replaced the 38 origin-and-destination regional dummies by 322 route dummies.[118] The OLS estimate finds an elasticity of the navigation speed with respect to the transport price of 0.0027 (s.e. 0.0014) while in the IV specification with the month dummies as instruments this elasticity is equal to 0.0077 (s.e. 0.0036).[119] A Hausman t-test shows that the difference between these estimates is not significant (t-value = -1.49) implying that the logarithm of the transport price is exogenous. First, we observe that the estimated effect is smaller than in specification 2 of Table 6.3 and second, that it is statistically significant. The route dummies capture more relevant unobserved factors that affect speed than the region of origin-and-destination dummies so that the effect of the logarithm of the transport price does not contain indirect effects of (unknown) correlated factors. The route dummies may also be the reason why exogeneity of the logarithm of the transport price per trip is not rejected: if in the previous OLS and IV estimates, which contain the regional origin-and-destination dummies, the effect of the transport price biased, two biased estimators are compared which may lead to a type one error.

Including the logarithm of the transport price of the next trip

One might argue that increasing navigation speed is useful when it helps to create an opportunity. In other words, a carrier increases navigation speed of the current trip if he thinks he can obtain a higher price for a next trip by doing so. Therefore, in the current sensitivity analysis the logarithm of the transport price per trip is replaced by the logarithm of the transport price of the next trip *for each panel*, using the OLS specification from the previous sensitivity analysis. Only those ships that have at least reported 25 trips are

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[118] With 20 regions, in theory, there exist 400 routes. However, in our data, some routes are not used so that the number of used routes is 322.

[119] The effect of the transport price is significant at the 10% level in the OLS specification and at the 5% level in the IV specification.

included in the estimation in order to prevent long time periods between two reported trips of the same ship.[120] We find a significant elasticity which is equal to 0.0022 (s.e. 0.0009).

6.4.5 Interpretation of the results

Our estimation results imply that there is a significant, though limited, effect of transport prices on speed.[121] In line with the interpretation given in Section 2, this means that we find a slightly upward sloping supply curve of barge operators: when market prices go up, their short run response is to increase speeds, implying an increase in the supplied capacity. The mechanism is that the higher price allows them to cover the higher costs of fuel following from a higher cruising speed. However, there is also another possible mechanism. Part of the barge operators do not work on a 24 hours per day basis and may therefore hire extra labor in periods with high transport prices.[122] This interpretation is supported by the finding that the effect of the fuel price on speed is absent.[123] Another reason why the latter interpretation may be more relevant is that the choice for a particular navigation speed is not fully free because of traffic rules on rivers and canals. These two considerations make it plausible that the main mechanism used by barge operators to increase the number of kilometres covered per day is not a speed increase itself, but an increase in the number of operating hours per day. Thus, we have identified a clear difference with maritime transport, where ships are used 24 hours a day, implying that the longer operating period per day option is simply not available there. Because we find a small elasticity of the transport price with respect to navigation speed, we may conclude that the increase in fuel

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[120] Excluding the ships that report less than 25 trips reduces the number of observations available for analysis to 9136.

[121] A possible explanation for this small effect of the (future) transport price on navigation speed in the inland waterway transport sector is that the volatility in trip prices may not be strong enough to generate an effect of a size like in the maritime transport sector. In this sector price volatility is much stronger. Lundgren (1996) for example shows that freight rates can increase by 200 or 300 per cent in 2 or 3 years. At the end of 2008, bulk freight rates even fell by 90 per cent in a few months.

[122] Depending on the size of a ship and the size of the shipcrew a barge operator is allowed to navigate maximally 14, 18 or 24 hours per day. About 25 to maximally 30 per cent of all inland waterway carriers operate on a 24-hour basis.

[123] Navigating more or less hours, keeping the number of kilometres an hour equal does not compensate for a lower or higher fuel price.

consumption (and thus the increase in emission of greenhouse gases) due to those higher transport prices is negligible.

6.4.6 The results in a broader context

If we focus on the effect of climate change on energy use, we can put our results in a broader context. First, we observe from Table 6.3, that navigation speed is somewhat slower at low water levels. This may be the result of safety measures and longer waiting times at locks. Second, due to low water levels, inland ships are restricted in their load factor. Consequently, inland ships face less water resistance. Although this implies a reduction in fuel consumption per trip, because of technical reasons this reduction is likely to be small.[124] Third, lower load factors imply that more trips have to be made to be able to comply with demand. More trips suggest an increase in fuel consumption. Descriptives from the Vaart!Vrachtindicator show that the mean load factor during low water levels was 22 per cent lower than during normal water levels and the mean price per tonne during low water levels was 24 per cent higher than during normal water levels in the year 2003. Considering the demand elasticity of about -0.5 (see Chapters 2 and 3) for inland waterway transport, about 10 per cent more trips are being made in periods with low water levels in a year like 2003, implying a 10 per cent increase in fuel consumption.[125] Figure 6.2 displays the discussed effects in the previous and in the present subsection.

We may conclude that the main effect of low water levels on energy use of barges is via the load factor: more trip movements are needed. The effect via speed is very small.

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[124] Low water levels imply that the amount of water between the ship keel and the soil of the fairway is small. As a result, the screw propeller of an inland ship is not able to replace as much water as in a situation with normal water levels, holding the fuel consumption level equal. So, in periods with low water levels, the reduction in fuel consumption as a result of a lower load factor is (partly) offset by a less fuel efficient inland ship engine. (Expert opinion by Mr. H. Blaauw from MARIN).

[125] Note that a share of the tonnes lost by inland waterways will be transferred to other modes, implying an increase in fuel consumption for those modes, as is also shown in Chapter 3.

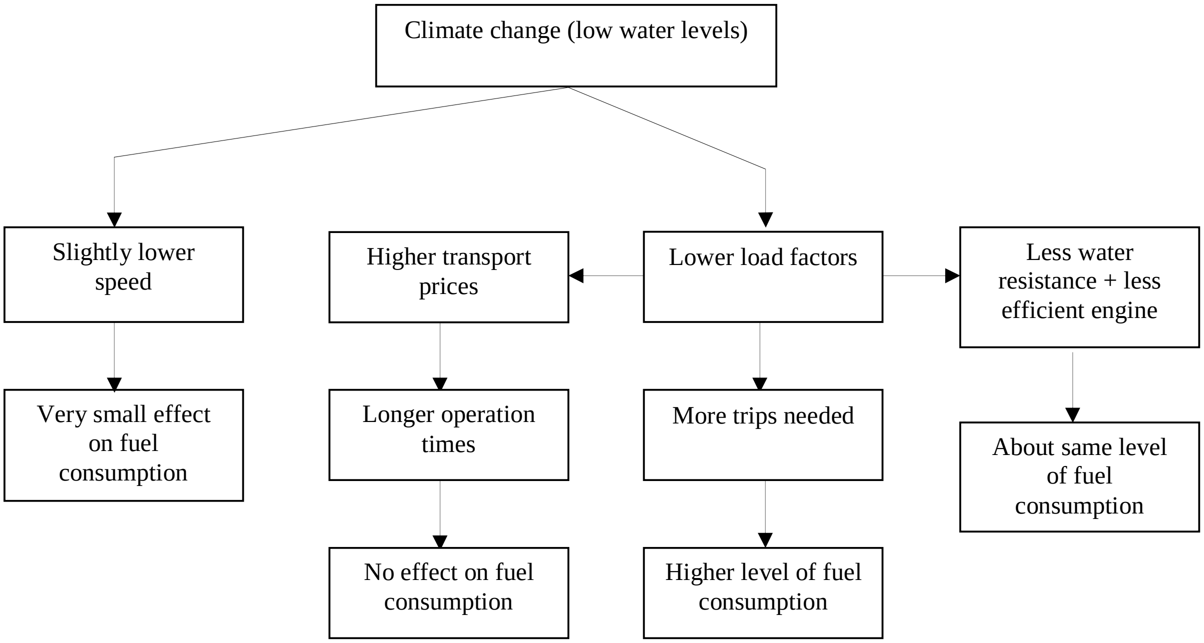

Figure 6.2: Climate change and its effects on inland waterway carrier navigation speed

6.5 Conclusion

Literature on navigation speed and transportation prices in maritime transport suggests that sea vessels navigate fast in periods with high transport prices, and slow in periods with low transport prices. The causal direction of the relationship between these two variables is not immediately clear however. Carriers may increase navigation speed because they earn higher profits in periods with high transport prices. However, they may also decide to navigate faster in order to obtain a higher service level and therefore ask a higher price. In addition, in the case of inland waterway transport, also natural forces (forecasted frozen waterways) may stimulate carriers to navigate faster, for which they want to be compensated. In the current chapter we study the effect of the transport price on navigation speed in the inland waterway transport sector from a climate change perspective.

As a result of climate change it is expected that both, a higher number of days with low water levels per year, and more severe low water levels, will occur in the future. Consequently, inland ships are restricted in their load factor implying a reduction of cargo hold supply in the market and therefore an increase in transport prices. Higher transport prices in their turn may result in an increase in navigation speed. Higher speeds usually lead to more fuel consumption suggesting a higher emission of greenhouse gasses. This is undesirable from a climate mitigation point of view.

There are more factors than the transport price that affect the level of fuel consumption of the inland waterway transport fleet during periods with low water levels. Because inland ships are forced to navigate with lower load factors: (1) they face less water resistance implying a reduction in fuel consumption; and (2) more trips must be made to be able to comply with demand suggesting an increase in fuel consumption. Unfortunately, we do not have data to estimate the exact size of those effects.

We provide an empirical model to test the effect taking into account the possible endogenous character of the transport price. We employ panel data with detailed information about trips (13,061 observations) made by inland waterway transport carriers in North West Europe from January 2003 to January 2007.

Our results suggest that, in the inland waterway transport sector, transport prices have a small positive effect on navigation speed. We have good reasons to believe though that barges do not increase the speed itself (kilometres per hour) but increase the number of operational hours per day and thus hire extra labor in periods with high transport prices. Because we find a small effect, we may conclude that the increase in greenhouse gas emissions as a result of an increase in transport prices is negligible. However, because more trips have to be made in periods with low water levels, the level of fuel consumption (and thus the emission of greenhouse gases) will increase in these periods.

CHAPTER 7

CONCLUSION

7.1 Introduction

Climate change is likely to affect many sectors in the economy. The agricultural sector, for example, may be confronted with lower yields and quality of harvested products, and, in the tourist sector, new holiday destinations at higher latitudes may become more popular at the expense of the traditional sun-holiday destinations.

This study has addressed the impact of climate change on the transport sector, or, more specifically, on the inland waterway transport sector in North West Europe. Plausibly, the inland waterway transport sector is more vulnerable to climate change than other transport sectors. After all, the quality of the waterway infrastructure is directly dependent on the amount of precipitation and evaporation in the river basins in North West Europe. As more than 63 per cent of all cargo moved by inland waterways in Europe is transported on the river Rhine, we mainly focus on this waterway.

The river Rhine is a combined rain-snow river. As a result of climate change, it is expected that the Rhine will be more rain-oriented in the future. More specifically, it is expected that, in winter, precipitation will increase, and higher temperatures will cause a smaller proportion of precipitation to be stored in the form of snow in the Alps. As a result, in winter, more precipitation directly enters rivers, average and peak water levels will be higher, and the number of days with low water levels will decrease. However, as low water levels hardly occur during winter, the reduction of days with low water levels in winter will be small.

In summer, besides a reduction in meltwater contribution, there will be less precipitation and more evaporation due to higher temperatures. As a consequence, inland waterway vessels on the Rhine are expected to experience lower water levels, as well as an increase in the number of days with low water levels in summer and autumn (Middelkoop et al., 2000; 2001). Low water levels imply restrictions on the load factor of inland ships. This suggests that the capacity of the inland waterway transport fleet is (severely) reduced in periods with low water levels. Because low water levels occur far more often than high water levels, this study only focuses on the economic consequences of low water levels. Several research questions were formulated in Chapter 1 to address these consequences:

1. What is the effect of climate change on inland waterway transport prices in the river Rhine area, and, consequently, what is its effect on social welfare?
2. What is the effect of climate change on the modal split in the river Rhine area?
3. What is the effect of an imbalance in trade flows on inland waterway transport prices in North West Europe?
4. How will an imbalance in trade flows distribute the burden of higher inland waterway transport prices, due to low water levels, over North West Europe?
5. To what extent will higher inland waterway transport prices result in higher navigation speeds, and, consequently, in a higher emission of greenhouse gases?

The remainder of this concluding chapter is organized as follows. Section 7.2 summarizes each chapter and answers the research questions. Section 7.3 makes an attempt to estimate the total welfare loss, via inland waterway transport, as a result of low water levels in North West Europe. In Section 7.4 we explain how our findings can be used by policy makers. Finally, recommendations for further research are made in Section 7.5.

7.2 Summary and research results

Chapter 1 introduced the topics of climate change, inland waterway transport and how climate change will affect inland waterway transport. A problem with studying climate change is uncertainty. Experts expect that average global temperatures and the precipitation pattern will change, but it is very difficult to determine to what extent. Therefore, climate scenarios, which are pictures of how the future climate may look like, have been constructed.

The mode inland waterway transport has received little attention in the scientific literature. However, in countries like the Netherlands, Belgium and Germany, this mode has a substantial share in the modal split (33, 16, and 12 per cent respectively). The most important waterway is the river Rhine on which 63 per cent of all inland waterway transport in Europe takes place. It is a sector in which many carriers are operating who offer a relatively homogenous product, illustrating that the inland waterway transport market shows characteristics of a perfectly competitive market.

Climate change is likely to affect inland waterway transport through variation in the water level. Low water levels imply restrictions on the load factor of inland ships, reducing effective supply in the market. Consequently, changes in transport prices and model split are observed.

Chapter 2 answered the two parts of research question 1. First, the effect of low water levels on transport prices was estimated employing a data set which contains information on trips made by inland waterway carriers in North West Europe in the period 2003 until mid-2005 (about 9,000 observations). Second, the change in welfare as a result of the estimated change in transport prices was calculated, using a microeconomic theoretical model. The focus in this chapter is on the part of the Rhine market that is most strongly affected by low water levels, the Kaub market. Kaub is a town located on the East bank of the Rhine. All inland ships that pass Kaub are restricted in their load factor by the water level at this location when the water level is below a threshold level of 260 cm. A map indicating the location of Kaub can be found in Section 2.1. It appears from the regression analysis that the transport price per tonne may increase by 74 per cent at extreme low water levels, compared with a situation with water levels at which inland ships are not restricted in their load factor. This percentage applies to an inland ship of average size. Estimating an interaction effect between the water level and the ship size shows that, for larger ships, the transport price per tonne increases even more.

The welfare analysis calculates the change in economic surplus as a result of the higher transport prices, assuming a perfectly competitive inland waterway transport market with perfect elastic supply. We refer to Section 2.2, equation (1) for the theoretical model. In this equation, a demand elasticity of -0.6 for inland waterway transport, which is also estimated with the data, is used. We find that, in an average year (for the period 1987 – 2004), the annual welfare loss due to low water levels in the Kaub-related Rhine market is equal to € 28 million. For the year 2003, which was characterized by a very dry summer and can be seen as a typical year in the most extreme climate scenario (W+), the welfare loss was € 91 million.[126] Extending the estimation to the total Rhine market, we find a welfare loss of € 227 million. This estimate is based on the assumptions that: (1) the

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[126] The loss is about 14 per cent of total annual turnover in the Kaub-related inland waterway transport sector. An overview of the four climate scenarios can be found in Table 1.1.

increase in transport price for trips in the total Rhine market is equal to the increase in transport price for trips in the Kaub market; and (2) the number of days with low water levels per year in the total Rhine market is equal to the number of days with low water levels per year in the Kaub market. So, it is an overestimate. Because it is plausible that dry years like 2003 will happen more often as a result of climate change, annual welfare losses via the inland waterway transport sector are likely to increase.

The focus of Chapter 3 and research question 2 was to examine to what extent the estimated higher inland waterway transport prices in Chapter 2 result in a shift of cargo to other transport modes.

Using a strategic network model, called NODUS, we estimate how many tonnes the Kaub-related inland waterway transport market loses because of higher transport costs for shippers as a result of low water levels. NODUS is a Geographical Information System-(GIS-)based software model. It provides a tool for the detailed analysis of freight transportation over extensive multimodal networks, and is built around the systematic use of the concept of “virtual links”, which enables the development of a network analysis covering all transport operations by different modes, means and routes, including all interface services in nodal platforms and terminals. Cost functions are attributed to every operation (loading, unloading, moving, waiting and/or transit, transhipping) in the virtual network. It is then possible to minimize the corresponding total costs of freight transportation with respect to the choices of modes, means and routes, with intermodal combinations included in the choice set.

The model shows how annual transport flows in the Kaub-related Rhine market adapt in scenarios which represent a year under the two most extreme climate scenarios compared with the reference scenario which assumes a year under current climate conditions. The results demonstrate that demand for inland waterway transport (measured in tonnes) drops by 5.4 and 2.3 per cent in the most extreme and second-most extreme climate scenarios, respectively. The tonnes that are lost by inland waterways are shifted to road and rail. So, as a result of climate change, these shifted tonnes are transported over shorter distances, but by making use of more vehicles. In addition, the emission per truck or train tonne-kilometre is higher than per barge tonne-kilometre. Therefore total annual CO_2 emissions in the total Kaub-related transport market increase by 1.1 per cent in the most extreme climate scenario. In answering research question 2, we find that the loss of demand as a result of climate change is limited for the inland waterway transport sector.

However, from a transport policy point of view, and from an environmental perspective, the reverse modal shift and the increase in CO_2 emissions are highly undesirable.

Chapter 4 addressed the issue of imbalances in trade flows and thereby also research question 3. This research question is also relevant for climate change because imbalances in trade flows affect transport prices differently depending on the direction of transport, so the strength of the effect of low water levels on transport prices, estimated in Chapter 2, may be sensitive to the transport direction. This issue, the interaction between the effect of low water levels and the effect of an imbalance in trade, was then discussed in Chapter 5.

The theoretical basis of Chapter 4 can be found in microeconomics textbooks such as Boyer (1998). The theory implies that imbalances in trade flows affect transport prices because (some) carriers have to return without cargo from the low demand region to the high demand region. Therefore, transport prices in the high demand direction have to exceed those in the low demand direction. This implies that transport costs, and therefore trade costs, are fundamentally endogenous with respect to trade imbalances. We study this effect using a similar, but extended, version (22,000 observations) of the data set with inland waterway trips which was employed in Chapter 2. In contrast to previous chapters, in Chapter 4 the inland waterway transport market in North West Europe is considered instead of only the Kaub-related Rhine market. In total, 20 regions are distinguished where inland waterway trips depart and arrive. This setting is different from the standard textbook one, where only two regions are considered. Therefore, imbalance is measured in a different way than just the ratio of the size of the flow in one direction to the size of the flow in the opposite direction (the route imbalance). First, in each region the imbalance is measured as the number of trips with cargo originating from the region divided by the number of trips with cargo arriving in the region, taking into account the spatial dimension of the network by weighting the imbalance in each region according to the distance to, and imbalance in, the other regions. This variable is defined as I_i. Then, we define our imbalance variable as the imbalance in the destination region over the imbalance in the origin region ($I_{ij} = I_j/I_j$). We call this variable the ‘region imbalance’. A regression analysis shows that region imbalances play a much more prominent role than route imbalances in the determination of transport prices in our setting of a spatial network. We find that a 1 standard deviation increase in the region imbalance from its mean value decreases the transport price by about 8 per cent. A range of sensitivity analyses show that this effect is robust. As the physical flow of goods by inland waterways from regions along the North

Sea coast (where seaports like Rotterdam and Antwerp are located) to regions in the hinterland is substantially larger than in the opposite direction, unit transport prices from the coast regions to the hinterland regions are substantially higher than the other way round. This can be illustrated with an example: for inland waterway transport from the Rotterdam port area to the Neckar area in Germany, transport prices are 37 per cent higher than in the opposite direction.

Chapter 5 combined the analyses in Chapters 2 and 4 to find an answer to research question 4. That question is whether differences in imbalance in trade flows over space affect the size of the effect of an exogenous change in transport costs on transport prices: for example, as a result of low water levels. We employ the data set from Chapter 4 but include only those trips in the regression that pass at least one out of the three locations where the water level is measured: Duisburg, Koblenz or Kaub. The locations of these towns are shown in Figure 5.2. Also, as in Chapter 4, 20 regions are distinguished. The variable of interest is the interaction effect of the (location-specific) water level and the region imbalance, and the dependent variable is the logarithm of the transport price per tonne. The three interaction effects (one for every location) are statistically equal to each other. Therefore, we also estimated a specification in which we do not allow the effects to be location-specific. With this specification it is more straightforward to interpret the results. To answer research question 4, we find a marginal effect of the water level which is equal to a 0.63 per cent increase in the transport price for the mean region imbalance value when the water level drops by 1 centimetre, conditional on the fact that the water level is below the threshold value. We also find that, depending on the origin-destination combination (and thus on the region imbalance), the marginal effect of an increase in transport costs on transport prices in the high demand direction can be almost twice as large as in the low demand direction. Translating the results into practice, they indicate that, for shippers who are located in regions in the hinterland (in, for example, the Neckar, Moselle and Saar areas, and also the Middle and Upper Rhine area), and who pay for transportation by barge from the coastal regions to the German hinterland, the increase in transport prices as a result of low water levels will be higher than for shippers who pay for transport in the opposite direction. As a result of climate change, the difference in transport prices is likely to become greater in the future.

Because the water level is not only measured at Kaub, but also at other locations, a more reliable estimation of the welfare loss as a result of low water levels in 2003 was carried out. So, returning to research question 2, the re-estimation of the welfare loss concerns the total Rhine market plus the Moselle market and is estimated to lie between € 194 million and € 263 million.[127] This is much more precise than the previously mentioned welfare loss interval of [91, 227] in Chapter 2.

Finally, Chapter 6 aimed to answer research question 5. Here, we assess the effect of the transport price per trip on navigation speed in the light of climate change.[128] In the maritime transport sector, it is observed that the sea cargo fleet increases navigation speed in periods with high freight prices. As those periods are likely to occur more often in the inland waterway transport sector in North West Europe because of climate change, it is interesting to determine whether the above- mentioned phenomenon in the maritime sector is also present in the inland waterway transport sector. Higher speeds imply a disproportionate increase in fuel consumption, leading to more emissions, which is undesirable from a climate mitigation perspective. Again, we employ the same data set as in Chapter 4, and we construct an econometric model taking into account the endogeneity of the transport price variable. The results show that there exists a small effect of transport prices on navigation speed. A 10 per cent increase in the transport price leads to a maximum increase in navigation speed of between 0.03 and 0.3 per cent. However, the reaction of barge operators to a possible increase in speed is different from carriers in the maritime sector. They do not increase navigation speed as such, but instead they increase the number of operational hours per day. So, to address research question 5, higher transport prices hardly result in faster navigation, but carriers confine themselves to changes in the number of operational hours. Because we find a small effect, the increase in fuel consumption and thus the emission of greenhouse gases as a result of higher transport prices is negligible. However, as a consequence of an increase in the number of trips by barge of about 10 per cent in periods with low water levels as in 2003, an increase in the emission of greenhouse gases may be expected.

7.3 Estimation of total welfare loss

The welfare losses as a result of low water levels reported previously only concerned parts of the inland waterway transport market in North West Europe. However, for decisions on

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[127] The Moselle is a tributary of the Rhine. See Figure 5.2. for the location of the Moselle.

[128] Navigation speed is defined as the number of kilometres navigated *per day*.

adaptation measures, reporting an aggregate welfare loss for the year 2003 would be more informative.

The welfare loss for the Rhine market (with a size of 187 million tonnes) was estimated to lie between € 194 and € 263 million for the year under consideration. This amount concerns inland waterway traffic on the Rhine in Germany (including Dutch-German border-crossing traffic) plus traffic on the Moselle. RIZA et al. (2005) focused on the Dutch domestic inland waterway transport market and assessed the 2003 extra inland waterway transport costs as a result of low water levels for this area to be about € 111 million.[129] Chapter 1 mentioned that 15 per cent of total inland waterway transport in Europe (500 million tonnes) takes place between France, Belgium and the Netherlands (the North-South market) and about 4 per cent in North Germany. This implies that the size of these two markets is about 75 million tonnes and 20 million tonnes, respectively. We use the estimated amount of extra inland waterway transport costs in the Dutch domestic market in order to assess the amount of extra transport costs for the North-South market and the North German market. These costs are estimated to be equal to € 83 million and € 22 million, respectively.[130] So, the total welfare loss via the inland waterway transport sector due to low water levels in the year 2003 in North West Europe is estimated to lie between € 410 million and € 479 million. For a future year like 2050, however, for which the dry year of 2003 is representative, the estimated total welfare loss is more likely to be an underestimate because it is based on observed flows for 2003. According to socio-economic scenarios, demand for transport is likely to be higher in 2050.

Another reason why the mentioned total welfare loss is likely to be an underestimate is that more expensive transport by rail and road in periods with low water levels is ignored. If we would have information on the change in transport costs and tonnes transported for these modes, the welfare loss via the *total* transport sector due to low water levels can be calculated.

To put the estimated total welfare loss in perspective it can be compared with total turnover. The number of tonnes transported by barge in the above mentioned markets (Rhine + Moselle, Dutch domestic, North-South market and North-German market) is 382

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[129] The Dutch domestic market concerns inland waterway transport with a place of loading and unloading in the Netherlands. The size of the Dutch domestic inland waterway transport market is about 100 million tonnes (Min. V&W and CBS, 2003).

[130] North-South market: (75/ 100) x € 111 million = € 83 million. North German market: (20/ 100) x € 111 million = € 22 million.

million tonnes and the mean price per tonne is € 7.48 (see Table 4.1). This implies that in a year like 2003, the welfare loss is about 15 per cent of the turnover in the market.

7.4 Implications for adaptation

This dissertation is written within the framework of the Dutch National Research Programme Climate *changes* Spatial Planning for good reason. This programme was launched given the need to make the Netherlands climate-proof in the coming decades. So, the implications of climate change on spatial planning, transport, and safety with respect to water (Deltacommissie, 2008) have top-priority in current policy making. This section aims to contribute to adaptive decision making within this context for the inland waterway transport sector. As inland waterway transport is an international-oriented business, it is inevitable to look across borders and to cooperate with Germany in particular.

First of all, in Chapters 2 and 5 and in the previous section, we estimated welfare losses for several geographical inland waterway transport markets for the year 2003. According to Beniston (2004), this is a year that can be used as an example for future summers in the coming decades in climate-impact and policy studies. These welfare estimations are useful in, for example, social cost-benefit studies which give an indication of whether investment in projects that aim to make inland waterway transport more robust to low water levels is economically sound.[131] Note that the estimated amounts do not imply that adaptation measures to solve the low water level problems at, for example, Duisburg, Koblenz and Kaub may cost as much as between € 194 and € 263 million. After all, the benefits of adaptation measures such as barrages will last for many years. Second, the volume transported by barge in future years will be different. Third, if the bottlenecks at the above mentioned locations are solved, there will be another location at the Rhine that determines the minimum load factor and that will cause a certain welfare loss.[132] Finally, adaptation measures may impose costs or create benefits to other sectors.[133]

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[131] Examples of adaptation measures that can be considered are the construction of barrages in the river Rhine and the canalization of this river.

[132] This can be illustrated by an example. Suppose that, if the load factor restrictions at Duisburg, Koblenz and Kaub are solved, Oestrich (located upstream of Kaub) is the next bottleneck. Let us assume that 2003 low-water levels at Oestrich cause an annual welfare loss of € 50 million. Then the costs of investment to eliminate the welfare loss of € 194 to € 263 million a year caused at Kaub must be less than € 144 to € 213

Apart from an estimation of the welfare loss, in Chapter 2, an elasticity of demand for inland waterway transport of -0.6 was also estimated. This elasticity indicates that adaptation of demand for inland waterway transport by shippers is limited when transport costs increase (as a result of low water levels, for example). This information might be valuable when making (climate-related) policy decisions that affect the price of inland waterway transport.

Chapter 3 addressed the potential adaptation of transport flows to climate change. Under the most extreme climate scenario a reverse modal shift from inland waterways to road and railways is observed. The main result is that this shift will be limited in terms of tonnes, as well as in a relative sense. The transport policy of some countries in the European Union and the Union itself is aiming to establish a modal shift from road to more environmentally-friendly modes, such as inland waterways. Policy makers may be reassured that the goal of establishing the shift will not be particularly hampered by climate change.

A result of the reverse modal shift is a 1.0 per cent increase in the number of truck-vehicle kilometres and a 1.1 per cent increase in CO_2 emissions in the part of Europe considered. Detailed road network analysis can be used to calculate the increase in traffic intensity and, consequently, in congestion levels. Expressing the increase in congestion and CO_2 emissions in monetary terms produces valuable information on external effects for the previously mentioned social cost-benefit analysis.

Chapters 4 and 5 demonstrated that the combined effect of low water levels and an imbalance in inland waterway transport flows between the coastal and hinterland regions in North West Europe lead to substantial differences in transport prices in opposite directions. Climate change is likely to reinforce this effect. As a result, shippers in the hinterland regions, who already pay high transport prices, may be confronted with an extra increase in transport prices. Consequently, those shippers may start thinking about relocating, for example, closer to or in the coastal regions. This may not be desirable from a spatial planning point of view, given the relatively high congestion and flood risks in coastal zones.

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million a year assuming that these investments do not reduce the load factor restrictions of inland ships at Oestrich.

[133] For example, the amount of available water for the agriculture sector in dry periods may increase due to the construction of barrages in the Rhine.

From Chapter 6, it would appear that high transport prices (which usually occur in periods with low water levels) do not result in faster navigation by inland waterway carriers, but at most in navigating a few more hours per day, not leading to a significant increase in fuel consumption. However, as a result of an increase in the number of trips during periods with low water levels (due to lower load factors), a negative external effect in the form of higher emissions of greenhouse gases will probably appear. These external costs should be taken into account when assessing cost-benefit-analyses of adaptation measures.

7.5 Recommendations for further research

Climate models are becoming more and more sophisticated and time series on climate data are becoming longer. Therefore, climate researchers regularly come up with modified and more reliable information on climate change. This proves that it is not only important to conduct new research in the field of economic effects of climate change but also to revisit previous research and do some re-estimation. A nice example can be found in this dissertation: the re-estimation of the welfare loss in Chapter 5.

This study has focused on the effects of low water levels on the inland waterway transport sector. We have analysed this sector from the perspective of transport prices, modal share, an imbalance in trade flows, and speed, all in relation to climate change. But obviously more research can be conducted. Something which is not addressed is, for example, the issue of (un)reliability: how will low water levels affect the reliability of inland waterway transport? Because inland ships cannot be fully loaded in periods with low water levels the reliability of the quantity delivered to the customer decreases. Also, the arrival time of inland ships becomes less reliable as a result of longer waiting times in front of locks, for example. It would be worthwhile to focus on this issue in future research.

Then, a logical next step after assessing the effects of low water levels would be to focus on the effect of high water levels. Although high water levels occur much less frequently than low water levels, their impact is more far-reaching. During low water levels, inland ships are restricted in their load factor but are still able to navigate. At high water levels, the height of bridges may become problematic for transportation of containers.[134] In addition, above a certain threshold water level, navigation is prohibited by authorities and, as a result, supply in the market is reduced to zero. If a high water level period exists for several days, inland waterway-dependent production firms may be confronted with great losses because their production processes come to a standstill.

The data, used in the analyses in this dissertation are representative for the inland waterway transport spot market. It would be interesting, however, also to examine the effects of low and high water levels in the long-term (contract) market. Climate change may increase uncertainty concerning transport costs and punctuality of delivery for shippers and the revenue for carriers. This may have an impact on the formation of contracts and possibly create an opportunity for an insurance market to cover this risk.

Next, this dissertation only focuses on the effects of climate change on the inland waterway transport sector itself. However, the effects of climate change will also seep into sectors that are served by the inland waterway transport sector. It would be interesting to conduct stated preference research on shippers that hire inland waterway transport services. Higher transport prices and changes in transport reliability may have an impact on the behaviour of those shippers. They may, for example, start to consider relocating, or to rely more on alternative transport modes. They can also put effort into the adaptation of production procedures, as well as with modified storekeeping. These adaptation opportunities are all worth considering for research.

Another interesting research area is (social) cost-benefit analysis of adaptation measures to climate change for inland waterway transport. Assessing the costs and benefits of large infrastructural projects such as barrages, canalizations, and dredging can support decision making on whether and how to adapt inland waterway transport to climate change. But one can also think of adaptations at the operational or technical level like new logistical concepts and new ship designs. These types of adaptation measures seem to be more a task for the sector itself and an interesting research area for people concerned with logistics, engineering and business administration. If climate change increasingly starts to hamper conventional inland vessels, the higher capital costs of newly designed ships will outweigh the higher unit transport costs incurred because of the low load factors of conventional ships. According to economic theory, the pricing mechanism will settle this, so that public investments will probably not be necessary. In addition, adaptation from a

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[134] As container transport is expected to be the largest growth segment (the other segments are those for dry and wet bulk) in the coming decades and because this segment is ignored in this dissertation, it would also be interesting to assess the effects of climate change on this specific segment.

logistics perspective is an interesting research field. It would also be worthwhile to examine aspects like the capacity and availability of other transport modes or the condition under which a change of transport mode is profitable and feasible in periods with low or high water levels.

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NEDERLANDSE SAMENVATTING (SUMMARY IN DUTCH)

AANPASSINGEN IN DE BINNENVAART AAN KLIMAATVERANDERING

Samenvatting en onderzoeksresultaten

Het onderwerp ‘klimaatverandering’ is ‘hot’! Bijna dagelijks wordt in de media op de een of andere manier wel aandacht besteed aan dit onderwerp. Vooral als zich ergens in de wereld extreme klimaatomstandigheden voordoen, met alle gevolgen van dien, wordt dat breed uitgelicht. Denk bijvoorbeeld maar eens aan orkaan Katrina in New Orleans in 2005 of de extreme hitte in combinatie met enorme bosbranden in Australië begin 2009.

Maar klimaatverandering leidt niet alleen tot het vaker voorkomen van extreme weersomstandigheden. Geleidelijk aan veranderen wereldwijd temperatuur en neerslagpatronen en tussen regio’s kan de mate van verandering heel verschillend zijn. Dit is een onderwerp wat intensief bestudeerd wordt door klimaatexperts. Een probleem bij het bestuderen van klimaatverandering is echter onzekerheid. Klimaatexperts weten dat temperatuur en neerslagpatronen veranderen, maar het is erg moeilijk te bepalen in welke mate. Daarom zijn er klimaatscenario’s ontwikkeld. Dit zijn plaatjes van hoe het toekomstige klimaat (in het jaar 2050 of 2100 bijvoorbeeld) eruit kan zien.

Het is zeer waarschijnlijk dat klimaatverandering invloed gaat hebben op onze samenleving. Een aantal rivieren voeren hun water af via Nederland en bovendien ligt ons land aan zee. We zijn daardoor kwetsbaar voor overstromingen bij hogere rivierafvoeren en een stijging van de zeespiegel. Maar er kan ook op sectorniveau naar de effecten van klimaatverandering worden gekeken. De landbouwsector zal door een stijging van de temperatuur misschien wel andere gewassen moeten gaan verbouwen en de toeristische sector zal door een toenemend aantal zonuren wellicht met een grotere vraag naar toeristische faciliteiten aan de kust te maken krijgen. Dit proefschrift is erop gericht om inzicht te verkrijgen in de effecten van klimaatverandering op een specifieke modaliteit in de transportsector: de binnenvaart. In landen als Nederland, België en Duitsland heeft binnenvaart een aandeel in de modal split van betekenis met respectievelijk 33, 16 en 12 procent. Met de binnenvaart worden traditioneel vooral bulkgoederen als olie, kolen en zand vervoerd maar de laatste jaren laten ook een stijging van de containertrafieken zien. De belangrijkste waterweg is de rivier de Rijn waarover 63% van alle binnenvaartvervoer in Europa plaatsvond in 2006. De dikste goederenstroom op deze rivier vinden we op het traject van Rotterdam naar het Ruhrgebied in Duitsland waar veel zware industrie gelegen is. De aanbodkant van de binnenvaartsector wordt gekenmerkt door een groot aantal vervoerders welke een relatief homogeen product aanbieden. De binnenvaartsector vertoont dan ook duidelijke kenmerken van een perfect competitieve markt.

Klimaatverandering beïnvloedt de binnenvaartsector via de waterstand in rivieren en kanalen. Hoge waterstanden kunnen leiden tot stremmingen en lage waterstanden impliceren een beperking van de beladingsgraad van binnenvaartschepen. Omdat lage waterstanden in de toekomst waarschijnlijk veel vaker zullen voorkomen dan hoge waterstanden richt dit onderzoek zich alleen op de effecten van, en adaptaties aan, lage waterstanden.

Het proefschrift bestaat uit zeven hoofdstukken. In het eerste hoofdstuk worden de onderwerpen klimaatverandering en binnenvaart, die hierboven zijn behandeld, geïntroduceerd. In hoofdstuk 2 wordt het effect van lage waterstanden op binnenvaart transportprijzen, en via deze prijzen op maatschappelijke welvaart, geanalyseerd. We gebruiken daarvoor een dataset, genaamd de Vaart!Vrachtindicator, welke informatie bevat over binnenvaartreizen die gemaakt zijn in Noord West Europa in de periode januari 2003 tot juni 2005 (ongeveer 9.000 observaties). We richten ons op dat gedeelte van de binnenvaartmarkt in Noord West Europa welke het zwaarst wordt getroffen door lage waterstanden. Dit is de zogenaamde Kaub-markt. Kaub is een klein stadje gelegen aan de oever van de Rijn in Duitsland. Bijna alle binnenvaartschepen die Kaub passeren zijn voor hun beladingsgraad afhankelijk van de waterstand op dit punt wanneer die waterstand lager dan 260 cm is.[135] Paragraaf 2.1 bevat een kaartje met daarin de locatie van Kaub. Uit de regressie analyse blijkt dat de transportprijs per ton met 74% kan toenemen bij extreem lage waterstanden (lager dan 180 cm) in vergelijking met transportprijzen die worden betaald voor reizen die plaatsvinden bij 'normale' waterstanden (hoger dan 260 cm) waarbij schepen niet worden belemmerd in hun beladingsgraad. Het genoemde percentage geldt voor een binnenvaartschip van gemiddelde grootte. Uit een extra analyse blijkt dat voor grotere schepen de transportprijs een nog grotere relatieve stijging vertoont naarmate de waterstand daalt.

In een welvaartsanalyse is vervolgens de verandering in economisch surplus als gevolg van de toename in transportprijzen berekend. Hiervoor is een micro-economisch

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[135] Waterstand is hier synoniem voor waterdiepte.

theoretisch model gebruikt waarin wordt verondersteld dat de binnenvaartmarkt een perfect competitieve markt is met een perfect elastisch aanbod. We vinden dat in een gemiddeld jaar (voor de periode 1987 – 2004) het jaarlijkse welvaartsverlies € 28 miljoen is voor de Kaub markt. In het jaar 2003, wat een zeer droog jaar was en kan worden gezien als representatief voor een jaar in het meest extreme klimaatscenario van het KNMI (W+), bedroeg het welvaartsverlies € 91 miljoen.[136] Breiden we deze analyse voor 2003 uit naar de totale Rijnmarkt, dan vinden we een maximaal welvaartsverlies van € 227 miljoen. Omdat het aannemelijk is dat droge jaren als 2003 vaker zullen voorkomen in de toekomst, is het waarschijnlijk dat de jaarlijkse welvaartsverliezen door hogere binnenvaart transportprijzen zullen toenemen.

In hoofdstuk 3 zoeken we uit in hoeverre de hogere binnenvaart transportprijzen resulteren in een adaptatie van de verdeling van vracht over de verschillende modaliteiten. Hiervoor is een strategisch netwerkmodel gebruikt, genaamd NODUS. Dit model is een instrument voor gedetailleerde analyse van vrachttransport over uitgebreide multi-modale netwerken en gaat ervan uit dat de vervoerde hoeveelheid met een bepaalde modaliteit verandert in de tegengestelde richting waarmee de kosten van transport met die modaliteit veranderen. We maken onderscheid naar drie modaliteiten: binnenvaart, spoor, en wegvervoer. In onze studie laat NODUS dus zien hoe aggregate (jaartotalen) transportstromen in de Kaub gerelateerde transportmarkt zich aanpassen aan klimaatverandering. De resultaten laten zien dat de vraag naar transport per binnenvaart (gemeten in tonnen) met 5,4% daalt in een jaar in het meest extreme KNMI klimaatscenario (W+) in vergelijking met een jaar met de huidige klimaatomstandigheden. In het op een na meest extreme klimaatscenario (M+) bedraagt het verlies 2,3%. De tonnen die de binnenvaart verliest worden overgenomen door het spoor en wegvervoer. Deze verschoven tonnen worden getransporteerd over kortere afstanden (het spoor- en wegennetwerk hebben een hogere dichtheid dan het binnenvaartnetwerk) maar met gebruikmaking van meerdere voertuigen (treinen maar vooral trucks hebben een kleinere capaciteit dan binnenvaartschepen). Daarbij is de CO_2-emissie per truck of trein tonkilometer hoger dan per binnenvaart tonkilometer. We vinden dan ook een stijging van de jaarlijkse CO_2-emissie in het meest extreme klimaatscenario in de Kaub gerelateerde transportmarkt van 1,1%.

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[136] Zie Tabel 1.1 in Hoofdstuk 1 voor een overzicht van de KNMI 2006 klimaatscenario's.

De verschuiving in vrachtvervoer van de binnenvaart naar de concurrerende modaliteiten als gevolg van lage waterstanden kan als beperkt worden bestempeld. Echter, gezien vanuit het perspectief van beleidsmakers op het gebied van transport en milieu zijn de voorziene omgekeerde modal shift en de stijging van de CO_2-emissie zeer onwenselijk.

Hoofdstuk 4 behandelt het effect van een onbalans in vervoersstromen op transportprijzen in de binnenvaart. Op het eerste gezicht is de relatie met het onderwerp klimaat afwezig. Echter, een onbalans in vervoersstromen in de binnenvaart zorgt ervoor dat transportprijzen niet gelijk zijn op verschillende transportroutes. De mate van het waterstandeffect, zoals geschat in hoofdstuk 2 zou daarom wel eens gevoelig kunnen zijn voor de transportrichting. Dit onderwerp, de interactie tussen het effect van lage waterstanden en het effect van een onbalans in vervoersstromen, staat centraal in hoofdstuk 5.

Standaard micro-economische theorie vermeldt dat een onbalans in vervoersstromen transportprijzen beïnvloedt omdat, uitgaande van een twee-regio setting, sommige vervoerders zonder vracht terug moeten keren vanuit de regio waar de vraag naar transport laag is, naar de regio waar de vraag naar transport hoog is. Daarom zullen transportprijzen in de richting waarin de vraag naar transport hoog is, hoger zijn dan die in de richting waarin de vraag naar transport laag is. Dit betekent dat transportprijzen in essentie endogeen zijn ten opzichte van een onbalans in handels-of-vervoersstromen. We bestuderen dit effect waarbij we een uitgebreidere versie van de Vaart!Vrachtindicator (nu 22.000 observaties) uit hoofdstuk 2 gebruiken. In tegenstelling tot de twee vorige hoofdstukken, waarin we ons richtten op de Kaub gerelateerde binnenvaartmarkt, wordt in dit hoofdstuk de binnenvaartmarkt in heel Noord West Europa beschouwd. In ons ruimtelijke netwerk zijn in totaal 20 regio's onderscheiden van waaruit en waarin binnenvaartreizen vertrekken en arriveren. Deze multi-regio setting is verschillend van de standaard micro-economische theorie, die uitgaat van twee regio's. De onbalans is dan ook anders gemeten dan de ratio van de grootte van de transportstroom in de ene richting en de grootte van de transportstroom in de tegengestelde richting (de zogenaamde 'route onbalans'). We gaan uit van het aantal in- en uitgaande reizen van een regio. In eerste instantie meten we de onbalans in een regio door het aantal reizen dat uit een regio vertrekt te delen door het aantal reizen dat in de regio arriveert waarbij de onbalans in iedere regio wordt gewogen naar de afstand tot, en onbalans in andere regio's. Deze variabele definiëren we als I_i. Vervolgens definiëren we onze onbalansvariabele als de ratio van de onbalans in de aankomstregio en de onbalans in de vertrekregio ($I_{ij} = I_j/I_i$). We noemen deze variabele de ‘regio onbalans’. Een regressie analyse laat vervolgens zien dat de ‘regio onbalans’ een veel grotere rol speelt dan de ‘route onbalans’ in de bepaling van transportprijzen in onze setting van een ruimtelijk netwerk van 20 regio’s.

Met het empirische model vinden we dat een standaarddeviatie stijging in de regio onbalans vanaf zijn gemiddelde, leidt tot een daling van de transportprijs van 8%. Een aantal gevoeligheidsanalyses laten zien dat dit resultaat robuust is. Omdat de fysieke goederenstroom per binnenvaart vanuit regio’s grenzend aan de Noordzee (waar de havens van Rotterdam en Antwerpen ook gelegen zijn) naar regio’s in het achterland substantieel groter is dan in de omgekeerde richting, zijn transportprijzen voor binnenvaartvervoer vanuit de kustregio’s naar het achterland substantieel hoger dan in omgekeerde richting. De prijs voor vervoer per binnenvaart van de regio Rotterdam naar de Neckarregio in Duitsland is bijvoorbeeld 37% hoger dan in de tegengestelde richting.

Hoofdstuk 5 combineert de analyses uit hoofdstukken 2 en 4 om uit te zoeken of het effect van een exogene verandering in transportkosten (bijvoorbeeld door lage waterstanden) op transportprijzen gevoelig is voor verschillen in vervoersonbalans over de ruimte. We gebruiken de dataset uit hoofdstuk 4 maar we beschouwen alleen die binnenvaartreizen in de regressie die minimaal een van de locaties passeren waar we de waterstand meten, Duisburg, Koblenz of Kaub. De kaart in Figuur 5.2 laat zien waar deze steden liggen. Net als in hoofdstuk 4, onderscheiden we ook nu 20 regio’s. De variabele waarin we geïnteresseerd zijn is het interactie-effect van de (locatiespecifieke) waterstand en de ‘regio onbalans’ en de afhankelijke variabele is de transportprijs per ton. Het blijkt dat de drie interactie-effecten (één voor iedere locatie) statistisch gelijk zijn aan elkaar. Daarom is ook een specificatie geschat waarin we niet toelaten dat het effect locatiespecifiek is. Uit deze specificatie blijkt dat het marginale effect van de waterstand gelijk is aan een 0,63% stijging van de transportprijs wanneer de waterstand met 1 cm daalt, onder de voorwaarde dat de waterstand zich beneden de drempelwaarde, waarbij beladingsbeperkingen optreden, bevindt. We vinden ook dat, afhankelijk van de herkomst-bestemmingscombinatie (en dus van de regio onbalans), het marginale effect van een toename in transportkosten op transportprijzen bijna twee maal zo groot kan zijn in de transportrichting waarin de vraag hoog is ten opzichte van de transportrichting waarin de vraag laag is. Voor de praktijk betekent deze bevinding dat voor verladers die gevestigd zijn in het Duitse achterland (bijvoorbeeld de Moezel- en Neckarregio), en die betalen voor vervoer vanaf de kustregio’s naar het achterland, de toename in transportprijzen als gevolg van lage waterstanden hoger zal zijn dan voor verladers die betalen voor vervoer in de tegengestelde richting. Door klimaatverandering is het waarschijnlijk dat het verschil in transportprijzen groter wordt in de toekomst.

Omdat in dit hoofdstuk de waterstand op meerdere locaties dan alleen Kaub is gemeten, kan een nauwkeuriger schatting van het welvaartsverlies door lage waterstanden in 2003 worden uitgevoerd dan in hoofdstuk 2 is gedaan. Voor de Rijnmarkt en de Moezelmarkt samen vinden we nu een interval voor het welvaartsverlies van tussen de € 194 en € 263 miljoen. In hoofdstuk 7 breiden we deze analyse nog verder uit naar heel Noord West Europa. Voor dit gebied schatten we een maximaal welvaartsverlies van ongeveer € 479 miljoen voor het jaar 2003.

Tenslotte analyseren we in hoofdstuk 6 in welke mate transportprijzen in de binnenvaart van invloed zijn op de vaarsnelheid in de binnenvaart. In de maritieme sector zien we dat de vloot haar vaarsnelheid verhoogt in perioden waarin hoge transportprijzen worden betaald. Omdat het waarschijnlijk is dat perioden met hoge transportprijzen vaker gaan voorkomen in de binnenvaartsector in Noord West Europa door klimaatverandering, is het interessant om te bestuderen of het zojuist genoemde fenomeen in de maritieme sector ook aanwezig is in de binnenvaartsector. Hogere vaarsnelheden duiden op een disproportionele toename van het brandstofverbruik wat leidt tot een hoger emissieniveau wat niet gewenst is vanuit het perspectief van mitigatie van klimaatverandering.

We gebruiken voor de analyse wederom de dataset uit hoofdstuk 4 en we construeren een econometrisch model die rekening houdt met endogeniteit van de transportprijs, de verklarende variabele waarin we geïnteresseerd zijn. We definiëren de vaarsnelheid in onze studie als het aantal gevoerde kilometers per dag. De resultaten tonen aan dat er een klein effect bestaat van de transportprijs op de vaarsnelheid. Een 10% toename in de transportprijs leidt tot een adaptatie van de vaarsnelheid van maximaal +0,3%. Echter, de manier waarop vervoerders in de binnenvaartsector hun vaarsnelheid aanpassen is anders dan die van vervoerders in de maritieme sector. Ze gaan niet sneller varen door het aantal kilometers per uur op te voeren maar door het aantal operationele uren per dag te verhogen. Omdat we zo een klein effect vinden is de toename in brandstofverbruik, en daardoor ook de extra uitstoot van broeikasgassen door hogere transportprijzen verwaarloosbaar. Echter, doordat binnenvaartschepen tijdens lage waterstanden met een lagere beladingsgraad moeten varen, zien we een toename in het aantal scheepsbewegingen van ongeveer 10 procent in een periode met lage waterstanden zoals in het jaar 2003. Deze toename leidt wel tot een hoger brandstofverbruik.

Implicaties voor adaptatie

De resultaten van het onderzoek in dit proefschrift kunnen worden gebruikt bij het maken van beleids- en investeringsbeslissingen voor wat betreft aanpassingen in de binnenvaart aan klimaatverandering. De schattingen van de omvang van het welvaartsverlies als gevolg van lage waterstanden kunnen bijvoorbeeld van waarde zijn bij het uitvoeren van maatschappelijke kosten-baten analyses. Investeringsprojecten die tot doel hebben het vervoer per binnenvaart klimaatbestendig te maken kunnen zo worden beoordeeld op hun economische haalbaarheid.[137] Een voorbeeld van zo een investeringsproject is het plaatsen van stuwen in de Rijn.

De geschatte elasticiteit van de vraag naar transport per binnenvaart is -0,6. Dit impliceert dat de verandering van de vraag relatief klein is bij een verandering van de transportprijs. Deze informatie kan nuttig zijn bij het maken van (klimaat gerelateerde) beleidsbeslissingen die de transportprijs voor binnenvaartvervoer beïnvloeden.

Door de inelastische vraag is de verwachte omkering in de modal shift als gevolg van lage waterstanden beperkt. Dit betekent dat de binnenvaart relatief weinig vracht zal verliezen aan concurrerende modaliteiten. Nationaal en Europees beleid op het gebied van transport is gericht op het bewerkstelligen van een modal shift van wegvervoer naar meer milieuvriendelijke modaliteiten (spoor en binnenvaart). Beleidsmakers zijn wellicht enigszins gerustgesteld dat het bereiken van dit doel niet zwaar zal worden gehinderd door klimaatverandering in de vorm van lage waterstanden.

Doordat een onbalans in vervoersstromen het effect van lage waterstanden op de transportprijs versterkt is het mogelijk dat verladers in het achterland die geconfronteerd worden met grote prijsstijgingen zich in de kustzone willen gaan vestigen. Vanuit het perspectief van beleid op het gebied van ruimtelijke planning kan men zich afvragen of deze potentiële verhuizing wel gewenst is gezien de relatief hoge congestie en overstromingsrisico's in kustzones.

Tenslotte blijkt uit het onderzoek dat binnenvaartschepen nauwelijks sneller varen in perioden met hoge transportprijzen.[138] Echter, omdat binnenvaartschepen met een lagere beladingsgraad varen in perioden met lage waterstanden, neemt het aantal

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[137] Voor een jaar onder het meest extreme klimaatscenario is het geschatte welvaartsverlies maximaal € 263 miljoen voor de Rijnmarkt en maximaal € 479 miljoen voor heel Noord West Europa.

[138] Als gevolg van klimaatverandering is het waarschijnlijk dat perioden met lage waterstanden, en daardoor perioden met hoge transportprijzen vaker zullen voorkomen.

scheepsbewegingen toe. Dit leidt tot een toename van de emissie van broeikasgassen waardoor er een negatief extern effect optreedt als gevolg van lage waterstanden. De monetaire waarde van dit effect moet worden meegenomen in kosten-baten analyses voor adaptatiemaatregelen.

Aanbevelingen voor vervolgonderzoek

Het onderzoek in dit proefschrift heeft veel interessante bevindingen aan het licht gebracht binnen het thema ‘klimaat en binnenvaart’. Echter, er zijn binnen dit thema nog diverse onderwerpen over waar aandacht aan besteed kan worden. Een voorbeeld van zo een onderwerp is transportbetrouwbaarheid: in welke mate zullen lage waterstanden invloed hebben op de betrouwbaarheid van binnenvaartvervoer? Omdat binnenvaartschepen hun capaciteit niet volledig kunnen benutten in tijden met lage waterstanden daalt de betrouwbaarheid van de aangevoerde hoeveelheid. Daarnaast kunnen de aankomsttijden van schepen minder betrouwbaar worden door langere wachttijden bij sluizen of omvaren.

Een ander onderwerp, en een logische stap na het onderzoeken van effecten van lage waterstanden op de binnenvaartsector, is om te focussen op het effect van hoge waterstanden. Hoge waterstanden komen dan wel minder vaak voor dan lage waterstanden, de impact is ingrijpender. Tijdens lage waterstanden worden binnenvaartschepen beperkt in hun beladingsgraad, maar het blijft mogelijk om te vervoeren. Bij hoge waterstanden wordt de hoogte van bruggen ten opzichte van het wateroppervlakte kleiner, wat problemen op kan leveren voor transport van containers.[139] Daarnaast is het boven een bepaald waterniveau verboden voor de binnenvaart om te varen waardoor het aanbod van vervoerscapaciteit van het ene op het andere moment kan terugvallen tot nul. Het is interessant om te kijken hoe het prijsmechanisme hiermee omgaat. Tevens kunnen bedrijven geconfronteerd worden met onderbrekingen van hun productieprocessen indien hoge waterstanden voor langere tijd aanhouden, wat kan leiden tot grote schade.

De data die is gebruikt voor de analyses in dit proefschrift is afkomstig uit de binnenvaart spot markt. Het is echter ook mogelijk om de effecten van lage en hoge waterstanden op de lange termijn (contractenmarkt) te onderzoeken. Klimaatverandering

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[139] Omdat wordt verwacht dat het transport van containers per binnenvaart de grootste groei zal laten zien (de andere segmenten zijn die voor droge en natte bulk) in de komende decennia en omdat dit segment niet is meegenomen in dit proefschrift zou het ook interessant zijn om de effecten van klimaatverandering op containertransport per binnenvaart te onderzoeken.

leidt waarschijnlijk tot meer onzekerheid in de hoogte van de transportkosten en de punctualiteit van de leveringen voor verladers en de opbrengsten voor vervoerders. Dit kan invloed hebben op de totstandkoming van contracten en kan wellicht een markt creëren voor verzekeringen om dit risico af te dekken.

Dit proefschrift richt zich alleen op de effecten van klimaatverandering op de binnenvaartsector zelf. Echter, de effecten kunnen doorwerken in de sectoren die door de binnenvaart worden bediend. Het uitvoeren van stated preference onderzoek bij verladende bedrijven die schepen inhuren is een mogelijkheid om dit te onderzoeken. Hogere transportkosten en een mogelijke verslechtering van de betrouwbaarheid kunnen effect hebben op het gedrag van verladers. Ze kunnen bijvoorbeeld overwegen om te gaan verhuizen of om meer gebruik te gaan maken van andere modaliteiten. Een andere mogelijkheid is dat ze hun productieprocessen en voorraadsystemen anders gaan inrichten. Deze adaptatiemogelijkheden zijn allen de moeite waard om te onderzoeken.

Een ander interessant onderzoeksveld is maatschappelijke kosten-baten analyse met betrekking tot adaptatiemaatregelen voor de binnenvaart. Het tegen elkaar afwegen van kosten en baten van stuwen, kanalisatie en baggeren kan de kwaliteit van de besluitvorming betreffende het klimaatbestendig maken van de binnenvaart bevorderen. Naast deze grootschalige adaptatiemogelijkheden kan men echter ook denken aan het afwegen van kosten en baten van aanpassingen op het operationele niveau zoals nieuwe logistieke concepten en lichtgewicht schepen.

Het onderzoek in dit proefschrift is uitgevoerd binnen het kader van het onderzoeksprogramma “Klimaat voor Ruimte”. Dit programma, en daarmee dit proefschrift, is gefinancierd door het Ministerie van Economische Zaken en heeft tot doel bij te dragen aan het klimaatbestendig maken van Nederland.

The Tinbergen Institute is the Institute for Economic Research, which was founded in 1987 by the Faculties of Economics and Econometrics of the Erasmus University Rotterdam, University of Amsterdam and VU University Amsterdam. The Institute is named after the late Professor Jan Tinbergen, Dutch Nobel Prize laureate in economics in 1969. The Tinbergen Institute is located in Amsterdam and Rotterdam. The following books recently appeared in the Tinbergen Institute Research Series:

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