Climate change and inland waterway transport; welfare effects of low water levels on the river Rhine

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Abstract

We derive the annual welfare effects of low water levels on the river Rhine employing detailed trip data reported by bargemen between January 2003 and July 2005. We find a considerable effect of water levels on freight price *per ton* and load factor, but the effect on the price *per trip* is close to zero. Using water level information over a period of almost 20 years, the average annual welfare loss due to low water levels is estimated to be about € 28 million. In years with extremely low water levels, such as in 2003, the loss amounts to about € 91 million, about 13% of the market turnover in the part of the Rhine market considered.

Keywords: Climate change, Inland waterway transport, Water level, Welfare loss

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).[1] After stabilization of the emissions of greenhouse gasses, surface air temperature is projected to continue to rise for a century or more (IPCC, 2001).

Little attention has been given to the effect of changes in the natural environment on transport costs.[2] Such attention is relevant however because it may contribute to formulate policies to adapt to these changes (e.g. de Groot et al., 2006). Examples of the thin literature on the effects of climate change on transportation can be found in Suarez et al. (2005) and Nankervis (1999). Besides, there exists quite some literature on the effects of weather on safety in road transport (e.g. Edwards, 1999; Brodsky & Hakkert, 1988).

The current study contributes to this literature as it 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. The river Rhine is the most important waterway in Europe. About 70% of all inland waterway transport in the former EU-15 member states is transported on the Rhine.

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[1] 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).

[2] In contrast, a substantial number of studies have examined the effects of transport on environmental costs. We mention e.g. 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.

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 specific, 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 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).[3]

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 ton, and thus also the price per ton transported will rise. To be more specific, we determine to what extent higher prices per ton emerge when the water level drops below a certain threshold, implying additional transportation costs for the economy in times of low water levels.[4]

We focus on water levels at a particular location along 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

[3] The current paper starts with the observation that low water levels occur more often and have more severe impacts than high water levels, so it concentrates only on the consequences of low water levels on the economy.

[4] 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.

the trips that pass Kaub, the water depth at Kaub is the bottleneck.[5] The estimated size of the welfare loss thus concerns cargo that is transported via Kaub during low water levels. Figure 1 shows the location of Kaub.

Estimation of the welfare loss is based on the effect of water levels on freight prices *per ton* observed during the period from beginning 2003 to July 2005. In addition, we asses the effects of water level on load factor and 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.

The purpose of this paper is to contribute to the knowledge about the effects of climate change on the economy. Given the welfare loss of low water levels, one is able to examine whether investment in projects that aim to make inland waterway transport more robust to low water levels might be economically sound.

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 3 deals with the data we use for our research and in section 4 the results will be presented. In section 5 we conduct the welfare analysis and section 6 offers some concluding remarks.

[5] 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 along 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 in this paper and regard water depth and water level as synonyms.

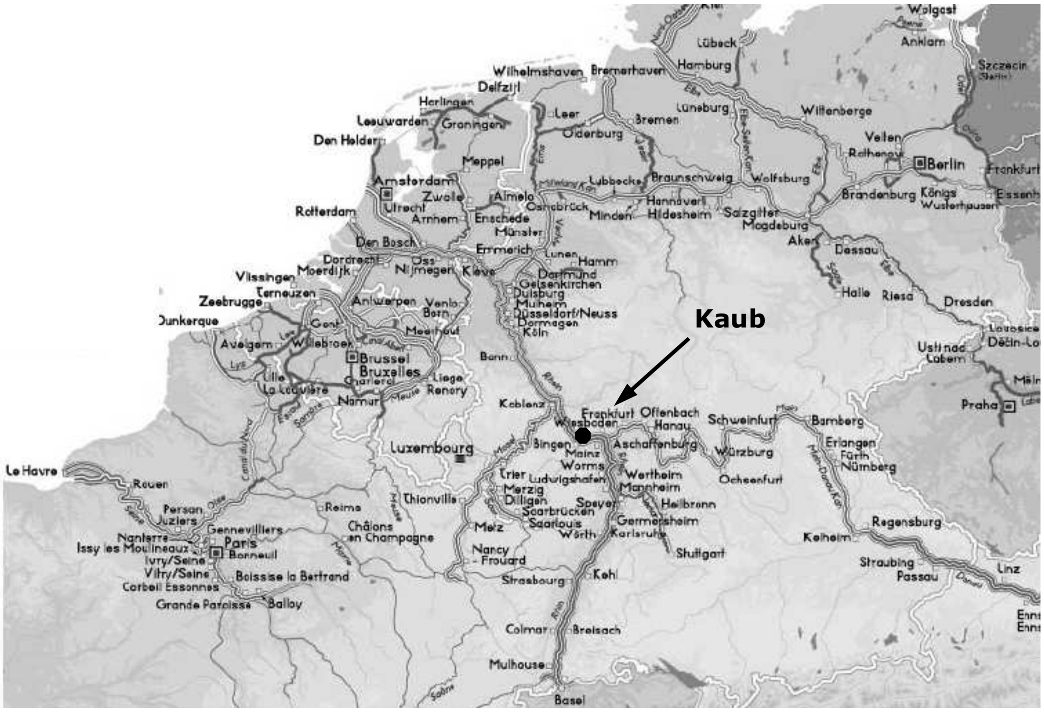

Figure 1: Location of Kaub (Germany) at the river Rhine

2 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 1). Large ships enjoy economies of vessel size and operate in the market segment for large shipments (e.g. more than 2500 tons). However, large ships are not able to underprice small ships, because small ships operate in the market segment for small shipments. Due to the heterogeneity in demand concerning shipment size, different markets exist at the same time. Consequently, within each segment, it is reasonable to assume a horizontal supply curve.

Because the inland waterway transport market can be described as a market with perfect competition[6] and perfectly elastic supply[7], the economic surplus[8] equals the consumer surplus and the welfare loss due to low water levels equals the reduction in consumer surplus. 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 ton, *p*. The price per ton includes costs like interest, labour, fuel costs, handling costs etc.

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[6] For theoretical considerations on perfect competition see studies of e.g. Stigler (1957) and Robinson (1934). In these studies several definitions and characteristics of (perfect) competition are discussed.
[7] This assumption is of importance for the correct estimation of the welfare loss. If supply is inelastic, the size of the welfare loss would be larger than reported here.
[8] Hausman (1981) and Willig (1976) address the concept of the economic surplus.

The quantity transported is denoted by *q*. Note that under the assumption of perfect competition, the price per ton equals the costs per ton, ($p = c$) and the price per trip equals the costs per trip ($P = C$). The load factor is denoted as θ. We will now distinguish 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 ton at low water levels are $c_1 = c_0 \times \theta_0 / \theta_1$, so transport costs *per ton* are a factor θ_0 / θ_1 higher given low water levels. As a consequence inland waterway transport enterprises charge a higher price per ton 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 $C_1 = C_0$[9], so the transport costs per trip do not depend on the water level. This finding is consistent with our assumption that supply is perfect elastic. [10] Besides, it is a strong indication for the existence of perfect competition in the inland waterway transport market.

3 Dataset and methodology

3.1 Data

We employ a unique dataset, the Vaart!Vrachtindicator, which contains detailed information about trips made by inland waterway transport enterprises in Western Europe.[11] The enterprises report information via internet about their trips such as the price per ton, place and date of loading, place and date of unloading, capacity of the ship, number of tons transported, type of cargo, etc. Although the dataset contains repeated information for some enterprises, the data cannot be characterized as trip panel data. Enterprises only accidentally make the same trip, so our sample can be best viewed as repeated cross-section data. The dataset contains information on inland waterway transport enterprises that operate in the spot market where the price per ton, and the number of tons 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 ton throughout the year are not included in the dataset.

[9] 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% 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.

[10] 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.

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

The database contains 8946 observations of trips, reported between beginning 2003 and July 2005. We exclude all trips that do not pass Kaub,[12] (6059 observations), which means we have 2889 remaining trips. 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 tons. So, we have 2864 remaining trips suitable for analysis.

Table 1 shows the distribution of the vessel sizes in the Kaub dataset. The Kaub market is dominated by vessels between 1000 and 2000 tons. The average capacity of the fleet in the Kaub-dataset is 1776 tons.

Table 1: Distribution of vessels over tonnage classes

Vessel size	Kaub dataset
0 – 649 ton	2.8%
650 – 999 ton	12.2%
1000 – 1499 ton	31.9%
1500 – 1999 ton	20.5%
2000 – 2499 ton	11.4%
> 2500 ton	21.3%

Source: The Vaart!Vrachtindicator (2003 – 2005).

3.2 Descriptives

The descriptives of the key variables, price per ton, load factor, price per trip and water level, which play a major role in the theoretical section, are given in Table 2 and Figure 2. In Table 2 we distinguish between trip and day observations.

The latter are obtained by taking averages of several trips over a day. We have about 750 valid day observations. The mean price per ton is about € 8.50 and the mean load factor is 0.78. Figure 2 shows the water level variation over a 2.5 year period. Particularly in the second half of 2003, water levels are below 260 cm at Kaub, which

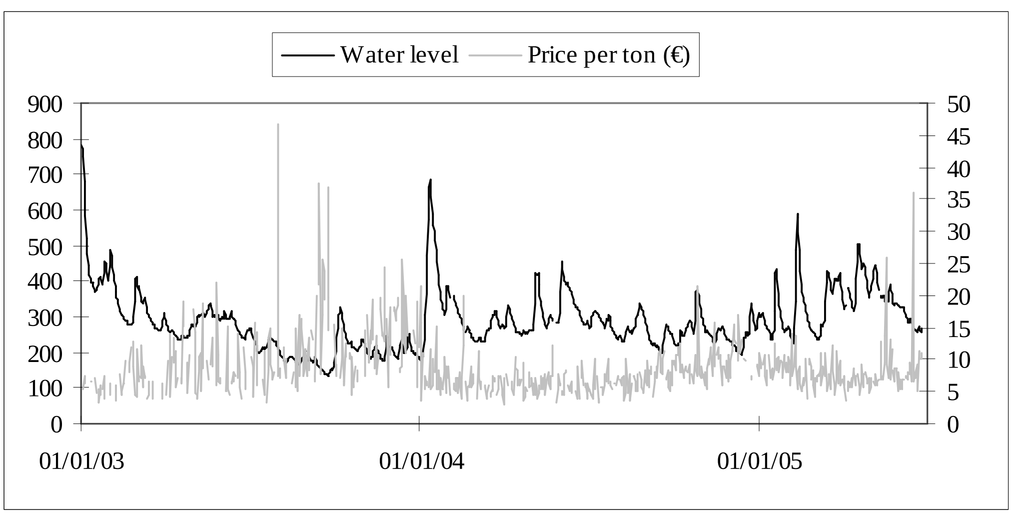
[12] As stated in the introduction, vessels that pass Kaub are particularly restricted in their load factor.

will be identified later on as the threshold level for low water levels. There is clearly a seasonal pattern (e.g. in late summer, water levels are low).[13] The figure shows a strong negative relationship between the price per ton and water level. For example, in September 2003 water levels were exceptionally low and prices per ton 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.

Table 2: Descriptives of key variables

Variable	No. of observations (day data)	No. of observations (trip data)	Minimum (trip data)	Maximum (trip data)	Mean (trip data)	Std. Deviation (trip data)
Water level (Kaub) in cm	903	2849	135.00	780.00	192.66	79.57
Price per ton (in €)	773	2847	1.80	52.00	8.56	5.39
Load factor (in %)	745	2530	0.10	1.01	0.78	0.17
Price per trip (in €)	759	2586	1036.55	71000.00	9810.82	5571.08

Source: The Vaart!Vrachtindicator (2003 – 2005).



[13] Note that there is still sufficient variation *within* months to identify a separate effect of water level controlling for monthly variation.

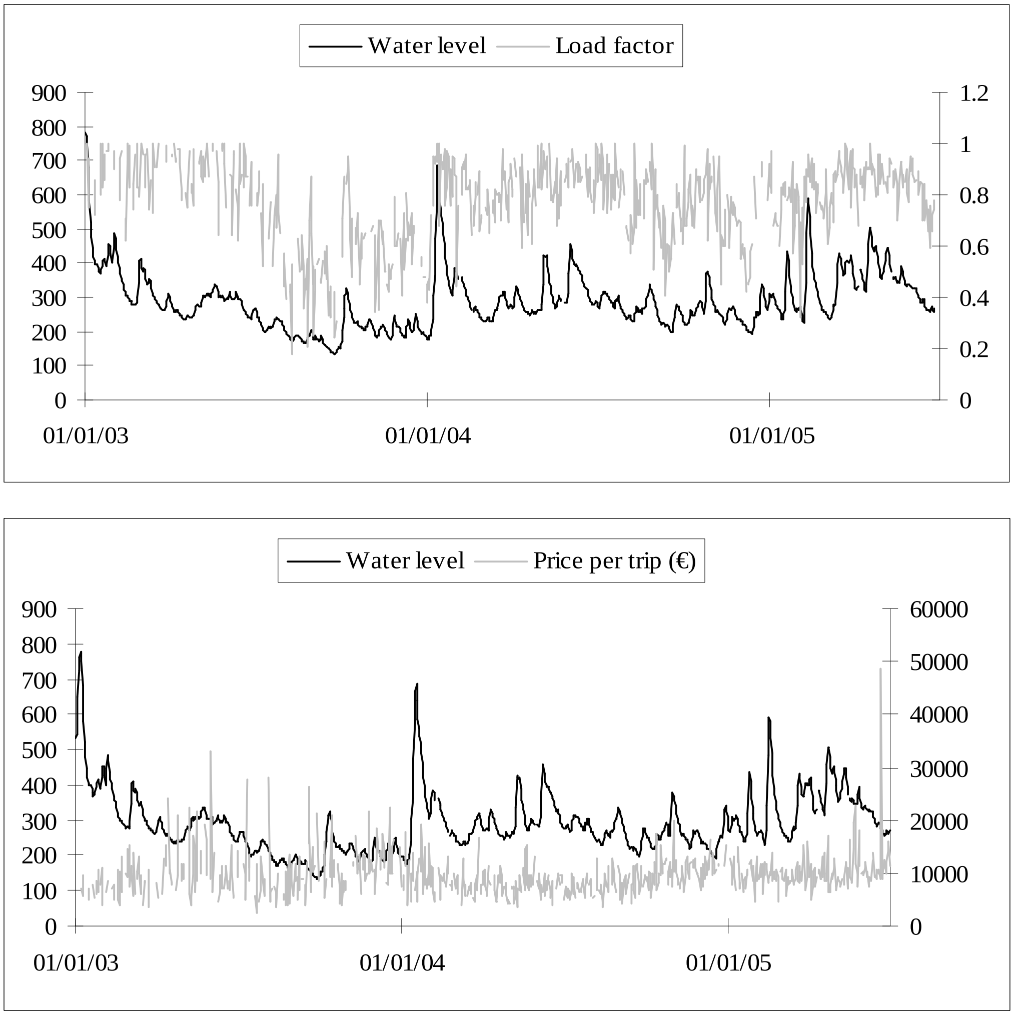


Figure 2: Relation between water level and price per ton, load factor and price per trip. Source: The Vaart!Vrachtindicator (2003 – 2005).

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.

4 Multiple regression analysis

We assess the impact of water level on the logarithms of freight price per ton, 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 backhaul 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. 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 (e.g. 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 effects 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 (e.g. 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 types generate very similar results. Tables 3 and 4 show the estimated coefficients for both trip and day data.

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.[14] 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 ton. We employ the Ljung-Box test (or Q-statistic), 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. To eliminate the serial correlation, we estimated several regression models with lagged values of the concerning explained

[14] Scatter plots showed that, after this transformation, the variance of the residuals is close to constant.

variables. On the basis of information criteria (AIC and SIC) and LR-tests, models are selected.[15] 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 ton, 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 is a competitive market as assumed in the theoretical section.[16]

By definition, the price per trip is equal to the price per ton times the number of tons 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 ton 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 and serves as a kind of guideline for both parties for setting up short- and long term contracts.[17]

[15] Evaluation of these criteria on the different models is shown in Appendix A.
[16] Bishop and Thompson (1992) apply a similar approach to show that their theoretical assumption of a competitive market is plausible.

Table 3: Estimation results for trip data.

Variable	Price per ton		Load factor		Price per trip	
Water level, 9 dummies	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
> 261	Reference category					
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 tons	0.253	0.017	0.240	0.013	- 0.744	0.018
1000 – 1500 tons	0.117	0.012	0.223	0.011	- 0.444	0.014
1500 – 2000 tons	0.080	0.014	0.128	0.011	- 0.292	0.015
2000 – 2500 tons	0.038	0.019	0.092	0.015	- 0.092	0.020
> 2500 ton	Reference category					
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 category					
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.

The effect of water level on the price per ton is the opposite of the effect on load factor. Note that the drop in load factor, as presented in Tables 3 and 4, is relative to the situation of ‘normal’ water levels, which we defined as water levels higher than 260 cm at Kaub.

[17] The IVTB also give guidelines for low water surcharges which can be used in negotiations. The IVTB state that usually at 240 or 250 cm water level at Kaub low water surcharges can be charged.

Table 4: Estimation results for day data.

Variable	**Price per ton**		**Load factor**		**Price per trip**	
Water level, 9 dummies	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
> 261	Reference category					
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 tons	0.241	0.038	0.229	0.032	- 0.632	0.045
1000 – 1500 tons	0.120	0.028	0.251	0.024	- 0.297	0.034
1500 – 2000 tons	0.068	0.030	0.124	0.026	- 0.152	0.037
2000 – 2500 tons	0.019	0.051	0.083	0.042	0.010	0.061
> 2500 ton	Reference category					
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 category					
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.

Given normal water levels, the average load factor is 84%. The drop in load factor has to be regarded relative to this percentage. In Table 5 we derived the average prices per ton, load factors and prices per trip for an average ship at the different water level intervals based on the estimates reported in Table 3. We see that in the lowest water level interval an average ship uses less than 50% of its capacity. The estimated effect on the price per ton more or less offsets the reduction in load factor, as we can see in the column for price per trip.

Table 5: Estimated prices per ton, load factors and prices per trip

Water depth Kaub (cm)	**Estimated price per ton 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 ton and price per trip but does not affect the load factor. The effect of vessel size on price per ton 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 ton and price per trip while there is no increase 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 backhaul indicates that trips upstream on the Rhine with destinations at the Danube have a relatively large increase in price per ton 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 ton 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 3 and 4.

Let us define α as the logarithm of the vessel size in tons. The marginal effect of water level on the logarithmic price per ton 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 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 ton is less than for large ships. For large ships the increase in price per ton 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 6, a decrease of water level with one centimetre leads to an increase of 0.654% of the price per ton for vessels of 3000 tons. For a ship size of 1507 tons, the increase in price per ton exactly offsets the reduction in load factor. The interaction effects will be ignored in the welfare analysis as these are secondary.

Table 6: Marginal effect of water level on dependent variables

Dependent variable in logarithm	**Ship size (in tons)**			
	500	**1000**	**3000**	**5000**
Price per ton	-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 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 7. The results in Table 7 suggest that bargemen take into account future water levels when determining the load factor of their ships in periods of low water levels.

Table 7: Significance of coefficients for lead values of water level at the 5% 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 ton	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).

However, future water levels do not seem to play a role in determining the price per ton. We find that the total effect of water level (the sum of the different water level effects) in the estimations underlying Table 7 is about the same as in Tables 3 and 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 3.1 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 freight price per ton. Furthermore, in non-Kaub areas, freight prices per ton 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 ton in North Germany can be observed[18].

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 (Table 11), 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 dataset that contains trips of inland waterway vessels between beginning 2003 and mid 2005. The average price

[18] Note that we do not have the water levels in these canals at our disposal, but it is likely that these water levels strongly correlate with the water level at Kaub.

per ton of all trips made at normal water levels is € 7.53 and at low water levels € 9.39. The coefficients in Table 3 (trip data) are used to calculate the price increase at each water level interval.

Estimates of the price elasticity of demand (ε) for inland waterway transport are mainly found in North-American literature. Table 8 gives an overview.

Table 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.

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 one 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 ton has to rise substantially before other transport modes become competitive and modal shift effects are expected to be small. 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% 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.[19]

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 *daily* price per ton[20] controlling for a number of explanatory variables. 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[21]. Also distance is likely to be valid, 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 validity of the instruments is empirically confirmed. We have experimented with a range of control variables, and the results are quite insensitive to the inclusion of control variables.

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

[20] A Hausman test showed that the logarithm of the daily price per ton is endogenous.

[21] If we only use water level as an instrument we are not able to test the validity of this instrument. The drawback of the instrumental variable analysis with two instruments however is that the validity of the instrument distance is somewhat questionable. A Sargan test showed that water level and distance together are valid instruments.

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 3 shows the annual welfare loss for the period of 1986 to 2004 using an elasticity of -0.6.

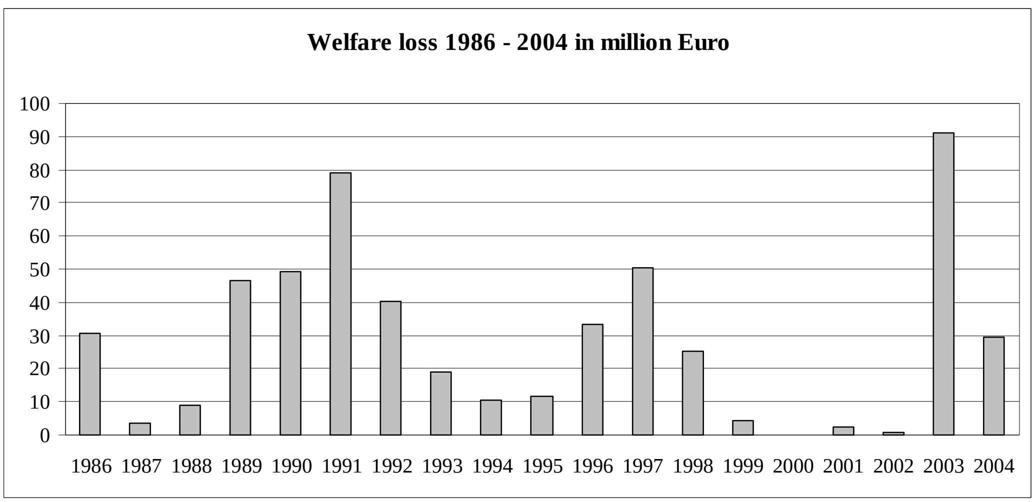

Figure 3: Welfare loss due to low water levels affecting inland waterway transport via Kaub. The results are based on data from the Vaart!Vrachtindicator and (CCNR, 2005; 2002; 2000).

The current study is the first to focus on freight 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 to the turnover in the Kaub related Rhine market of about € 680 million[22] the welfare loss in 2003 is about 13%. 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 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 tons) is comparable to that of the Kaub related market (80 million tons). Other attempts to estimate the costs for inland waterway transport due to low water levels are performed by Millerd (2005) and Marchand et al. (1998). They use simulation models that minimize transportation costs on the Great Lakes in North America. We emphasize that the current study is based on observed prices in the market.

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% less. This indicates that the size of the welfare loss is rather insensitive to the chosen elasticity.

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

[22] The annual amount of cargo transported through the Kaub related Rhine market is about 80 million tons. The average price per ton for all journeys in the dataset that pass Kaub is about € 8.50.

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.[23]

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-Western Europe. This also implies that there are other locations at the Rhine where welfare losses occur.[24] 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.[25] This implies the existence of a positive producer surplus that reduces the welfare loss presented here. In an

[23] € 91 million – (0.11 * € 91 million) = € 81 million.
[24] For instance, inland waterway vessels that navigate from Rotterdam to Andernach, situated north of Kaub, may suffer from load factor restrictions caused at Cologne.
[25] 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

empirical analysis not shown here, it appears however that the number of empty kilometres does not relate to low water levels. We do not have information about waiting and loading times so the impact of these factors cannot be analysed.

In the introduction it was mentioned that estimating the annual welfare loss of low water levels can give an indication if investment in projects that aim to make inland waterway transport more robust to low water levels is economically sound. We estimated an average welfare loss of € 28 million a year. This does not mean that investments to solve the low water level problem at Kaub may maximally cost € 28 million a year. After all, if the bottleneck at Kaub is solved, there will be another location at the Rhine that determines the minimum load factor and that will cause a certain welfare loss.[26]

6 Conclusion

In this paper, we studied the effect of water level on freight prices per ton in inland waterway transport and consequently on welfare. For our estimation, several characteristics of inland waterway transport on the river Rhine were taken into account. The effect of water level on freight price per ton was found to be negative. The effect on the load factor is positive and on the price per trip no effect was found. We derived an annual average welfare loss of € 28 million due to low water levels on the river Rhine for the period of 1986 to 2004 for all waterway transports that passed the current bottleneck Kaub. The welfare loss in 2003 of € 91 was much higher due to

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enter the Kaub related inland waterway transport market to sufficiently cut down the price per ton, and thus the producer surplus is positive.

[26] This can be illustrated by an example. Suppose that if the load factor restrictions at Kaub are solved, Östrich is the next bottleneck. Let's assume that low water levels at Östrich cause an average annual welfare loss of € 15 million. Then the investment to eliminate the welfare loss of € 28 million caused at Kaub must be less than € 13 million.

a very dry summer. In the light of the observation that 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.

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Appendix A

Table 9: 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 and SIC. [27] 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 10: 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

Table 11: Annual amount of cargo that passes Kaub[28] (x 1000)

Year	Tons 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).

[27] AIC = Akaike information criterion and SIC = Schwarz (or Bayes) information criterion.

[28] The figures for 1986 – 1996 are approximated using an index for the transported annual amount of tons on the Rhine. The figures for 1997 – 2004 come from CCNR (2002, 2000, 1998).

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