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Modeling the impact of the River Information Services Directive on the Performance of inland navigation in the ARA Rhine Region

Edwin Verberght[1]
Department Transport and Regional Economics, University of Antwerp, Belgium.

Yasmine Rashed[2],[3]
College of International Transport & Logistics, Arab Academy for Science, Technology & Maritime Transport, Egypt
&
Hapag-Lloyd Center for Shipping and Global Logistics (CSGL), Kuehne Logistics University, Hamburg, Germany.

Edwin van Hassel[4]
Department Transport and Regional Economics, University of Antwerp, Belgium.

Thierry Vanelslander[5]
Department Transport and Regional Economics, University of Antwerp, Belgium.

River Information Services (RIS) are harmonized digital services that support safety, transport and traffic management in the inland navigation. RIS refer mainly to four key technologies such as Vessel Tracking and Tracing (VTT) with onboard Inland Automatic Identification System transponders (Inland AIS), Electronic Reporting International (ERI), Notices to Skipper (NtS) and Inland Electronic Chart Display and Information System (Inland ECDIS). These key technologies were developed during the nineties and received in Europe a regulatory framework through the Directive EC/2005/44 (the RIS-Directive). In 2009, most EU Member States

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[1] A: Prinsstraat 13, 2000 Antwerpen, Belgium E: edwin.verberght@uantwerpen.be

[2] A: El Moshir Ismail St., 2033 Elhorria, Cairo, Egypt E: yasmine.rashed@aast.edu

[3] A: Groβer Grasbrook 17, 20457 Hamburg, Germany.

[4] A: Prinsstraat 13, 2000 Antwerpen, Belgium E: edwin.vanhassel@uantwerpen.be

[5] A: Prinsstraat 13, 2000 Antwerpen, Belgium E: thierry.vanelslander@uantwerpen.be

had implemented the Directive. One of the claimed benefits of the implementation of RIS relates to a growing performance of inland navigation. In this paper, the impact of RIS on the performance of inland navigation is analyzed via a structural break cointegration approach, followed by an Error Correction Model (ECM) estimation. The empirical analysis shows that the performance of the dry bulk market is highly dynamic, while the liquid bulk market is moderately responsive to shocks. The structural break analysis could not capture any effect of the Directive on the performance of both markets, which can be attributed to several factors, such as the difficulty to isolate the policy impact, other drivers of variation, interferences of other policies and changes at the demand side.

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1. Introduction

The inland waterway transport in the Rhine region plays a crucial role in the transport of bulk cargo. The past decades, inland waterway transport (IWT) services became more digital because of the implementation of policies concerning River Information Services (RIS).

RIS policy has been focusing so far on four key technologies: (1) Vessel Tracking and Tracing (VTT), (2) Electronic Reporting International (ERI), (3) Notices to Skipper (NtS) and (4) Inland Electronic Chart Display and Information System (Inland ECDIS). In order to support the inland waterway transport with a goal to enhance safety, efficiency and environmental friendliness and to facilitate interfaces with other transport among the EU Member States, the RIS Directive (EC/2005/44) was developed. The RIS Directive was published in 2005 and targeted full implementation in 2007. However, Member States implemented the RIS Directive on average in 2009. The delay in implementation can be partially explained by the fact that Member States needed more time to allocate means to build sufficient RIS centers in order to fully implement the Directive and the RIS key technologies. Nevertheless, a significant part of the European fleet still needed to acquire RIS devices, in order to make the implementation of the Directive more complete.

One of the expected benefits of RIS is that they improve the competitive position of inland navigation (i.e. an increase in growth of cargo transported via inland waterways) due to a better integration of inland navigation in the logistics chain (Ten Broeke et al., 2001; Muilerman, 2006;). This can also happen in urban contexts (Durajczyk et al., 2021). RIS are said to contribute to traffic management and to reduce waiting times at locks and terminals. In the latter case, there is currently a growing problem at terminals in seaports, where waiting time for IWT barges increases. This is mainly caused by the priority handling of seagoing vessels. Barges can only commence operations if the quay is free. Other modes do not have that specific problem. Inland RIS can contribute and improve compatibility between digital mode systems (in this example maritime and IWT) and a more integrated traffic management for both of these flows at the terminal side. The most significant diffusion of RIS key technologies lies in the Rhine region, which has the most dense inland navigation traffic and largest registered fleet in Europe (IVR Annual Report, 2017).

In this paper, the research objectives are formulated as: (1) to investigate the drivers of the IWT market performance; (2) to construct and estimate the market dynamics, considering the specific demand and supply market drivers for both the liquid and dry bulk markets, specifically, the existence of a long-run IWT performance equation; and (3) to examine, whether the RIS directive has an impact on the IWT performance. The main research question that will be addressed in the paper is:

Did the RIS Directive have an impact on the performance of the inland navigation market in the ARA Rhine region?

In order to study the impact of policies, both the supply and the demand factors are modelled, separating the dry and liquid bulk markets. In order to measure the possible impact of the RIS Directive on IWT in this article, possible changes in performance expressed in tonne.kilometer (tkm) are analyzed for both the dry and liquid markets.

Following the introduction presented in this section, Section 2 gives an overview of the European IWT sector and how the RIS directive was developed to support the sector. Section 3 provides the state-of-the-art of RIS and other information technology in IWT, along with the institutional setting of the RIS Directive. Section 4 deals with the research methodology adopted in this paper to measure the dynamic interaction of the total performance expressed in IWT tkm. The empirical analysis is conducted in Section 5. Finally, Section 6 comprises the discussion and conclusions.

2. Setting of the European IWT sector

One of the largest challenges for transport policy makers is to reduce the negative external effects of freight transport and to support a more sustainable transport network, such as IWT and rail transport. As shown in Figure 1, the transport in the European Union has grown from 1996 to 2017. Moreover, road congestion will become a larger problem if the modal split does not change. Road congestion reportedly costs the EU around EUR 130 billion a year (or 1% of GDP) (European Union, 2017).

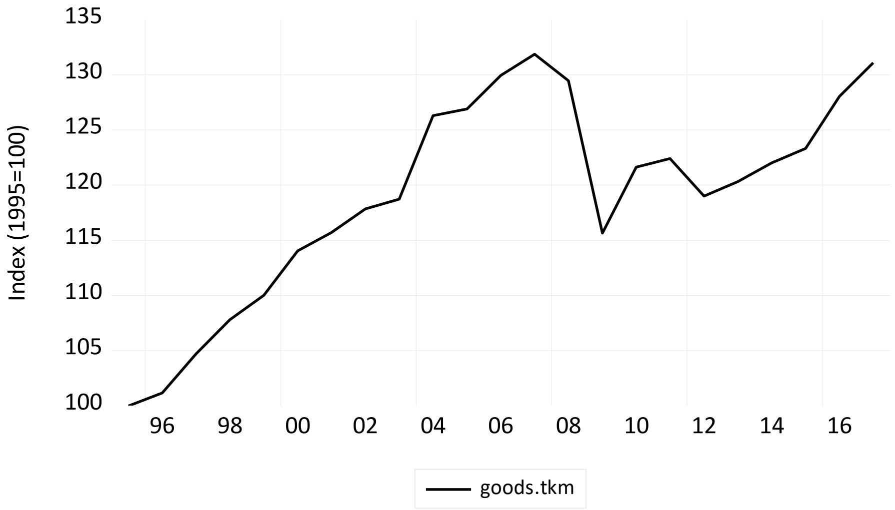

Figure 1. EU-28 Total freight transport performance 1995-2017 (road, rail, IWT & pipelines). Source: Based on data retrieved from European Commission (2019).

The EU's inland waterway network stretches for around 37,000 kilometers and connects seaports, cities and industrial centers across Europe (European Commission, 2018). Inland waterway transport represents a sustainable alternative (Inland Navigation Europe, 2014). Despite several modal shift policies, road haulage remains dominant in the EU-28 and even increased between 1995 and 2017 its performance by 45% (Figure 2) and its modal share by 6%, mostly at the expense of railways (European Commission, 2019). Road haulage had a mode share of 73.3% in 2017 as compared to 16.5% for rail transport, 5.8% for inland navigation and 4.5% for pipelines. Figure 2 shows roughly a consolidation for the IWT mode share during the period 1995-2017, but closer examination shows an increased performance of 20.4% in tkm for the same period. The mod split in the EU remains virtually unchanged between 2001 and 2015.

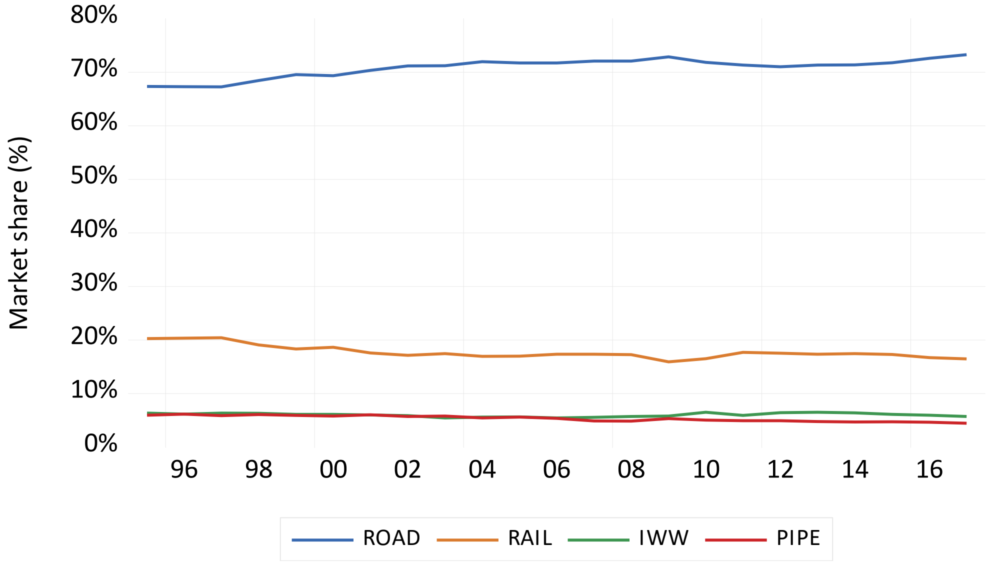

Figure 2. Figure 1: EU-28 Modal split 1995-2017. Source: Based on data retrieved from European Commission (2019).

However, when looking at the evolution of the performance of IWT, an increase is noticeable in some European countries such as Romania and Belgium. The sector shows some kind of seasonal variation because of returning periods of low water on major rivers such as the Rhine, which temporarily complicates freight transportation.

Based on the dataset of IVR (2017), it can be concluded that the following categories of IWT ships are present in the European waterways: general cargo ships, freight push barges, tank vessels and cruise ships. Considering the business structure of IWT ships, most European IWT companies are small- and medium-sized enterprises (SMEs) with only one vessel and where often vessel owners are the actual operators on board. Around twenty thousand registered vessels are active on the European inland waterways (IVR, 2017).

IWT alone uses around 17% of the needed energy for road haulage (per tonne-km) and 50% of rail transport (per tonne-km). It also creates significantly less noise emissions (European Commission, 2020a).

Safety is another critical advantage of IWT. For instance, it has a lower number of accidents, particularly in the transportation of dangerous goods, when compared to other modes. Around 75% of EU IWT is across national borders, which underlines the importance of harmonizing the exchange of information and to support overall interoperability of systems along Europe's inland waterways (European Commission, 2017).

In order to improve the further usage of inland waterway transport and to improve the digital innovation in the IWT the European commission developed the RIS directive. The RIS supports navigation on the inland waterway network, is looking to enhance safety in inland ports and rivers, as well as the efficiency of navigation and calamity abatement processes, the better utilization of existing infrastructure, and increased integration of inland waterway transport into multimodal supply chains via the timely provision of relevant information[6]. In the next section, this RIS is explained in more detail.

3. River Information Services

This section provides more details of the key technologies of RIS and the relatively complex institutional setting. Section 3.1 explains the importance of RIS and Section 3.2 shows the institutional setting behind the RIS Directive.

3.1 Information technology in IWT

RIS, as foreseen in the Directive, aim at contributing to a safe and efficient transport process and utilizing the inland waterways to its fullest extent. RIS are already in operation in manifold ways and key technologies such as Inland ECDIS and Inland AIS became more and more mandatory the past five years on the Rhine. RIS are also a generic term for all individual information services to support inland navigation in a harmonized way. The RIS framework is provided by public and private actors. RIS centers are mostly run by public actors such as waterway managers, while the on-shore and on-board equipment is developed and sold by private companies.

Within the RIS framework, a number of projects and pilots have been developed at the European, national and regional levels. The RIS geographical scope is divided in areas, which all have a RIS center that monitors the area and sends out Notices to Skippers (NtS), which can contain weather reports, waterway depth, calamities and maintenance activities (bridges and locks).

Further transport digitalization is still important for four main reasons (European Commission, 2017):

- to improve navigation and traffic management (e.g. locks and bridges; terminals);
- to efficiently integrate IWT with other transport modes or logistic activities (e.g. synchromodality);
- to enhance safety (calamity abatement management); and
- to reduce the administrative burden (e.g. more efficient and effective law enforcement).

The IWT comprises various categories of interrelating actors, which can be divided in three groups:

1. service users (shippers and logistics service providers);
2. sector or service providers (barge owners, operators, terminal operators) and
3. public actors such as fairway managers or port authorities (infrastructure and traffic management).

Communication between these actors is vital to guarantee a reliable (on-time), safe and continuous flow of goods. Within this complex reality, logistics solutions that support synchronized processes and communication are of utmost importance. As shown in Figure 3, shippers look for supply chain management solutions to optimize their production activities by predicting their stock size of production materials. These solutions include an easier access to operators, improvements on the overall efficiency of the supply chain and bundling of multiple shipments.

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[6] See https://ris.cesni.eu/

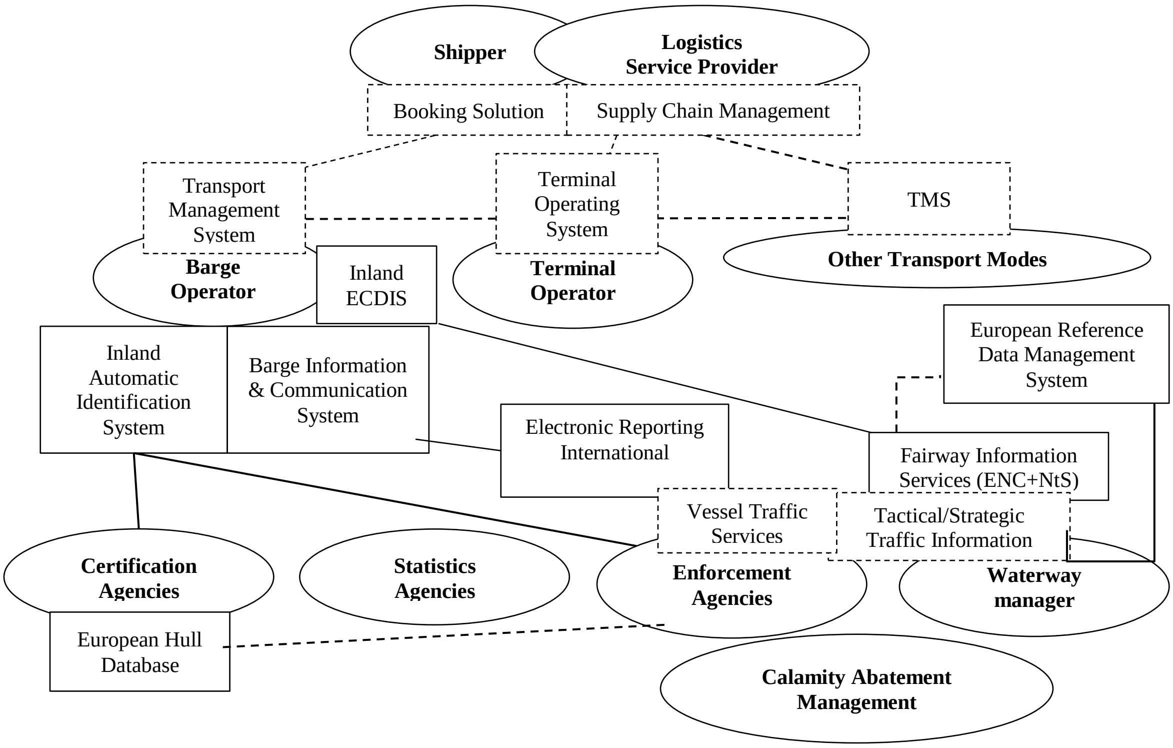

Figure 3. Current state of digitalization in IWT. Source: European Commission (2017), pg.32, The dotted lines indicate mandatory systems/technologies/data exchanges which are widely implemented and used; the dotted lines indicate systems/technologies/data exchanges used by some actors

Advantages of RIS for inland waterway freight transport, are also recognized by Durajczyk and Drop (2021) by their research on the potential application of IWT between Polish cities and the role of River Information Services (RIS) as facilitator. They conclude that RIS enables inland navigation to be fully integrated into the intermodal supply chains in urban agglomerations and allows for better planning of urban freight transport. According to de la Vega et al. (2020), RIS harmonizes information services to aid traffic and transport management, improves safety, mode efficiency, and even optimizes IWT. The implementation of RIS services can improve the efficiency of vessel usage with applications for trip planning, thus decreasing operating costs (Niedzielski et al., 2021).

The logistics service provider (LSP) plays a vital role in organizing the reliable flow of goods to or from its customers and optimize the choice of transport mode(s).The procurement of e-documents and the provision of additional accurate data concerning cargo and transshipment procedures, next to linking a compatible terminal operating system (TOS) with a transport management system (TMS), could stimulate and improve the organization of transport and especially IWT in the supply chain. Furthermore, electronic documents lower the transaction costs of operators, who are still often obliged to write paper reports for authorities and other mandatory declarations (e.g. vessel clearing at border crossings). With the upcoming development of automated vessels, further RIS development and digitization (e.g. e-documents) could prove essential success factors for automation and even autonomous vessels.

Figure 3 also mentions 'Statistics'. The quality and available quantity of IWT statistics is lower as compared to other modes of transport. RIS can be used to improve the quality and quantity for IWT and thus provide more knowledge for policy makers, researchers and IWT enterprises if, of course, RIS data is properly collected.

To summarize, there are four integrations as considered by the Commission (European Commission, 2017). Firstly, the vertical integration between customers and operators within the supply chain by using barge booking systems and transparent exchange of data concerning cargo status, track and trace and the calculations of the estimated arrival time. Secondly, the horizontal integration between barge operators and ports and terminal operators to reduce waiting times for berthing and commence (un-)loading procedures. Thirdly, operational integration, where barge operators exchange information concerning the fairway and infrastructure with the fairway managers and vice versa. And finally, the administrative integration concerning e-IWT, law enforcement, calamity abatement management, data collection, etc. In all types of integration, real-time data and a centralized database are needed concerning cargo, route, crew and vessel data, next to governance to address privacy and cybersecurity challenges, and to share across Member States (which could be cloud-based technology). These four integrations of digitalization could lead, according to European Commission (2017), to cost reduction for both shipper and, as a result of that also to the skipper. Finally, cost reduction could in its turn attract more volumes to IWT from road transport, stimulating a modal shift.

3.2 Institutional Framework for RIS Directive

The RIS Directive does not operate in isolation. A range of institutional actors at the international level (UNECE[7], PIANC committee[8], River Commissions CCNR, Danube Commission, Sava Commission, and Mosel Commission) play a role in the development and implementation of RIS in Europe. They all strive to harmonize technical RIS specifications in Europe (Panteia, 2014, pg.31), but can differ in vision. This complex structure shows how difficult it is to come to a common and generic approach to develop the RIS Directive.

The European Union allocates co-funding for several RIS projects and pilots. In addition, Member States are involved through different platforms and expert groups, including the four official RIS Expert Groups, which are tasked with the development and updating of the technical specifications for the different RIS technologies[9]. These are envisaged to be integrated through the recently established CESNI[10] working group on information technology (CESNI/TI)[11].

There are also RIS expert groups within branch organizations such as the IWT platform[12] uniting the ESO[13] and the EBU[14]. Since the publication of the RIS Directive, the institutional framework of IWT has changed with the enlargement of the EU (more Danube riparian Member States), rapid technological developments and new challenges (e.g. privacy and big data). Between the institutions, much more collaboration is being structuralized and formalized, such as the mentioned CESNI. The actual RIS institutional setting is shown in Figure 4.

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[7] The United Nations Economic Commission for Europe (UNECE) has resolutions for international standards for tracking and tracing, ERI, NtS and guidelines for Vessel Traffic Services (VTS), RIS in general, and Electronic Chart Display Information Systems.

[8] The Permanent International Association of Navigation Congresses (PIANC) is known for the RIS guidelines

[9] Expert Group on Electronic Chart Display and Information Systems (ECDIS); Expert Group on Electronic Reporting International (ERI); Expert Group on Notices to Skippers (NtS); and Expert Group on Vessel Tracking and Tracing (VTT).

[10] Comité Européen pour l'Élaboration de Standards dans le Domaine de Navigation Intérieure-CESNI.

[11] CESNI/TI was established in June 2019 and its activities thus fall outside of the scope of the present study.

[12] The Inland Waterway Transport Platform is an organization in which ESO and EBU are cooperating in a more structured way.

[13] European Skippers Organisation (ESO): branch organisation that represents the interest of independent vessel owners / operators and national organisations.

[14] European Barge Union (EBU): branch organisation that represents the interests of freight brokers and some larger IWT companies with multiple vessels.

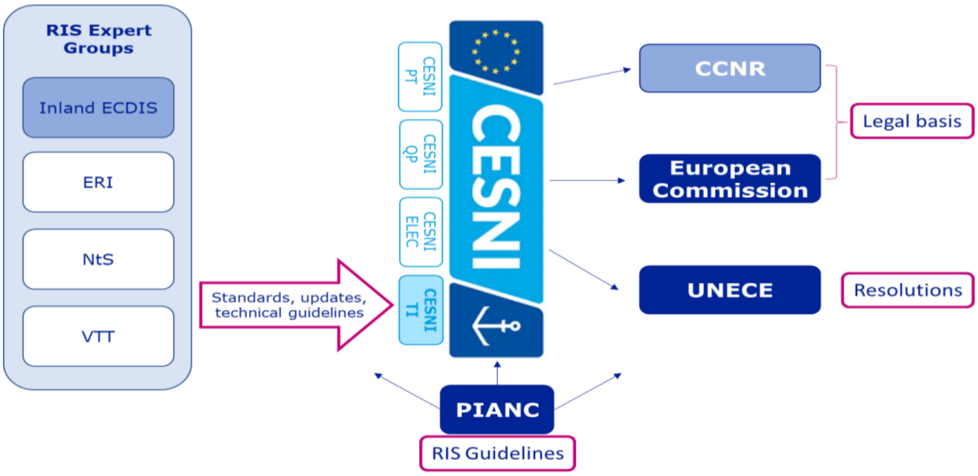

Figure 4. Institutional RIS environment. Source: European Commission (2020b)

Figure 4 shows the RIS Expert Groups that are divided according to the four RIS key technologies, each with their own terms of reference. They work rather independently of supranational organizations such as the EU or the CCNR to a certain extent. These expert groups propose standards, technical documents, guidelines and other documents, in addition to the input they deliver to the RIS Index to all institutions. Currently, they have been integrated in the framework of CESNI/TI, which is the new reference for standards for upcoming Directives from the European Commission and the CCNR.

After describing some of the current IWT challenges, the RIS Directive and the implementation of the four key technologies within a complex European institutional setting, the following section dives into the research methodology and the applied modelling approach to analyze the IWT sector and the impact of the RIS Directive on the IWT performance.

4. Research Approach

Modelling of the IWT freight market is faced by many challenges. Firstly, there is no rigorous time series studies or economic theories, that we may rely on and use as a base for the model. Secondly, the freight market is heterogenous, each type of cargo has different market drivers, and consequently, disaggregate models are to be used. A third challenge is the problem of sources and limitation of data for the IWT market.

The applied methodology builds on the Error Correction Model (ECM), which is used in van Hassel and Rashed (2019) and avoids spurious regression caused by the nonstationary nature of the time series. The ECM provides a tool to test for the cointegration relationship between the variables and the long-run relationship in the market. A cointegration relationship implies that, although the variables are not stationary, there exists a stable long-run relationship that could be modelled. A structural break test based on Phillips and Perron (1988) and Gregory and Hansen (1996), is conducted to measure the impact of the RIS Directive and other breaks. Hence, the ECM provides an estimate for the short and long run dynamic relationships in the market. The visual inspection may suggest the existence of structural break(s) that may be incorporated in the ECM as an exogenous variable. To construct, estimate and validate our model, the following three steps are applied. The first step is used to identify the breaks in the series and testing the impact of the RIS Directive. The cointegration relationship is tested and the ECM is constructed and estimated in step two. Finally, step three tests the model for stability and robustness.

Step one, testing for structural break. Bai (1997) and Bai and Perron (1998) developed a comprehensive test (BP henceforth), which allows for multiple unknown breakpoints as in Equation 1 The apply a multiple regression model with T periods and m potential breaks, resulting in an m+1 regime. For the observations $T_j, T_j + 1, \dots, T_{j+1} - 1$ for regime j, we have the regression model:

$$y_t = X_t'\beta + Z_t'\gamma_j + \varepsilon_t, \text{ for j=0, …, m.} \tag{1}$$

Where X is a matrix of regressors whose parameters are regime-invariant, while Z is a matrix of regressors whose coefficients are regime-specific. The multiple breakpoint tests are broadly divided into three categories of tests: tests that use sequentially-determined breakpoints, tests that employ global maximizers, and hybrid tests that combine the first two methods. The optimal number of breaks (m-1) is evaluated based on the optimal break that gives the lowest sum of squared residuals.

Step two, construct the ECM. In order to construct the ECM, the following sub-steps are taken:

1. Testing the stationarity of the variables using the Augmented Dicky-Fuller Test (ADF) (Dickey and Fuller, 1979) and Phillips-Perron (PP) (Phillips and Perron, 1988). This is necessary to avoid spurious or misspecified regression.

2. The identification of the lag length is determined by estimating a Vector Autoregression (VAR) model at a level where two tests are considered: the VAR Lag Order Selection Criteria and the VAR Lag Exclusion Wald Tests.

3. If all variables are integrated of degree 1, i.e. [I(1)], then a test is conducted for the cointegration relationship using the Johansen (1988) cointegration test and the two-step residual-based procedure of Engle and Granger (1987). The critical value for the small sample is calculated based on the response surface regression in MacKinnon (1991), with a functional form as in Equation 2.

   $$\widehat{C}\,(p,T) = \hat{\beta}_\infty + \hat{\beta}_1 T^{-1} + \hat{\beta}_2 T^{-2} \tag{2}$$

   Where $\widehat{C}\,(p,T)$ denotes the estimated critical value for a test at the p per cent level, when the sample size is T. The β's are estimated parameters, based on simulation experiments obtained from the response surface estimates (MacKinnon, 2010).

4. Apply the Gregory and Hansen (1996) Structural Breaks Cointegration Test (GH henceforth) to focus on a regime shift in the cointegration relationship. The GH test was developed to identify any regime shift in the existence of series' long-run relationship for three settings; within a level shift, a level shift with trend (slope changes) and a regime shift (structural changes in both level and slope coefficient).

5. Estimate the ECM in a natural logarithmic form that enables the interpretation of the coefficients such as elasticity and include the dummy variables as exogenous variables (Banerjee, Dolado, Galbraith, and Hendry, 1993, pp. 50-52).

In step two, we use more than one test to ensure the validity of the model, given the data availability limitation that resulted in a small sample size (n=27).

Step three, applying diagnostic tests to analyze the validity and robustness of the model. To ensure that the model adequately describe the data, diagnostic tests are applied. The residual diagnostic tests (Breusch-Godfrey Serial Correlation LM Test) is applied to ensure the unbiasedness of the regression coefficient. The test result did not reject the hypothesis of no serial correlation up to order 6. The variance inflation factor (VIF) test is applied to test for the multicollinearity between the independent. The test result showed in Table A.8 shows that the VIF are below 5, therefore the independent variables are not correlated. To test for the model stability, the cumulative sum of squares test (CUSUM) showed in Figure A.1 a stable function (Brown et al., 1975). The tests applied in this step indicate the validity and robustness of the model.

5. Empirical analysis

The dataset includes time series between 1991-2017 (27 annual observations). The dependent variable is the performance of IWT (tonne.km), accounting for the fluctuations of the demand and supply factors. The development of the IWT performance is caused by multiple effects such as economic growth, industrial production, fleet size and other factors which depend on the cargo type. Accordingly, different drivers affect the bulk market, therefore, the bulk market is analyzed into two disaggregate markets; liquid and dry bulk markets. As shown in Figure 5, the visual inspection suggests few structural breaks.

(a) Dry bulk time series (b) Liquid bulk time series

Figure 5. Time series and trend breaks in the IWT bulk sector in ARA-Rhine Region[15].

In Figure 5a, the dry bulk series show a sharp decline in 1995 which is attributed to the demolition period between 1994 and 1996. The demolition of barges impacted on the fleet size significantly. Furthermore, there was a moderate decline in 2003 below the average trend due to low water levels, which caused a decrease in transport performance. This was followed by a sharp decline in 2009 attributed to the financial crisis that affected the global markets.

In Figure 5b, the time series of the liquid bulk market are highly volatile: a continuous increase during 1991-2003 characterized by fluctuations over an increasing trend; a sharp increase in 2010 that is attributed to the stocks that were built up due to low oil prices; on top of that, also the low prices of other chemical products result in increasing trade and consequently, the demand for transport.

Due to the heterogeneous nature of the factors affecting the IWT sector, two markets are analyzed separately using the 3-step procedure in Section 4: (1) the dry bulk market in Section 5.1; and (2) the tank barge market in Section 5.2.

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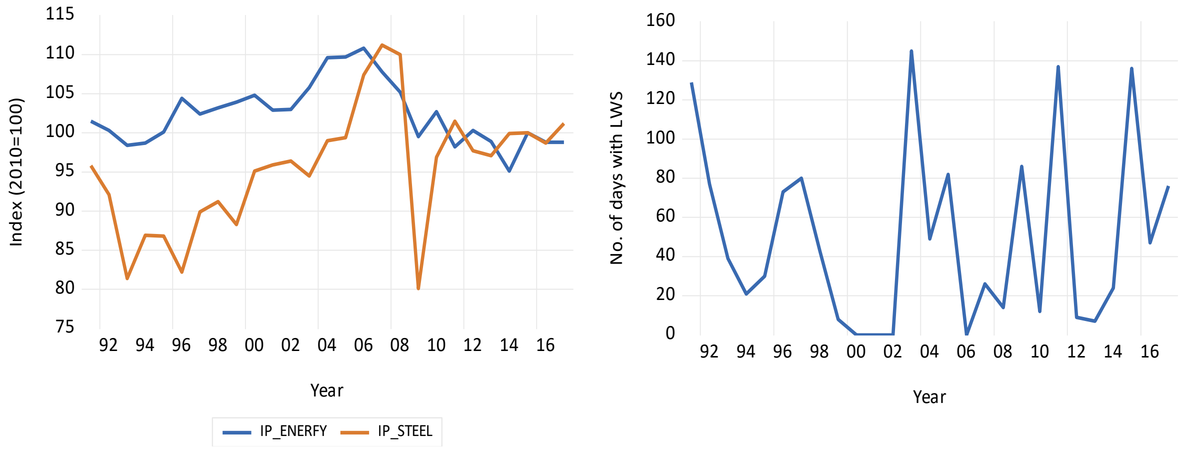
[15] ARA is short for Antwerp-Rotterdam-Amsterdam and covers all the waterway activities in and between these major ports

5.1 *Analysis of the Dry Bulk Market*

The analysis for dry bulk includes both the supply and demand factors. The demand for the IWT dry cargo transport is determined by the industrial production of the steel and the energy sectors. These sectors need coal and iron ore, which are the major bulk freight categories that are transported with IWT dry cargo barges. The development of both the industrial production of the steel and energy sector is given in Figure 6a. Figure 6b shows the days per year when a low water surcharge has to be paid and consequently a higher freight rate is to be paid by the shippers if they want to charter an available dry cargo inland barge.



(a)

Industrial production of steel and energy (b) Low water surcharge

Figure 6. Dry bulk supply and demand factors. Source: based on data of Eurostat (2019) (left), and CCNR (2018) (right)

For the dry cargo market, the three-step procedure as illustrated in Section 4 is followed. The structural break investigation using BP multiple breakpoint using the null of no breaks against an alternative of *l* breaks. As indicated by the test and as shown in Table A.1., the years 1995, 2009, and 2010 are suggested. However, the visual inspection and industry survey indicated that the two main impacts are in 1995 and 2009, where it reflects an additive break in the supply side due to high scrapping and the 2009 global financial crisis that caused a shift in the level without impacting the trend, respectively.

The following notations and variables are used, defined as:

- LN: the natural logarithm;
- Δ: denotes the first difference;
- DRY −TON.KM$_t$: the total dry bulk performance in tonne.km for Belgium, Germany and the Netherlands at time t;
- IP-STEEL$_t$ = the industrial production of related steel products at time t (index, 2010 = 100);
- D-LWS t = the number of days for which a low water surcharge needs to be paid;
- IP-ENERGY$_t$ = industrial production of energy in north-western Europe at time t (index, 2010 =100);
- DUM$_{1995}$: a dummy to account for the supply adjustments during the demolition period (the impact is clear in Figure 5a);
- Dum$_{2009}$: a dummy to account for the financial crisis impact;

The unit root tests of ADF and PP shows that all the variables are integrated of degree one (See Table A.2). The lag length criteria selection indicates the use of one lag (see Tables A.3a and 3b).

To test for the cointegration relationship, the residual estimated from the level equation is stationary as shown in Table A.2 (resid_cointeg). The Johansen cointegration test shows that there is one cointegration relationship (see for the details of the cointegration test Table A.4 in the appendix). The Engle and Granger cointegration test using the Mackinnon critical values for small samples, calculated a critical value at 5% significance with T=25 and N=4, and with an outcome -4.6213, while the calculated t-statistics are -4.12 as shown in Table A.5. Therefore, the null hypothesis of no cointegration is rejected, as indicated in step 2.3-Equation 2.

The Gregory-Hansen (GH) cointegration, which is used in series' level long run equilibrium, shows that there is a structural break in 1995 with a level shift and no evidence of a regime shift (see Table 1).

Table 1. The Gregory-Hansen Cointegration test for 2 models

MODEL 2: Level Shift		MODEL 3: Level Shift with Trend	
ADF Procedure		**ADF Procedure**	
t-stat	-7.355.389	t-stat	-7.672.535
Lag	0.000000	Lag	0.000000
Break	1995	Break	1995
Phillips Procedure		**Phillips Procedure**	
Za-stat	-3.650.292	Za-stat	-3.729.140
Za-break	1996	Za-break	1996
Zt-stat	-7.563.355	Zt-stat	-7.916.371
Zt-break	1995	Zt-break	1995

This indicates that the 2009 financial crisis and the RIS directive had no impact on the dry bulk market performance, since the stochastic data generating process of the dry bulk market performance is explained by the other independent variables included in the model. For example, the 2009 financial crisis had an impact on the demand of steel and energy for production purposes that consequently had an implicit impact on the demand for the IWT transport of dry bulk. This is in accordance with the results in European Commission (2020b). Therefore, only the structural break of 1995 is included as exogenous variable in the long-run equation that could not be explained by the independent variables in the model.

The estimated structural break model is represented in Equation 3, building on Equation 1.

$$\Delta LN\ DRY\_TONKM_t = b_0 + b_1 \Delta LN\ IPSteel_t + b_2 \Delta LN\ IPEnergy_t + b_3 \Delta LN\ DLWS_t + \lambda\ ect_{t-1} \quad (3)$$

The ECM is estimated in a natural logarithmic form; hence, the coefficients can be interpreted as elasticities. The results for the ECM and the long-run models are presented in Tables A.7 and A.8, respectively. The error-correction term (ect) is defined by Equation 4, building on Equation 2.

$$ect_{t-1} = b_0 + b_1\ LN\ IPSteel_{t-1} + b_2\ LN\ IPEnergy_{t-1} + b_3\ LN\ DLWS_{t-1} + b_4\ DUM_{1995} \quad (4)$$

The model's fit is shown in Figure 7, which includes the actual and fitted dry bulk performance, along with the plot of the residuals. The R-squared indicates that almost 64% of the variation in the dry bulk market performance is explained by the model.

Figure 7. The Actual, fitted and error plots for dry bulk freight performance in IWT.

To validate the model: (1) both the autocorrelation function and the Augmented Dicky-Fuller test (ADF) show that the residual series of the estimated model is not serially correlated and stationary; (2) the Cumulative sum of squares (CUSUMQ) test shows that the model is robust since the CUSUMQ statistic falls between critical values at 5% as shown in Figure 8; and (3) the variance inflation factor (VIF) shows no multicollinearity since all the VIFs coefficients are less than 5, as shown in Table A.9 (see Gujarati and Porter, 2009, pg. 340).

The estimated ECM quantifies the effects of supply and demand factors of the dry bulk IWT market. The IP_STEEL and ect are highly significant at a 1% level, while the low water level is significant at 5%. The IP_ENERGY is not significant; however, it is significant for the cointegration test. The DAYSLWS is significant because in the short run the shippers do not have the opportunity to use other modes of transport other than IWT. Moreover, if the water levels are low, shippers pay more for the IWT service. Moreover, in the long run (more than one year), they could not change their behavior and shift to other modes that will be more expensive. The elasticity of the dry bulk performance with respect to the steel industrial production is equal to 0.67%.

The ect is significant and estimated at 0.76; which indicates a large immediate response to changes in the industrial production of steel, energy and when there is a low water level. The negative coefficient of the ect ensures that the long-run equilibrium is achieved. The adjustment toward equilibrium is not instantaneous, however, 76% of any annual deviation from equilibrium is incorporated into the next year growth rate of the dry bulk IWT performance.

5.2 *Analysis of the Liquid Bulk Market*

A model is developed to test for the policy change based on the ECM as developed in van Hassel and Rashed (2019) for the tank barge sector for the ARA - Rhine region in Europe. The analysis in this section shows that the model in van Hassel and Rashed (2019) could be improved by removing the GDP and including the different indices in the long-run equation. Similar to the analysis of dry bulk in Section 5.1, the same three-step procedure in Section 4 is followed.

In step one, the structural break technique of the Bai and Perron procedure is conducted and the results show that the breaks are in 1996 and 2002 as shown in Table A.9. The test results show that the 2009 RIS directive is not significant as a structural break in the performance of the liquid bulk market.

The following notations and variables are used, defined as:

- Δ: denotes the first difference;
- LN: the natural logarithm;
- LIQ − TON.KMt: the total performance of the inland tanker sector expressed in ton-kilometer for Belgium, Germany and the Netherlands at time t;
- BRENTt: the average Brent crude oil price per barrel in constant US dollars at time t;
- IPCHEMt: the industrial production of the chemical sector expressed in index numbers at time t;
- FUELTRADEt: the traded amount of fuels (gasoline and diesel) in the NL & BE in tonnes at time t;
- DUM1995−99: a dummy to account for the demolition rule period that had a negative impact on the fleet supply;
- DUM2002: a dummy to account for the sector liberalization; and
- DUM2009−16 LWS t: the impact of low water surcharge (LWS) at time t, which impacted on the sector from 2008 onwards. From 2008 onwards, the average size of the tank barge sector grew to 1,350 tonnes, which corresponds to inland vessels of 'CEMT class IV'. These vessels are affected by water level fluctuations, which implies that from 2008 onwards, on average, all tank barge vessels are affected. Before 2008, this effect was not as prominently present as from 2008 onwards.

In step two, in order to test for the cointegration relationship, the unit root test of ADF and PP is conducted (Table A.10). The test results show that the variables are integrated of degree 1 and only the variable LWS shows different results of the ADF and PP, hence the ADF test is selected. The VAR lag length criteria in Tables A.11a and A.11b, identify one lag length. Moreover, the Johansen cointegration test shows the existence of one cointegration relationship (Table A.12).

Based on the Engle-Granger two-step procedure, the residual estimated from the level equation is stationary as shown in Table A.10 (resid_cointeg). The Engle and Granger cointegration test, using the Mackinnon critical values for small samples, calculated a critical value at 5% significance with T=25 and N=4 with an outcome of -5.0407, while the calculated t-statistics equal -3.97 in Table A.14. Therefore, the null hypothesis of no cointegration is rejected, as indicated in step 2.3-Equation 2.

The Gregory-Hansen cointegration, which is used in series level long run equilibrium, shows that there is a structural break in 1995 and 2002 of a level shift with trend and no evidence of regime shift (see Table 2).

This reflects the demolition period and the liberalization of the sector, respectively. This indicates that the RIS directive had no impact on the regime shift of the liquid bulk market, since the stochastic data generating process of the liquid bulk market performance is explained by the other independent variables included in the model, similarly to the dry bulk market This is in accordance with the results of the study of the European Commission (2020b). Therefore, only the structural breaks 1995 and 2002 are included as exogenous variables, while the impact of low water level is included as an interaction variable in the long-run equation.

Table 2. The Gregory-Hansen Cointegration test for 2 models

MODEL 2: Level Shift		MODEL 3: Level Shift with Trend	
ADF Procedure		**ADF Procedure**	
t-stat	-5.431.341	t-stat	-6.045.533
Lag	1.000000	Lag	1.000000
Break	2002	Break	2002
Phillips Procedure		**Phillips Procedure**	
Za-stat	-2.278.540	Za-stat	-3.135.963
Za-break	1995	Za-break	1995
Zt-stat	-4.452.383	Zt-stat	-6.136.858
Zt-break	1995	Zt-break	1995

This reflects the demolition period and the liberalization of the sector, respectively. This indicates that the RIS directive had no impact on the regime shift of the liquid bulk market, since the stochastic data generating process of the liquid bulk market performance is explained by the other independent variables included in the model, similarly to the dry bulk market This is in accordance with the results of the study of the European Commission (2020b). Therefore, only the structural breaks 1995 and 2002 are included as exogenous variables, while the impact of low water level is included as an interaction variable in the long-run equation.

The estimated model is represented in Equation 5, again building on Equation 1.

$$\Delta LN\ LIQ\_TONKM_t = b_0 + b_1 \Delta LN\ BRENT_t + b_2 \Delta LN\ IPCHEM_t + b_3 \Delta LN\ FUELTRADE_t + \lambda\ ect_{t-1} \tag{5}$$

The ECM is estimated in natural logarithmic form; hence, the coefficients can be interpreted as elasticities. The error-correction term (ect) is defined by Equation 6, again building on Equation 2.

$$LN\ LIQ\_TONKM_{t-1} = b_0 + b_1 LN\ BRENT_{t-1} + b_2 LN\ IPCHEM_{t-1} + b_3\ LN\ FUELTRADE_{t-1} + b_4\ DUM_{1995-99} + b_5\ DUM_{2002} + b_6 DUM_{2009-16} LWS_t \tag{6}$$

The model's fit is shown in Figure 8, where the actual and fitted tank barge performance, along with the plot of the residuals, are shown. Estimates are displayed in Tables A.14 and A.15, where the short and long-run impact of the different variables on the transport performance of the tank barge sector in the ARA-Rhine region are given.

To validate the model: (1) both the autocorrelation function and the Augmented Dicky-Fuller test (ADF) show that the residual series of the estimated model is not serially correlated and stationary; (2) the Cumulative sum of squares (CUSUMQ) test shows that the model is robust since the CUSUMQ statistics fall between critical values at 5% as shown in Figure A.2; and (3) the variance inflation factor (VIF) shows no multicollinearity since all the centered VIFs are less than 5, as shown in Table A.16 (see Gujarati and Porter, 2009, pg. 340).

From the analysis (see Table A.16) it can be also observed that the $IPCHEM_t$, and the ect_t are significant at 1%. While, $BRENT_t$ is significant at 10%. The $FUELTRADE_t$ is not significant, which might be attributed to a stringer impact of the IPCHEM and BRENT changes that also impact on the trade.

The model's parameters are interpreted as follows: (1) the coefficient of IPCHEM is equal to 0.77, which indicates that if the chemical industrial production increases by 1%, the tank freight performance will increase by 0.77%. The BRENT and LWS have a negative sign, as expected. The coefficients equal −0.07 and −2.2, respectively. The coefficient of -2.2 (in Table A.17) for the low water surcharge indicates that an increase of 1% in the transport price due to the imposed surcharge for the low water level, will result in a decrease by 2.2% in the tank freight transport. This result is also in line with stating that low water levels curb the (tank) barge transport. The impact of BRENT is relatively small (elasticity of -0.07). This implies that an increase of the crude oil price will also lead to a reduction of tank barge transport. This can be explained by the fact that an increase in the fuel price will lead to a reduction of the demand for oil and oil-related products for the petrochemical industry.

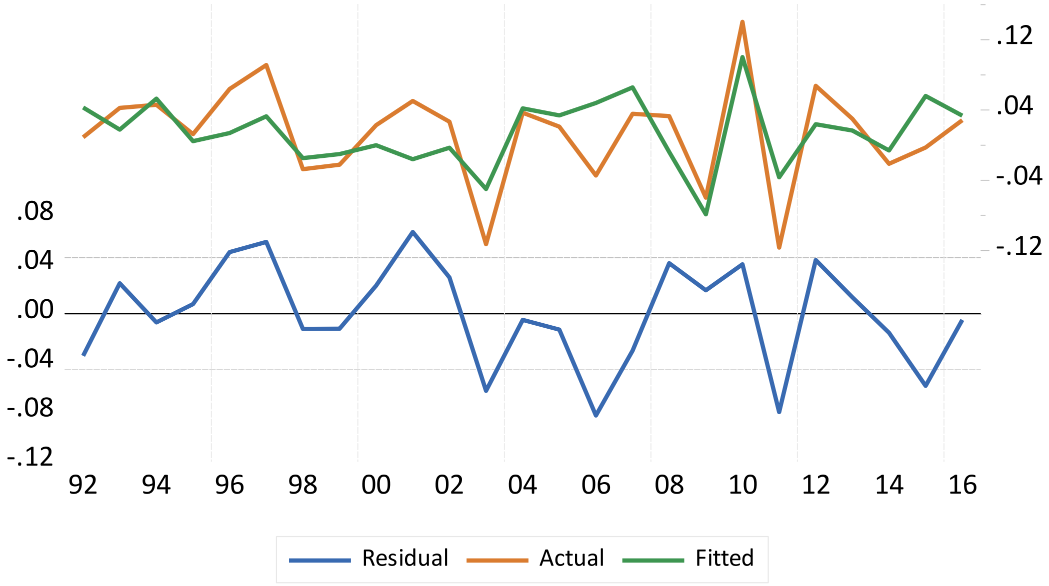


Figure 8. The Actual, fitted and error plots for tank barge freight performance in IWT

The ECM also shows the ect, where the coefficient (λ) = −0.56, and reflects the speed of adjustment to deviations from the long-run equilibrium as a result of any shock. This implies that almost 56% of the shock at time (t-1) is adjusted at time (t) i.e., the market corrects about 56% of all of its previous period disequilibria. Consequently, the market dynamics are moderate responsive and volatile to any shocks, even if they are temporary. Nevertheless, the market trend is expected to change if the shock is permanent.

6. Discussion and Conclusions

River Information Services are claimed to contribute to a more efficient inland navigation. In this article, the impact was analyzed of the European Commission's RIS Directive on IWT performance in the ARA Rhine region. The implementation of the Directive was tested using the Bai and Perron (1998) structural break test and the Gregory and Hansen (1996) Structural Breaks Cointegration Test that detected no significant impact.

Based on the ECM empirical model, the performance of both the dry and liquid cargo market is dynamic since the responsiveness and volatility to shocks estimated by the speed of adjustment is about 0.75 for the dry bulk market and 0.56 for the liquid bulk market (λ).

However, an important question remains concerning the reason why there is no significant effect found for the implementation of the RIS Directive. This could have two reasons:

1. there is an effect, but is not captured in the disaggregated models;
2. or, there was indeed no effect of the RIS directive on the performance of the IWT market.

The first reason could be attributed to factors such as:

- The fact that policy effects, even if significant, are typically very small and hard to isolate. This could come from the institutional complexity, which could lead to compromises which, in its turn, could impact the effectiveness of the implementation of the RIS directive. This means that the effect of "natural" fluctuations in IWT data on the ability to isolate RIS impact is difficult;
- Some countries were already more advanced with implementing RIS key technologies before the RIS Directive. This possibly explains additional major drivers of variation;
- The RIS Directive may have gotten interference of other IWT policies (e.g. concerning safety, environment...) and is also embedded in a larger IWT policy;
- The empirical analysis includes both the supply and demand factors in one mode, and hence, the policy impact in the supply side might be offset by other shocks in the demand side;
- Other modes of transport could have changed as much as IWT with respect to improved operation, integration in the logistics chain, increased safety, and reduction of administrative burdens. This possible effect is not taken into account.

The modelling work was concentrated on the Rhine riparian States and Belgium where RIS key technologies are deployed. The IWT traffic density in these countries is amongst the highest in Europe. Therefore, it was expected, if there would be any significant impact of the RIS directive noticeable in Europe, this must be in these countries. However, it needs to be mentioned that in the other European IWT countries (i.e. in Eastern Europe), the relative RIS impact might be higher due to a bigger leap in implemented vessel technology16. Although, given the fact that the penetration rate of RIS key technologies in the Danube fleet is assumably smaller than in the Rhine fleet, this potential bigger leap in technology might not have had a large absolute effect17. This implies that it is also difficult to determine a RIS Directive impact in Eastern Europe. Therefore, further research on this issue is recommended as there are significant differences between the Danube and the Rhine. Other regions in the world, which make use of inland waterway transport, such as the US, Brazil, Uruguay, China and South East Asia, could use a similar approach to analyze their RIS regulation (if any).

In order to place the above-mentioned reasonings in the literature, Niedzielski et al. (2021) also argued that most of the benefits of using the RIS system, in Poland, are intangible and incalculable, but could be translated into the company's finance performance. This observation is in line with the above-mentioned reasoning that there could be an effect of the RIS Directive, but that it can't be quantified.

If there is indeed no effect of the RIS Directive, and the models did capture the RIS effect on the performance of the IWT sector in the ARA–Rhine region (second reason), this would imply that the main objectives of the EC are not obtained and that the RIS Directive didn't support the increase of the market share of IWT. This does not mean that the investments made are lost. The RIS framework, along with the technologies that are developed, are used as a core infrastructure for smart shipping, for the different levels of autonomous shipping. This might not have been the intended objective of the European Commission when the RIS Directive was developed, but

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[16] The potential jump in technology implemented on the Danube is expected to be larger than in the Rhine riparian States and Belgium because RIS key technologies were already more diffused amongst the fleet and the waterway managers. This is not true for Austria which also can be regarded as one of the front-runners in RIS implementation and development.

[17] The absolute effect is the combination of both the change in RIS technology per vessel as the percentage of vessels in the fleet equipped with this technology.

without it, autonomous and smart inland shipping would not have been able to develop and mature as it is currently doing.

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Appendix: Model Estimations

The Dry Bulk Market Models' Estimations

Table A.1: The BP multiple breakpoint test.

```
Multiple breakpoint tests
Bai-Perron tests of 1 to M globally determined breaks
Sample: 1991 2016
Included observations: 26
Breaking variables: C
Break test options: Trimming 0.05, Max. breaks 3, Sig. level 0.05
Allow heterogeneous error distributions across breaks

Sequential F-statistic determined breaks:            3
Significant F-statistic largest breaks:              3
UDmax determined breaks:                             3
WDmax determined breaks:                             3

                          Scaled      Weighted      Critical
  Breaks    F-statistic   F-statistic F-statistic    Value

1 *         30.04070      30.04070    30.04070        9.63
2 *         25.06203      25.06203    27.48831        8.78
3 *         109.4602      109.4602    134.2805        7.85

UDMax statistic*          109.4602  UDMax critical value**     10.17
WDMax statistic*          134.2805  WDMax critical value**     10.91

* Significant at the 0.05 level.
** Bai-Perron (Econometric Journal, 2003) critical values.
Estimated break dates:
1:  1997
2:  1995, 1997
3:  1995, 2009, 2010
```

Table A.2: The unit root tests.

Variable	Level Data		First Difference	
	ADF	PP	ADF*	PP*
DRY.TONKM	0.273950	0.445414	-7.970212	-9.008505
IP_Energy	-0.255765	-0.271026	-6.007915	-6.001469
IP_Steel	-0.071776	0.328004	-6.531278	-11.47043
D-LWS	-0.459981	-1.374632	-5.616906	-7.252403
resid-cointeg	-4.519483*	-4.511201*	---------	---------

The table summarizes the calculated t-statistics of the tests with no intercept and trend.
The ADF and PP tests critical values are 1%: -2.66, 5%: -1.96, & 10%: -1.61.
* The first difference for all variables are significant at 1%, while the resid is stationary at level.

Table A.3a: VAR lag exclusion Wald test.

VAR Lag Exclusion Wald Tests
Sample: 1991 2017
Included observations: 24

Chi-squared test statistics for lag exclusion:
Numbers in [ ] are p-values

	LOG_DRY_TONKM	LOG_IP_ENG	LOG_IP_STEEL	LOG_DLW	Joint
Lag 1	3.950998 [0.4127]	25.63977 [0.0000]	4.766222 [0.3121]	4.544904 [0.3373]	39.61233 [0.0009]
Lag 2	3.272133 [0.5134]	12.22803 [0.0157]	1.325165 [0.8571]	4.822409 [0.3060]	21.92909 [0.1455]
Lag 3	2.606056 [0.2717]	4.554900 [0.4315]	5.897582 [0.1167]	2.303140 [0.5119]	12.56032 [0.3071]
df	4	4	4	4	16

Table A.3b: VAR lag order selection criteria.

VAR Lag Order Selection Criteria
Endogenous variables: LOG_DRY_TONKM LOG_IP_ENG LOG_IP_STEEL LOG_DLW
Exogenous variables: C
Sample: 1991 2017
Included observations: 23

Lag	LogL	LR	FPE	AIC	SC	HQ
0	71.83398	NA	1.02E-05	-5.819498	-5.721327	-5.793453
1	86.74612	26.09624*	4.11e-06*	-6.728843*	-6.434329*	-6.650708*
2	89.33102	4.09277	4.67E-06	-6.610919	-6.120063	-6.480694
3	92.08562	3.902341	5.30E-06	-6.507135	-5.819937	-6.324821

* indicates lag order selected by the criterion
LR: sequential modified LR test statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion
SC: Schwarz information criterion
HQ: Hannan-Quinn information criterion

Table A.4: Johansen Cointegration test

Sample (adjusted): 1993 2017
Included observations: 25 after adjustments
Trend assumption: Linear deterministic trend (restricted)
Series: LOG_DRY_TONKM LOG_IP_ENG LOG_IP_STEEL LOG_DLW
Lags interval (in first differences): 1 to 1

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None *	0.726182	68.20094	63.87610	0.0207
At most 1	0.578398	35.81863	42.91525	0.2130
At most 2	0.289941	14.22630	25.87211	0.6389
At most 3	0.202795	5.666101	12.51798	0.5038

Trace test indicates 1 cointegrating eqn(s) at the 0.05 level
* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.**
None *	0.726182	32.38231	32.11832	0.0464
At most 1	0.578398	21.59233	25.82321	0.1642
At most 2	0.289941	8.560196	19.38704	0.7687
At most 3	0.202795	5.666101	12.51798	0.5038

Max-eigenvalue test indicates 1 cointegrating eqn(s) at the 0.05 level
* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Table A.5: Engle Granger Cointegration test

Cointegration Test - Engle-Granger
Equation: COINTEG
Specification: LOG(DRY_TONKM) LOG(IP_ENG) LOG(IP_STEEL) LOG_DLW C @TREND
Cointegrating equation deterministics: C @TREND
Null hypothesis: Series are not cointegrated
Automatic lag specification (lag=1 based on Schwarz Info Criterion, maxlag=5)

	Value	Prob.*
Engle-Granger tau-statistic	-4.109794	0.2056
Engle-Granger z-statistic	-37.72539	0.0001

*MacKinnon (1996) p-values.

Intermediate Results:	
Rho - 1	-1.190393
Rho S.E.	0.289648
Residual variance	0.002297
Long-run residual variance	0.003691
Number of lags	1
Number of observations	25
Number of stochastic trends**	4

**Number of stochastic trends in asymptotic distribution.

Table A.6: The ECM estimation for Equation 3

Dependent Variable: DLOG(DRY_TONKM)
Method: Least Squares
Sample (adjusted): 1992 2017
Included observations: 26 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.008260	0.011412	0.723733	0.4772
DLOG(IP_STEEL)	0.668985	0.152698	4.381098	0.0003
DLOG(IP_ENG)	0.180592	0.477265	0.378390	0.7089
D(LOG_DLW)	-0.013355	0.006374	-2.095121	0.0485
Ect_{t-1}	-0.759004	0.237487	-3.195978	0.0043

R-squared	0.633294	Mean dependent var	0.004514
Adjusted R-squared	0.563445	S.D. dependent var	0.087249
S.E. of regression	0.057648	Akaike info criterion	-2.697893
Sum squared resid	0.069788	Schwarz criterion	-2.455952
Log likelihood	40.07261	Hannan-Quinn criter.	-2.628223
F-statistic	9.066651	Durbin-Watson stat	2.247669
Prob(F-statistic)	0.000204		

Table A.7 Estimated results of the long-run error correction term (ect) for Equation 4

Dependent Variable: LOG(DRY_TONKM(-1))
Method: Least Squares
Sample (adjusted): 1992 2017
Included observations: 26 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOG(IP_ENG(-1))	0.233711	0.331478	0.705058	0.4885
LOG(IP_STEEL(-1))	0.700305	0.151100	4.634722	0.0001
LOG(DLW (-1))	-0.014926	0.007435	-2.007452	0.0577
C	7.108103	1.483778	4.790542	0.0001
D_1995	0.024441	0.061041	0.400410	0.6929

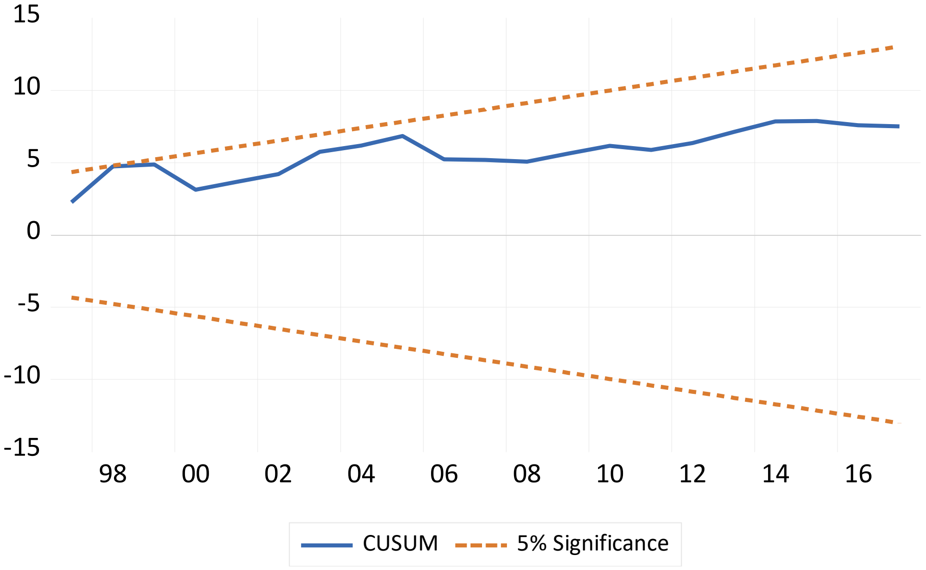
R-squared	0.650458	Mean dependent var	11.33278
Adjusted R-squared	0.583878	S.D. dependent var	0.089578
S.E. of regression	0.057784	Akaike info criterion	-2.693152
Sum squared resid	0.070120	Schwarz criterion	-2.451210
Log likelihood	40.01098	Hannan-Quinn criter.	-2.623482
F-statistic	9.769645	Durbin-Watson stat	1.473093
Prob(F-statistic)	0.000126		

Table A.8: Variance Inflation Factor

Variance Inflation Factors
Sample: 1991 2017
Included observations: 26

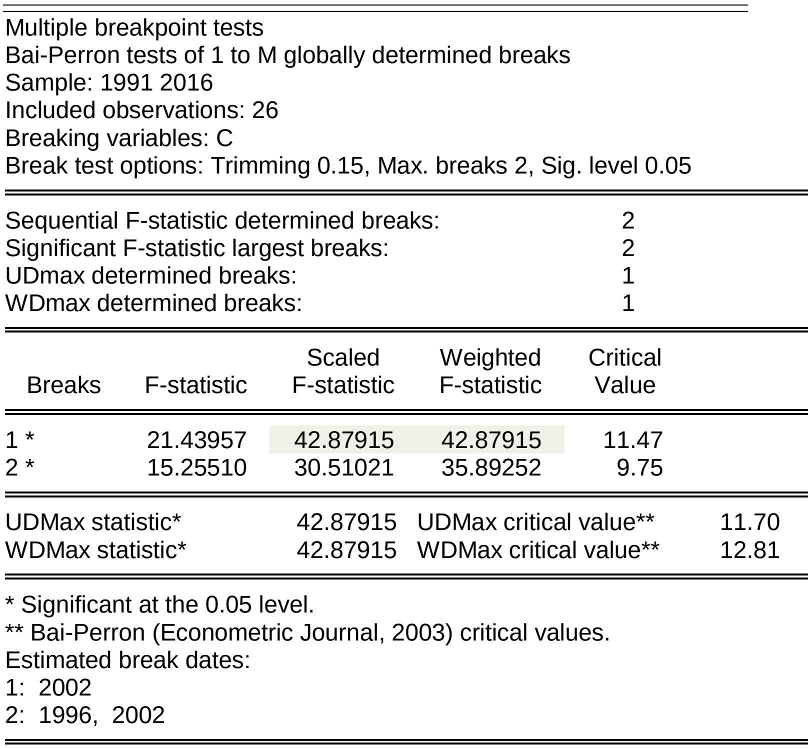
Variable	Coefficient Variance	Uncentered VIF	Centered VIF
C	0.000130	1.018978	NA
DLOG(IP_STEEL)	0.023317	1.339627	1.338816
DLOG(IP_ENG)	0.227782	1.216745	1.214828
D(LN_DLWS)	4.06E-05	1.132971	1.132839
ect	0.056400	1.211082	1.190047

Figure A.1: CUSUM of squares stability test for dry bulk barge freight performance in IWT



The liquid Bulk Market Models' Estimations

Table A.9: The BP multiple breakpoint test.



```
Multiple breakpoint tests
Bai-Perron tests of 1 to M globally determined breaks
Sample: 1991 2016
Included observations: 26
Breaking variables: C
Break test options: Trimming 0.15, Max. breaks 2, Sig. level 0.05

Sequential F-statistic determined breaks:                2
Significant F-statistic largest breaks:                  2
UDmax determined breaks:                                 1
WDmax determined breaks:                                 1

                          Scaled      Weighted     Critical
  Breaks    F-statistic   F-statistic  F-statistic  Value

1 *          21.43957     42.87915    42.87915     11.47
2 *          15.25510     30.51021    35.89252      9.75

UDMax statistic*          42.87915  UDMax critical value**    11.70
WDMax statistic*          42.87915  WDMax critical value**    12.81

* Significant at the 0.05 level.
** Bai-Perron (Econometric Journal, 2003) critical values.
Estimated break dates:
1:  2002
2:  1996,  2002
```

Table A.10: The unit root tests.

Variable	Level Data		First Difference	
	ADF	PP	ADF*	PP*
LIQ.TONKM	1.615562	2.792124	-7.500350	-7.611489
BRENT	-0.49575	-0.49575	-4.361707	-4.363160
IPCHEM	0.802373	1.378573	-5.942769	-6.077034
FUELTRADE	2.375709	2.669272	-4.363371	-4.401043
LWS	0.218840	-3.76946*	-6.738030	---------
resid-cointeg	-4.064590 *	-4.061939 *	---------	---------

The table summarizes the calculated t-statistics of the tests with no intercept and trend.
The ADF and PP tests critical values are 1%: -2.66, 5%: -1.96, & 10%: -1.61.
* The first difference for all variables are significant at 1%.

Table A.11a: VAR lag exclusion Wald test.

VAR Lag Exclusion Wald Tests
Date: 09/11/20 Time: 05:54
Sample: 1991 2016
Included observations: 24

Chi-squared test statistics for lag exclusion:
Numbers in [ ] are p-values

	LOG_LIQ_TONKM	LOG_BRENT	LOG_IPCHEM	LOG_FUELTRADE	LOG_LWS	Joint
Lag 1	3.346314	22.99334	3.838260	12.79377	4.907020	60.51500
	[0.6468]	[0.0003]	[0.5729]	[0.0254]	[0.4273]	[0.0001]
Lag 2	6.050970	5.885848	2.191836	8.346556	4.836826	32.55587
	[0.3013]	[0.3175]	[0.8220]	[0.1381]	[0.4361]	[0.1425]
df	5	5	5	5	5	25

Table A.11b: VAR lag order selection criteria.

VAR Lag Order Selection Criteria
Endogenous variables: LOG_LIQ_TONKM LOG_BRENT LOG_IPCHEM LOG_FUELTRADE LOG_LWS
Exogenous variables: C
Sample: 1991 2016
Included observations: 23

Lag	LogL	LR	FPE	AIC	SC	HQ
0	47.78354	NA	4.09E-06	-3.89422	-3.746113	-3.856972
1	87.00052	64.79327*	2.98E-07	-6.761431*	-5.929352*	-6.372789
2	92.79003	8.054976	2.80e-07*	-6.242611	-5.205856	-6.388943*
3	107.7565	16.91857	4.14E-07	-6.521784	-5.280351	-5.98187

* indicates lag order selected by the criterion
LR: sequential modified LR test statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion
SC: Schwarz information criterion
HQ: Hannan-Quinn information criterion

Table A.12: Johansen Cointegration test

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None *	0.865129	108.8087	88.80380	0.0009
At most 1	0.714364	60.72620	63.87610	0.0895
At most 2	0.525565	30.65335	42.91525	0.4639
At most 3	0.321350	12.75821	25.87211	0.7568
At most 4	0.134062	3.454618	12.51798	0.8187

Trace test indicates 1 cointegrating eqn(s) at the 0.05 level
* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.**
None *	0.865129	48.08247	38.33101	0.0028
At most 1	0.714364	30.07285	32.11832	0.0870
At most 2	0.525565	17.89515	25.82321	0.3853
At most 3	0.321350	9.303590	19.38704	0.6929
At most 4	0.134062	3.454618	12.51798	0.8187

Max-eigenvalue test indicates 1 cointegrating eqn(s) at the 0.05 level
* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Table A.13: Engle Granger Cointegration test

Cointegration Test - Engle-Granger
Equation: COINTEG
Specification: LOG(LIQ_TONKM) LOG(BRENT) LOG(IPCHEM) LOG(FUELTRADE) LOG(LWS) C
Cointegrating equation deterministics: C
Null hypothesis: Series are not cointegrated
Automatic lag specification (lag=1 based on Schwarz Info Criterion, maxlag=4)

	Value	Prob.*
Engle-Granger tau-statistic	-3.967526	0.2381
Engle-Granger z-statistic	-30.64971	0.0039

*MacKinnon (1996) p-values.
Warning: p-values may not be accurate for fewer than 25 observations.

Intermediate Results:	
Rho - 1	-0.739186
Rho S.E.	0.186309
Residual variance	0.001228
Long-run residual variance	0.003665
Number of lags	1
Number of observations	24
Number of stochastic trends**	5

**Number of stochastic trends in asymptotic distribution.

Table A.14: The ECM estimation for Equation 5

Dependent Variable: DLOG(LIQ_TONKM)
Method: Least Squares
Sample (adjusted): 1992 2016
Included observations: 25 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
DLOG(BRENT)	-0.072049	0.040326	-1.786663	0.0892
DLOG(IPCHEM)	0.772018	0.202785	3.807069	0.0011
DLOG(FUELTRADE)	0.099970	0.161339	0.619628	0.5425
C	-0.015434	0.013098	-1.178348	0.2525
ect	-0.556318	0.194182	-2.864936	0.0096

R-squared	0.471827	Mean dependent var	0.014398
Adjusted R-squared	0.366193	S.D. dependent var	0.057044
S.E. of regression	0.045414	Akaike info criterion	-3.169133
Sum squared resid	0.041249	Schwarz criterion	-2.925358
Log likelihood	44.61417	Hannan-Quinn criter.	-3.101520
F-statistic	4.466600	Durbin-Watson stat	1.845314
Prob(F-statistic)	0.009661		

Table A.15: Estimated results of the long-run error correction term (ect) for Equation 6

Dependent Variable: LOG(LIQ_TONKM(-1))
Method: Least Squares
Sample (adjusted): 1992 2016
Included observations: 25 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOG(BRENT(-1))	-0.022670	0.031509	-0.719469	0.4811
LOG(IPCHEM(-1))	0.663973	0.145629	4.559352	0.0002
LOG(FUELTRADE(-1))	0.184164	0.099594	1.849137	0.0809
D_1995_99	0.069493	0.031335	2.217774	0.0397
D_2002	0.084464	0.050387	1.676296	0.1110
D_1995*LOG(LWS)	-2.200217	3.625521	-3.606869	0.0415
C	5.014666	1.023342	4.900282	0.0001

R-squared	0.841567	Mean dependent var	10.08441
Adjusted R-squared	0.788756	S.D. dependent var	0.103197
S.E. of regression	0.047430	Akaike info criterion	-3.027610
Sum squared resid	0.040494	Schwarz criterion	-2.686325
Log likelihood	44.84513	Hannan-Quinn criter.	-2.932952
F-statistic	15.93549	Durbin-Watson stat	1.601146
Prob(F-statistic)	0.000003		

Table A.16: Variance Inflation Factor

Variance Inflation Factors
Sample: 1991 2016
Included observations: 25

Variable	Coefficient Variance	Uncentered VIF	Centered VIF
DLOG(BRENT)	0.001643	1.394369	1.374645
DLOG(IPCHEM)	0.041569	1.488701	1.418267
D(FUELTRADE)	1.33E-12	1.244042	1.018656
C	0.000168	2.015438	NA
ect	0.037637	1.733719	1.140105

Figure A.2: CUSUM of squares stability test for tank barge performance in the IWT