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Transport Infrastructure Interdependencies with Energy, Water, Waste and Communication Infrastructure in the United Kingdom

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Abstract

The role of infrastructure interdependencies is challenging due to the complexity and dynamic environment of all infrastructures and vital for critical infrastructure systems. There is an ongoing debate about the value of the benefits of the five national infrastructure sectors (energy, water, transport, waste and communication) in the UK and how they interact in terms of social, economic and environmental wellbeing (Hall et al., 2016, p.10; iBUILD, 2015; Liveable Cities, 2015; National Infrastructure Plan, 2013). This study focuses only on one of the three aforementioned values, the economic value. The hypothesis tested is whether the transport sector is economically complemented by the energy, water and waste sectors and economically substituted by the communication sector. The authors use the process analysis “networks and cohorts”, an analysis that uses tables, diagrams, models and networks of interactions along with organizational linkages (Hill, 1993). Of interest for this study in particular is the grand total of all revenues (capital value) which create incomes into other sectors and creates dependencies. This, by definition, is the Gross Value Added. The last five symmetric (product by product) Input-Output tables of gross value added are used: 2010, 2005, 1995, 1990 and 1984 (Office for National Statistics, 2015). The theory underpinning the hypothesis was verified and one mathematical equation was developed based on the historical data of the gross value added by the value created in millions of pounds (£m) from the other critical sectors to transport:

$$Y_{cr} = 0.32 \cdot X_{cr1} + 2.99 \cdot X_{cr2} - 0.35 \cdot X_{cr3} + 5.27 \cdot X_{cr4} + 125.74 \text{ [where } X_{cr1} \text{ : value created}$$

from Energy to Transport, X_{cr2} : value created from Waste to Transport, X_{cr3} : value created from

Communication to Transport and X_{cr4} : value created from Water to Transport; when

$$X_{cr1} \in [606, 1,765], X_{cr2} \in [0, 380], X_{cr3} \in [411, 1,628] \text{ and } X_{cr4} \in [43, 82].$$

Key Words

Infrastructure; Economic Value; Business Model

Introduction

“The system of infrastructure networks: Energy, Water, Transport, Waste, Communication, which supports crucial services, faces a multitude of challenges” (iBUILD, 2015). There is an ongoing debate about the value of the benefits of infrastructures and how to prioritize infrastructure investments in United Kingdom considering social, economic and environmental wellbeing considering energy, water, transport, waste, communication (Hall et al., 2016, p.10; iBUILD, 2015; Liveable Cities, 2015; National Infrastructure Plan, 2013). In the framework of this discussion, the devise of new business models is required to understand infrastructure financing, valuation and interdependencies under a range of possible futures (iBUILD, 2015). Regarding infrastructure, W. Edward Steinmueller (1996, p.117) observed: “Both traditional and modern uses of the term infrastructure are related to “synergies,” what economists call positive externalities that are incompletely appropriated by the suppliers of goods and services within an economic system.” The traditional idea of infrastructure was derived from the observation that the private gains from the construction and extension of transportation and communication networks, while very large, were also accompanied by additional large social gains.” Hall et al. (2016, p.6) defined the infrastructure as “the collection and interconnection of all physical facilities and human systems that are operated in a coordinated way to provide” a service. For the purposes of this research, interdependencies refer to the synergies, which Steinmueller (1996) described, or to the interconnections, which Hall et al. (2016) described, as they both meant the same thing. The dominant value model of infrastructure interdependencies today is the economic value model’s perspective of each infrastructure without considering the infrastructure interdependencies. This study aims to point out the findings that are relevant to economic value interdependencies of transport infrastructure.

Theoretical Frame of Reference

The interdependencies between transport infrastructure and production are very complex. The delimitations of this study include only economic value in terms of growth and no other types of value. The input-output tables are commonly used for tracing infrastructure interdependence through economic value. “By examining individual cells, we can see how much of this is caused by disruption to other types of infrastructure” (Rose, 2005, p.4). Economic input-output tables can be found at the Office for National Statistics (2015) where the five main infrastructure sectors are divided in their activities, which add value, so the economic value interdependencies can be studied. The value activities are already divided from the Office for National Statistics (2015), as follows:

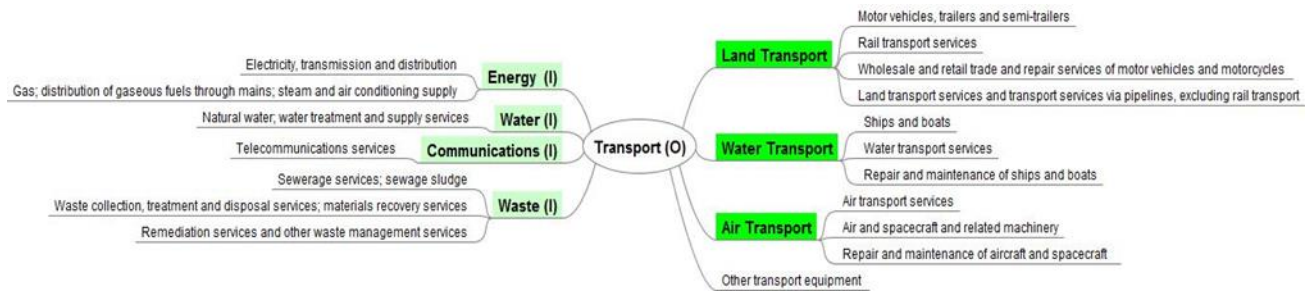


Figure 1. The value activities of the national infrastructure sectors

“In 2008 total contribution of the five national infrastructure sectors to Gross Value Added (GVA) in the U.K. economy was 9.2%,” with Transport having the largest contribution followed by Communication and then Energy (Hall et al., 2016, p.244). Energy and Transport interdependencies in United Kingdom have been quantified by Tran et al. (2016, p. 227-240). They conclude that, Energy and Transport infrastructure are complements as any change in Energy-Transport relationship will require at least new fuelling infrastructures and “even aggressive energy demand reduction” of energy “mean that the requirement for electricity infrastructure will be at least as high as present” (Tran et al., 2016, p. 230). Furthermore, Tapio et al. (2007) compared Energy and Transport with growth in GDP from 1970 to 2000 in the EU15 countries. Although they conclude that, Transport and Energy have contrary behaviour regarding the economic growth (Tapio et al., 2007, p.446), if their interactions between Transport with Energy compare, it can be noticed that in terms of GDP, Energy use in Transport increases as the total passenger travel distance per capital increase, almost proportionally, over the years (Tapio et al., 2007, p.434). This happened to every single country of EU15 countries (even in United Kingdom), so it can be safely concluded that Energy and Transport are complements. The total growth in GDP from Energy use in Transport of EU15 countries may be compared with the growth in GDP from Transport for each year and a virtual (non-pragmatic) equation will be given $y=0.35722x-4.237$. In this study, Waste and Transport interdependencies are studied in terms of economic value considering wastewater and solid waste, but not air pollution (e.g. carbon dioxide emissions), as the Office for National Statistics (2015) does not consider air pollution as economic factor of the Waste industry. The air pollution is considered by the authors as environmental type of value and it is not studied following the delimitations of this study. Regarding solid waste, “Changes in waste disposal patterns will have an impact on transport infrastructure capacity utilisation, but waste transport only forms a small proposition of total freight traffic these impacts are unlikely to be significant at a national scale” (Hall et al., 2016, p.110). On the other hand the sewerage system is “consisting of a piped system collecting and transporting wastewater to treatment plants” (Wong, 2006, p.213). Apart from other requirements (e.g. collection, treatment), the wastewater infrastructure requires high capital investment for transport

(Tjandraatmadja et al., 2005, p. 146). This investment is included in “Land transport services and transport services via pipelines, excluding rail transport” of Transport (Figure 1). It is safe to conclude that Waste and Transport are complements. Selvanathan and Selvanathan (1994) discussed Transport and Communication economic dependences and studied them by estimating the Rotterdam demand equations in United Kingdom and Australia. They compared (public and private) Transport and Communication and found that they are substitutes in both countries (Selvanathan & Selvanathan, 1994, p.5). The constant terms of the Rotterdam demand equations “for private transport and public transport are negative while that for communication is positive” in United Kingdom (Selvanathan & Selvanathan, 1994, p.5). There are researchers, who claim that Transport and Communication are complementary, but all of them are focusing on communication as an infrastructure service and not as an infrastructure system and most of them do not consider only the economic value through growth (e.g. Mokhtarian (2002) compared the growth of the absolute number of uses of each infrastructure without considering their dissimilar economic value). The negative impact of Communication improvement on Transport can be seen from the Gross Value Added (GVA) reduction in every single scenario developed from Hickford et al. (2015, p.21) for the United Kingdom. The Water supply infrastructure system and Transport are always complements not only in United Kingdom but everywhere. Either in tradition Water supply or in extreme socio-economic and climate scenarios, large-scale water transfer infrastructure will be required "to alleviate the disparity between regions with water scarcity and those with water abundance" (Hall et al., 2016, p.130-131). As it can be seen at Figure 1, one of the Transport industry sectors is the “Land transport services and transport services via pipelines, excluding rail transport”. Within this sector is included the transfer of goods and mainly of Water supply. It is obvious that, large-scale water transfer infrastructure is part of Transport, something that explains why Water and Transport are complements.

Empirical Findings and Analysis

The empirical data of this study comes from documents analysis and is considered as secondary data analysis since by definition it is “the analysis of pre-existing data” (Heaton, 2000, p. 1).

Administrative records and more specifically symmetric (product by product) Input-Output table show past dependencies by providing estimates of domestic and imported products to intermediate consumption and final demand and associated multipliers, were used to derive part of the empirical data and fulfil the objective of this research. These documents were provided by the UK’s Office for National Statistics (ONS) (public organization). There are three major economic factors to measure the national income and output: [1] Gross domestic product (GDP) is the sum of all products and goods produced by an economy, expressed in monetary value (Konchitchki & Patatoukas, 2014,

p.77). [2] Gross national product (GNP) is the market value of the sum of all products and goods based on location of ownership (Means & Seaborg, 1957, p.313-314). [3] Net national income (NNI) “measures the value of goods and services produced in the private sector of the economy valued at market prices, after deduction of depreciation charges, plus government services valued at cost” (Denison, 1947, p.8) However, what is of interest for this study in particular, is the grand total of all revenues (capital value) which are incomes into other sectors and create dependences. This, by definition (Bao & Bao, 1998, p.253), is the Gross Value Added (GVA) and it relates with GDP:

$$GVA = GDP + subsidies\ on\ products - taxes\ on\ products$$

The relationship between GVA and GDP allows the comparison of the results of this study with previous studies done using GDP. According to the UK’s Office for National Statistics (ONS) GVA is a measure of the contribution of each individual producer, industry or sector to the United Kingdom’s economy (Office for National Statistics, 2015). The GVA has been recognized as one key economic factor for tracking interdependencies (Hall et al., 2016, p. 244). The input-output matrix of GVA provided the economic value dependencies between different sectors. Therefore the most proper factor for this study is the GVA. These documents generate numerical findings. In line with the ontology and epistemology stance, this study adopts a quantitative data collection allowing a depth description and explanation of the value creation in infrastructure interdependencies. The target audience of the documents was investors and public audience, so there was a lack of scientific or economic data/text to support them. These documents were knowledge drivers and established the guidelines in relation to the processes of the public organizations, helping them to function and develop through the same processes as a whole. These documents were produced from different day-to-day or month-to-month reporting systems over the year from 1984 till 2010. There are five editions (1984, 1990, 1995, 2005, 2010) in an unevenly spaced time series, not explicit solution. Consequently, the research strategy followed is archival. Archival research refers to the analysis of “administrative records and documents as principal source of data because they are products of day-to-day activities” (Saunders et al, 2009, p. 587). Another reason that these documents are considered as secondary data is that they were “originally collected from different person” (Saunders et al, 2009, p. 150). According to Hill (1993) there is no fixed archival analysis method and the authors learn in the process how to extract information. The authors decided to implement the process analysis “networks and cohorts” due to the research nature. This type of analysis uses tables, diagrams, models, networks of interactions along with organizational linkages (Hill, 1993, p. 62). The steps for analyzing the documents are as follows: (1) Reading the documents, recognizing

and highlighting linkages with the research proposition, (2) creation of networks and/or tables with data needed and (3) mapping economic value interdependencies.

The analysis focused to a certain extent on the development and analysis of transport infrastructure in United Kingdom. Given that the study and development of the subject was based on only the United Kingdom, automatically this country constituted the basic case study of the present paper and guided the study of the primary research data.

The term “model” is only the standard expression of the experience of the researcher, regarding the nature and the expressions of a phenomenon. Although it is common to use mathematic relations for modelling, it is not a must. Conceptually they can be defined three types of modeling (Giannopoulos, 2002, p.25-26): mathematical models, operating models and procedural modelling. Regarding the purpose performed by the model, there are the following types (Giannopoulos, 2002, p.27): descriptive models, forecast models and planning models.

This research focuses on value creation and caption. Since, by definition, value can be measured then mathematical models will be used and not procedural. Procedural models are commonly qualitative explanation focusing on reasoning, why these dependencies exist and not how (Giannopoulos, 2002, p.26). Mathematical models consist of mathematical relationships, which usually are called algorithms and they are used for the calculation of the required variables (Giannopoulos, 2002, p.25). Furthermore, an operating model will be devised as a display of a total business model. Operating model is a combination of mathematical relationships and reasonable "rules of conduct" (Giannopoulos, 2002, p.25). In this case, the “rules of conduct” are the existed infrastructure dependencies and they are coming from the documents. From the moment this research investigates something new and innovative, there are no sufficient data for descriptive modeling. The devised model may be a possible forecast model for value creation with conditional predictions and impact analysis (e.g. creation of scenarios). The new business model may be used as a planning model under certain conditions and predetermined criteria. It worth noted, that the prediction of the future events is critical for considering the new business model as a planning one (deterministic behavior of the model and not stochastic/probabilistic).

The relationship form $Y = f(X_i) + u$, which is the most common function for mathematical modelling, is considered very general to be used as the starting point of modeling. Linear regression analysis is one of the best known model-building technique offered by statistical analysis. The method of the simple linear regression, which is the least squares estimator of a linear regression model, studies the relationship between two variables. Let X be the independent variable and Y be

the dependent variable. Respectively, the method of multiple linear regression investigates the relationship between the dependent variable Y and several independent variables X_i . Namely,

$$Y_c = b_0 + b_1 \cdot X_1 + b_2 \cdot X_2 + \dots + b_v \cdot X_v$$

[where Y_c : the dependent variable, X_1, X_2, \dots, X_v : the independent variables, b_0, b_1, \dots, b_v : partial regression coefficients, which are determinable parameters]

Following the three-step process analysis “networks and cohorts” (Hill, 1993): Step 1) The symmetric (product by product) Input-Output tables includes product input-output groups (IOGs). In the last version of the data (2010), the products and Producers are classified into 114 product IOGs consistent with Eurostat’s CPA 2008 and SIC 2007, respectively. The research proposition demands an industry-based analysis focusing on Transport, Energy, Waste, Communication and Water. Each of the IOGs was classified according to their principal product or service as Transport, Energy, Waste, Communication, Water or Other Goods/ Services (e.g. seven IOGs were classified as Transport, two IOGs were classified as Energy etc.). The secondary or indirect product or service cannot be calculated. The classification in the previous versions include similar product IOGs with the final version: the 2005 version has 123 IOGs, the 1995 version has 138 IOGs, the 1990 version has 123 IOGs and the 1984 version has 102 IOGs. In the versions of 1990 and 1984, the industry of Waste was not considered from the Office for National Statistics the as a separate product/service which adds value to the economy. Therefore, its value was allocated as indirect/secondary value in each other industry.

Step 2) Tables with the empirical data discussed above were created:

	GVA Consumption (2010)						
	Transport	Energy	Waste	Communications	Water	Other Goods/	Total
GVA Produced	9,200	52	1,030	181	19	126,843	137,325
	GVA Production (2010)						
	Transport	Energy	Waste	Communications	Water	Other Goods/	Total
GVA Consumed	9,200	1,662	192	514	43	51,267	62,878
	Capital Value Creation (2010)						
	Transport	Energy	Waste	Communications	Water	Other Goods/	Total Value
Transport	0	-1,610	+838	-333	-24	+75,576	+74,447

Table 2. Transport Input-Output Analytical Tables - 2010 Edition, Released: 12 February 2014

GVA Consumption (2005)							
	Transport	Energy	Waste	Communications	Water	Other Goods/	Total
GVA Produced	32,248	368	528	753	49	189,351	223,297
GVA Production (2005)							
	Transport	Energy	Waste	Communications	Water	Other Goods/	Total
GVA Consumed	32,248	1,765	380	1,628	82	62,949	99,052
Capital Value Creation (2005)							
	Transport	Energy	Waste	Communications	Water	Other Goods/	Total Value
Transport	0	-1,397	+148	-875	-33	126,402	+124,245

Table 3. Transport Input-Output Analytical Tables - 2005 Edition, Released: 02 August 2011

GVA Consumption (1995)							
	Transport	Energy	Waste	Communications	Water	Other Goods/	Total
GVA Produced	35,783	164	321	509	29	141,158	177,964
GVA Production (1995)							
	Transport	Energy	Waste	Communications	Water	Other Goods/	Total
GVA Consumed	35,783	1,009	214	1,016	54	47,103	85,179
Capital Value Creation (1995)							
	Transport	Energy	Waste	Communications	Water	Other Goods/	Total Value
Transport	0	-845	+107	-507	-25	+94,055	+92,785

Table 4. Transport Input-Output Analytical Tables - 1995 Edition, Released: 28 September 1995

GVA Consumption (1990)							
	Transport	Energy	Waste	Communications	Water	Other Goods/	Total
GVA Produced	15,499	75	N/A	301	21	93,895	109,791
GVA Production (1990)							
	Transport	Energy	Waste	Communications	Water	Other Goods/	Total
GVA Consumed	15,499	753	N/A	571	43	26,933	43,799
Capital Value Creation (1990)							
	Transport	Energy	Waste	Communications	Water	Other Goods/	Total Value
Transport	0	- 678	0	-270	-22	+66,962	+65,992

Table 5. Transport Input-Output Analytical Tables - 1990 Edition, Released: 02 August 2011

GVA Consumption (1984)							
	Transport	Energy	Waste	Communications	Water	Other Goods/	Total
GVA Produced	7,974	358	N/A	152	11	50,650	59,145
GVA Production (1984)							
	Transport	Energy	Waste	Communications	Water	Other Goods/	Total
GVA Consumed	7,974	6	N/A	411	65	33,284	42,340
Capital Value Creation (1984)							
	Transport	Energy	Waste	Communications	Water	Other Goods/	Total Value
Transport	0	-248	0	-259	-54	+17,366	+16,805

Table 6. Transport Input-Output Analytical Tables - 1984 Edition, Released: 29 September 1988

Step 3) The economic value interdependencies were mapped in the last line of each table and used for the development of a mathematical model (function). If it is assumed that the value is created from the infrastructure dependencies and other goods and services is a result of these dependencies, and the same time it is assumed that transport value creation is independent from the non-transport dependencies, then for four other sectors (independent variables) we get five unknowns. Additionally, the actual value creation may be calculated with the input (consumption) and output model (production) and “be transformed into a simple, operational model of interdependence by imparting a regularity relationship between inputs and outputs” (Rose, 2005, p.4) by aligning with the methodology described by Rose and “by assuming a fixed relationship between inputs and outputs” (Rose, 2005, p.4). To calculate the actual value creation we would need the data from at least two more years, as two more variables should be considered: value from Transport to Transport and value from Other Goods and Services to Transport. Based on the given data, it may be assumed that the difference of the total value produced with the two extra variables is the output of the value production of the four previous sections, which is a strong assumption, then:

$$Y_{cr} = b_1 \cdot X_{cr1} + b_2 \cdot X_{cr2} + b_3 \cdot X_{cr3} + b_4 \cdot X_{cr4} + b_5$$

[where X_{cr1} : value created from Energy to Transport, X_{cr2} : value created from Waste to Transport, X_{cr3} : value created from Communication to Transport and X_{cr4} : value created from Water to Transport]

This system of five linear equations for five unknown variables can be solved with Cramer's rule:

$$\begin{bmatrix} 1,662 & 192 & 514 & 43 & 1 \\ 1,765 & 380 & 1,628 & 82 & 1 \\ 1,009 & 214 & 1,016 & 54 & 1 \\ 753 & 0 & 571 & 43 & 1 \\ 606 & 0 & 411 & 65 & 1 \end{bmatrix} \cdot \begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \\ b_5 \end{bmatrix} = \begin{bmatrix} 1,282 \\ 1,698 \\ 1,023 \\ 397 \\ 521 \end{bmatrix}$$

where the unknown variables may be calculated with the following function:

$$b_i = \frac{Det(b_i)}{Det}, i = 1, \dots, 5$$

The system has a unique solution in real numbers and the transport value creation function is:

$$Y_{cr} = 0.32 \cdot X_{cr1} + 2.99 \cdot X_{cr2} - 0.35 \cdot X_{cr3} + 5.27 \cdot X_{cr4} + 125.74$$

[where X_{cr1} : value created from Energy to Transport, X_{cr2} : value created from Waste to Transport, X_{cr3} : value created from Communication to Transport and X_{cr4} : value created from Water to Transport; when $X_{cr1} \in [606, 1,765]$, $X_{cr2} \in [0, 380]$, $X_{cr3} \in [411, 1,628]$ and $X_{cr4} \in [43, 82]$].

The theory of the research proposition related with Energy was verified. Transport and Energy are complements. For purposes of size comparison, the determinable parameter of the virtual equation using GDP is 0.35722 (Tapio et al., 2007) and in this case it is almost the same 0.32. The theory of the research proposition related with Water and Waste was verified. It worth noted that the percentage of “Land transport services and transport services via pipelines, excluding rail transport” value from Water and Waste added is around 21% and 35% , respectively, of the total value added to Transport from each. The theory of the research proposition related with Communication was verified. Transport and Communication are substitutes. For purposes of size comparison, the constant term of this equation will be compared with the Rotterdam demand equations of Selvanathan and Selvanathan (1994). Although they are different methodologies, they compare values in the same unit within each methodology are, so the percentage will be similar. In this study, the constant term between the total Transport and Communication is -0.35, while in Rotterdam demand equation is (-0.010/0.362) -0.025 between the private Transport and Communication and (-0.203/0.362) -0.56 between the public Transport and Communication.

Conclusions and Recommendations

The hypothesis was verified with some exceptions. These exceptions may exist because of the strong assumption due to the lack of data. As all the types of infrastructure are in the same function, it is safe to rank them. The Transport infrastructure interdependencies ranking, based on the findings of this study, is as follows: (1) Water (positive impact), (2) Waste (positive impact), (3) Energy (positive impact) and (4) Communication (negative impact greater than Energy and Waste, but lower than Water).

To conclude it can be seen that value added in Energy, Waste and Water adds and creates value to Transport and value added or created in Communication reduces value to Transport. A possible explanation for communication it may be that the growth of communication sector reduces the need of transport (e.g. with telegraphy, communication became instant and independent of transport) and additionally transports are dependent on communication, as every single transport

system should be controlled and communicated by communication means. On the other hand Energy, Water and Waste are still dependent on Transport, even if it is with pipelines and cables, and so the expansion of these systems adds value to transport. The water sector has the greatest positive influence in transport value creation with major difference from the second-following sector. The function developed in this paper may be used in future scenarios for calculating the value added. Finally, the infrastructure interdependencies functions shows that investing in Water and Waste in the current situation of the United Kingdom creates, indirectly, more value to Transport than investing in Transport itself.

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