Next Generation Infrastructure Interdependencies: An economic deterministic model of transport interdependencies in the United Kingdom

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Introduction

There is an ongoing debate on infrastructure investment priorities related to: Energy, Water, Transport, Waste, Communication

(*Hall et al., 2016; iBUILD, 2015; Liveable Cities, 2015; National Infrastructure Plan, 2013*)

In 2008 their contribution to GVA in the UK economy was 9.2%

(*Hall et al., 2016*) …

… with Transport having the largest contribution

Aims and Objectives (aligning with iBUILD & Liveable Cities projects)

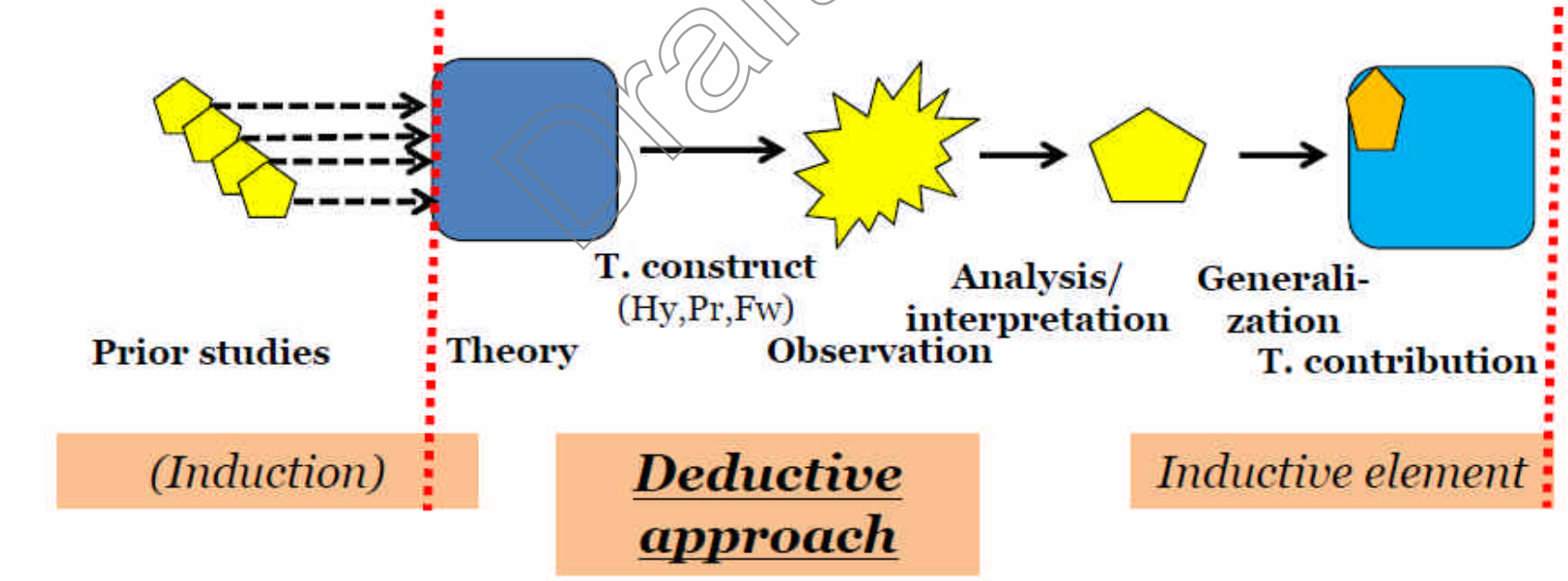
- *Understand the Value Interdependencies of Transport Infrastructure (this presentation)*
- *Devise a new Transport Business Model that takes account on these interdependencies (future research)*

Theoretical Methodology

Scientific ideal: Positivism (*Wainwright & Forbes, 2000*)

- Hypothetico-deductive model
- Quantitative methods

Deductive approach (*May, 2011*)



Theoretical Frame of Reference

Starting point:

- Business models focus on value creation and how value is captured (*Magretta, 2002; Casadesus-Masanell & Ricart , 2010*)
- Infrastructures are related to
  - "synergies" by economists (*Steinmueller, 1996*)
  - "interconnections" by engineers (*Hall et al., 2016*)
  - "interdependencies" in this study

Research propositions (deduction):

- From theory: e.g. infrastructure interdependencies

Research Gap of this Study:

- The dominant business model focuses on the economic value of each infrastructure **without** considering the **infrastructure interdependencies** **(between different infrastructures)**

Theoretical Frame of Reference

Research proposition: Economic Infrastructure Interdependencies

- *Tran et al*. (2016, p. 227-240) conclude that: **Energy and Transport** infrastructure are **complementary** as any change in the Energy-Transport relationship will require at least new fuelling infrastructures and "*even aggressive energy demand reduction*" applied to the energy part of the balance "*means that the requirement for electricity infrastructure will be at least as high as present*" (*Tran et al., 2016, p. 230*).
- 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). The sewerage system is "*consisting of a piped system collecting and transporting wastewater to treatment plants*" (*Wong, 2006, p.213*). The wastewater infrastructure requires high capital investment for transport through pipelines (*Tjandraatmadja et al., 2005, p. 146*), while solid waste is transported via trucks. So it is safe to conclude that **Waste and Transport complement each other.**

Theoretical Frame of Reference

Research proposition: Economic Infrastructure Interdependencies

- *Selvanathan & Selvanathan (1994)* discussed Transport and Communications economic dependences, having studied them in the UK and Australia. They compared (public and private) **Transport and Communications** and found that they **are substitutes** in both countries (*Selvanathan & Selvanathan, 1994, p.5*).
- The **Water Supply** infrastructure system **and Transport are always complementary**. Whether in the UK, EU and similar situations, where traditional water supply regimes exist, or in extreme socio-economic and/or 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*).

So it is expected that value added in **Energy, Waste and Water infrastructures** will **add and/or create value to Transport** , whereas value added or created in **Communications infrastructures** will **reduce value to Transport**.

Practical Methodology

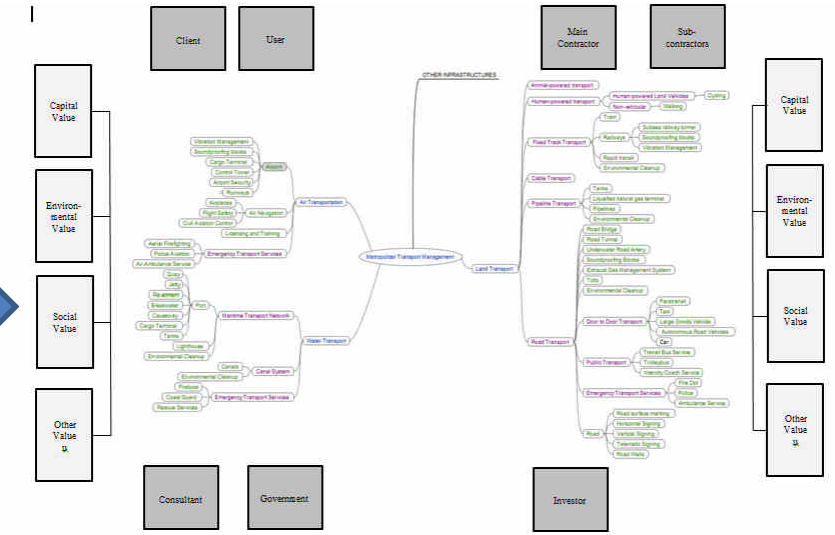
- Economic Value
  - Mathematical modelling with secondary data

    $Y_c = b_0 + b_1 \cdot X_1 + b_2 \cdot X_2 + \ldots + b_v \cdot X_v$ (*Giannopoulos, 2002*), where

    Y_c : dependent variable, and $X_1, X_2, \ldots X_v$: independent variables and $b_0, b_1, b_2, \ldots b_v$: are partial regression coefficients.
- Social Value (See Parallel Session in **GM at 14:00 Today**)
  - Sigmoid functions:

$f(x) = \tanh(x)$ and/or $f(x) = \operatorname{erf}(\frac{\sqrt{\pi}}{2} x)$

- Business Model



Practical Methodology

There are three major economic factors that are used to measure the national income and output:

[1] Gross Domestic Product (GDP)

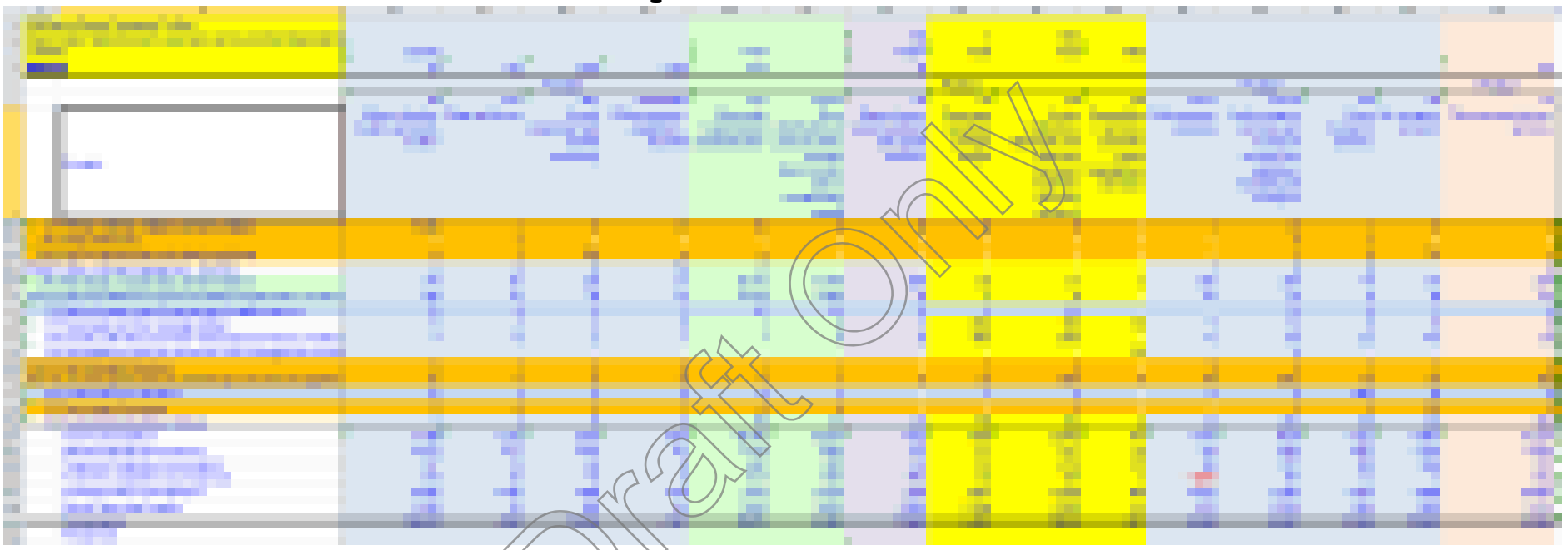
[2] Gross National Product (GNP)

[3] Net National Income (NNI)

Of interest for this study is the grand total of all revenues (capital value), which include incomes into other sectors and create dependences. This, by definition, is the **Gross Value Added (GVA)** and it relates with GDP:

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

Infrastructure Interdependencies



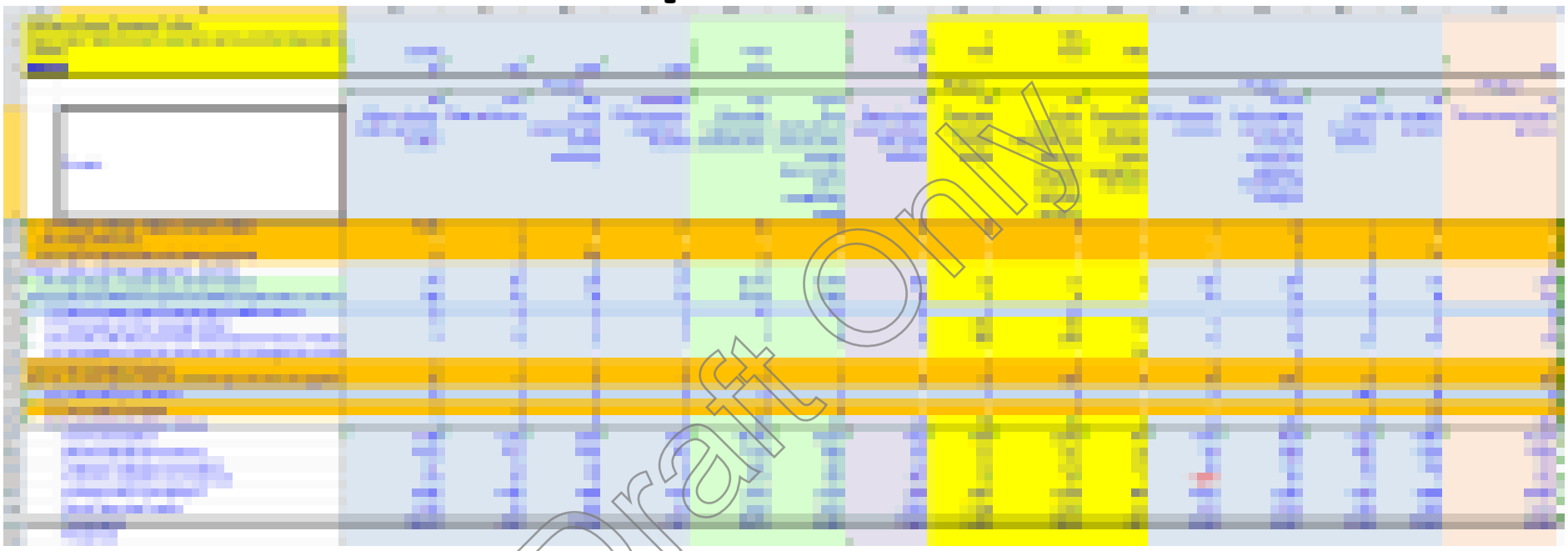
Following the **three–step process analysis** "networks and cohorts" (Hill, 1993)

STEP 1: The symmetric (product by product) Input-Output tables includes product input-output groups (IOGs; see ONS, 2015):

2010 version: 114 IOGs	1990 version*: 123 IOGs
2005 version: 123 IOGs	1984 version*: 102 IOGs
1995 version: 138 IOGs	

*the industry of Waste was not considered as a separate product/service which adds value to the economy

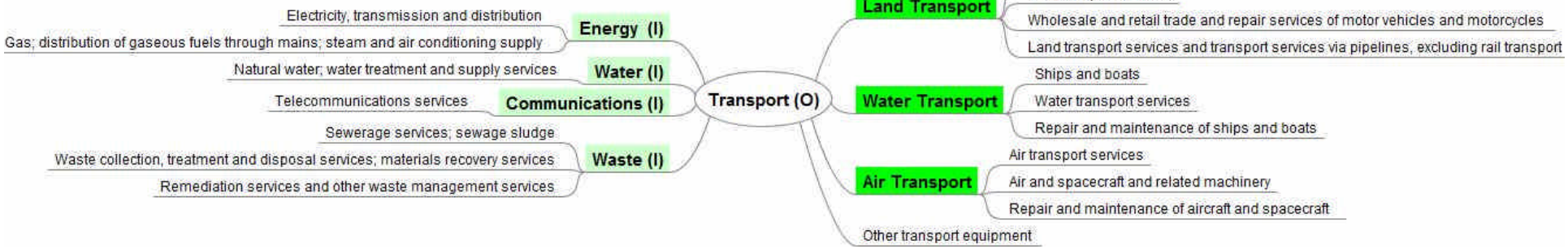
Infrastructure Interdependencies



Infrastructure: Transport Energy Water Waste Transport Communication

Inputs: 7 IOGs

Outputs: 11 IOGs

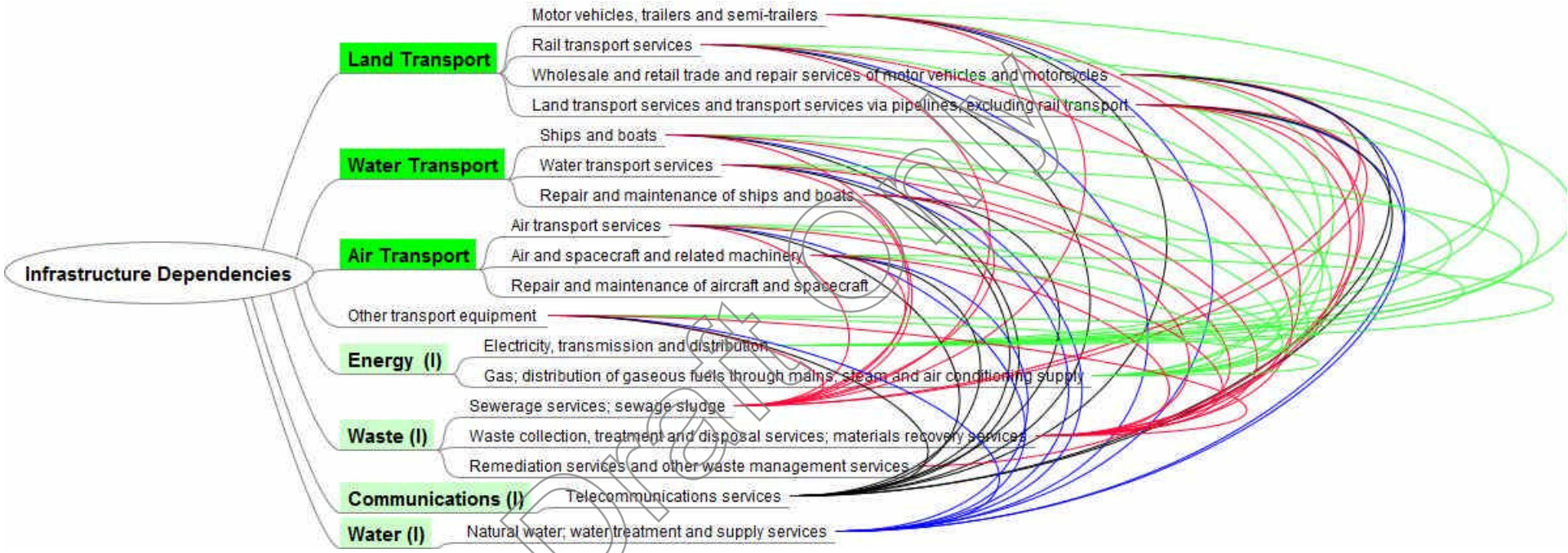


Infrastructure Interdependencies

		Energy		Water	Communication	Waste		
Transport		Electricity, transmission and distribution	Gas; distribution of gaseous fuels through mains; steam and air conditioning supply	Natural water; water treatment and supply services	Tele-communications services	Sewerage services; sewage sludge	Waste collection, treatment and disposal services; materials recovery services	Remediation services and other waste management services
Land Transport	Motor vehicles, trailers and semi-trailers	✓	✓	✓	✓	✓	✓	✗
	Rail transport services	✓	✓	✓	✓	✓	✓	✗
	Wholesale and retail trade and repair services of motor vehicles and motorcycles	✓	✓	✓	✓	✓	✓	✗
	Land transport services and transport services via pipelines, excluding rail transport	✓	✓	✓	✓	✓	✓	✓

Transport		Energy		Water	Communication	Waste		
		Electricity, transmission and distribution	Gas; distribution of gaseous fuels through mains; steam and air conditioning supply	Natural water; water treatment and supply services	Tele-communications services	Sewerage services; sewage sludge	Waste collection, treatment and disposal services; materials recovery services	Remediation services and other waste management services
Water Transport	Ships and boats	✓	✓	✓	✓	✓	✓	✗
	Water transport services	✓	✓	✓	✓	✓	✓	✗
	Repair and maintenance of ships and boats	✗	✗	✗	✗	✓	✓	✗
Air Transport	Air transport services	✓	✓	✓	✓	✓	✓	✗
	Air and spacecraft and related machinery	✓	✓	✓	✓	✓	✓	✗
	Repair and maintenance of aircraft and spacecraft	✗	✗	✗	✓	✗	✗	✗
Other Transport		✓	✓	✓	✓	✓	✓	✗

Infrastructure Interdependencies



Green: dependency from Energy

Red: dependency from Waste

Blue: dependency from Water

Black: dependency from **Communications**

Empirical Findings and Analysis

STEP 2: Tables with the empirical data

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

Value added: GVA Consumed by Transport

Value created: GVA Consumed - GVA Produced by Transport

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

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

	GVA Consumption (1990)						
	Transport (£Million)	Energy (£Million)	Waste (£Million)	Communications (£Million)	Water (£Million)	Other Goods/ Services	Total Production (£Million)
GVA Produced by Transport	5,745 9,754	3 72	N/A	20 281	1 20	21,368 72,527	27,137 82,654
	GVA Production (1990)						
	Transport (£Million)	Energy (£Million)	Waste (£Million)	Communications (£Million)	Water (£Million)	Other Goods/ Services	Total Consumption (£Million)
GVA Consumed by Transport	5,745 9,754	0 753	N/A	0 571	0 43	4,111 22,822	9,856 33,943
	Capital Value Creation (1990)						
	Transport (£Million)	Energy (£Million)	Waste (£Million)	Communications (£Million)	Water (£Million)	Other Goods/ Services	Total Value (£Million)
Transport	0	-678	0	-270	-22	66,962	+65,992
	GVA Consumption (1984)						
	Transport (£Million)	Energy (£Million)	Waste (£Million)	Communications (£Million)	Water (£Million)	Other Goods/ Services	Total Production (£Million)
GVA Produced by Transport	7,974	358	N/A	152	11	50,650	59,145
	GVA Production (1984)						
	Transport (£Million)	Energy (£Million)	Waste (£Million)	Communications (£Million)	Water (£Million)	Other Goods/ Services	Total Consumption (£Million)
GVA Consumed by Transport	7,974	606	N/A	411	65	33,284	42,340
	Capital Value Creation (1984)						
	Transport (£Million)	Energy (£Million)	Waste (£Million)	Communications (£Million)	Water (£Million)	Other Goods/ Services	Total Value (£Million)
Transport	0	-248	0	-259	-54	17,366	+16,805

Empirical Findings and Analysis

Step 3: 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).

Value created

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

$$b_i = \frac{Det(b_i)}{Det}, \quad i = 1,\ldots,5 \qquad \text{(Cramer's rule)}$$

Empirical Findings and Analysis

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

- X_{cr1}: value created from Energy, $X_{cr1} \in [606, \quad 1{,}765]$
- X_{cr2}: value created from Waste, $X_{cr2} \in [0, \quad 380]$
- X_{cr3}: value created from Communication, $X_{cr3} \in [411, \quad 1{,}628]$
- X_{cr4}: value created from Water, $X_{cr4} \in [43, \quad 82]$

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**!

Conclusions and Recommendations

- The hypothesis of **Economic Value Interdependencies of Transport Infrastructure** was verified with some deviations.
  - Energy, Waste and Water growth adds value to Transport (propositions were verified)
  - Communication growth deducts value to Transport (proposition was verified)
- Transport infrastructure dependencies ranking :

1) Water
2) Waste
3) Energy
4) Communication

Conclusions and Recommendations

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

- X_{cr1}: value created from Energy, $X_{cr1} \in [606, \quad 1{,}765]$
- X_{cr2}: value created from Waste, $X_{cr2} \in [0, \quad 380]$
- X_{cr3}: value created from Communication, $X_{cr3} \in [411, \quad 1{,}628]$
- X_{cr4}: value created from Water, $X_{cr1} \in [606, \quad 1{,}765]$

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.

Conclusions and Recommendations

Thank you for your attention!