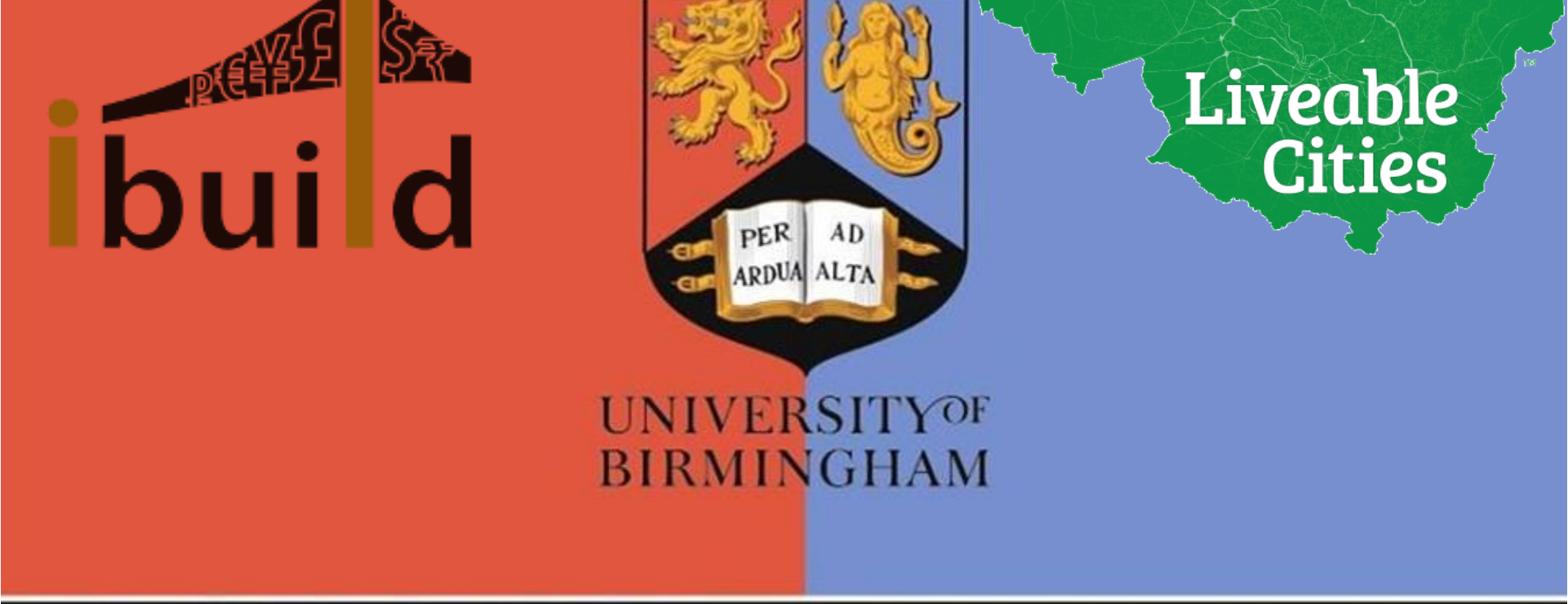

Infrastructure Interdependencies: Transport sector economic dependency with other critical infrastructure sectors in the UK

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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)

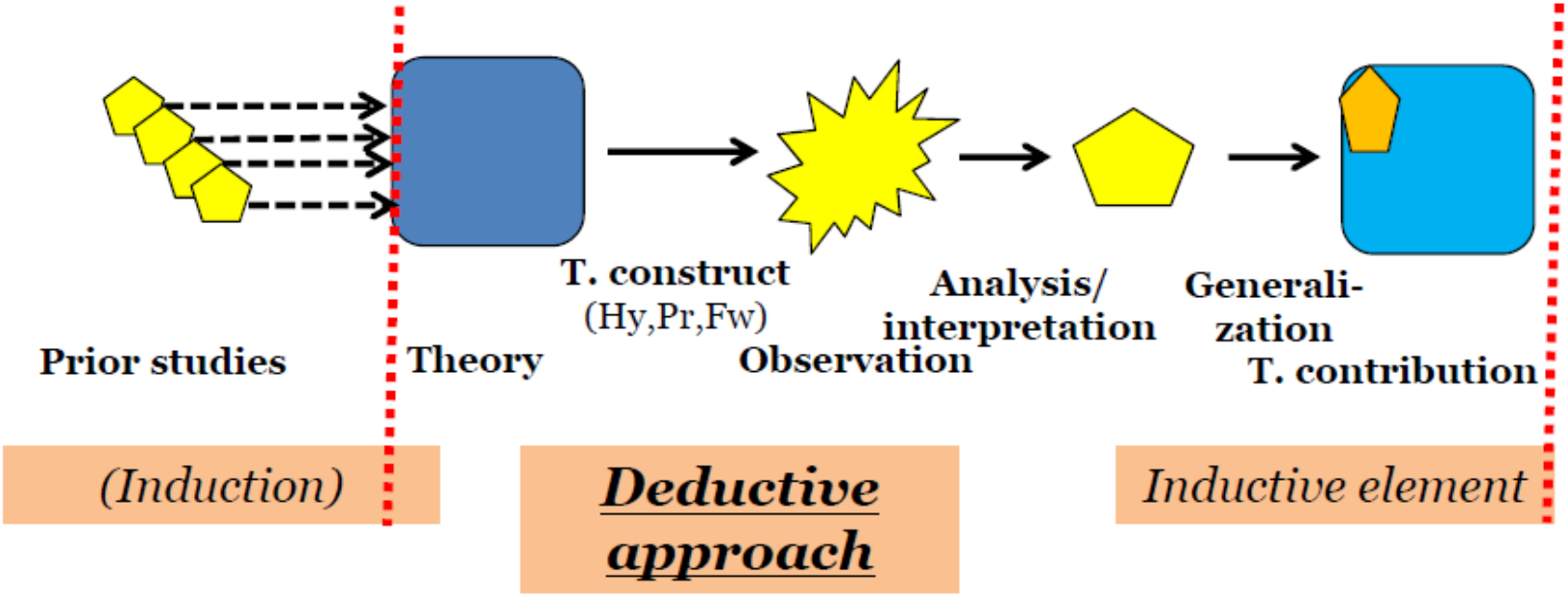
- *Understand the Value Interdependencies of Transport Infrastructure (this presentation)*
- *Devise a new Transport Business Model that takes account on these interdependencies (future research)*

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

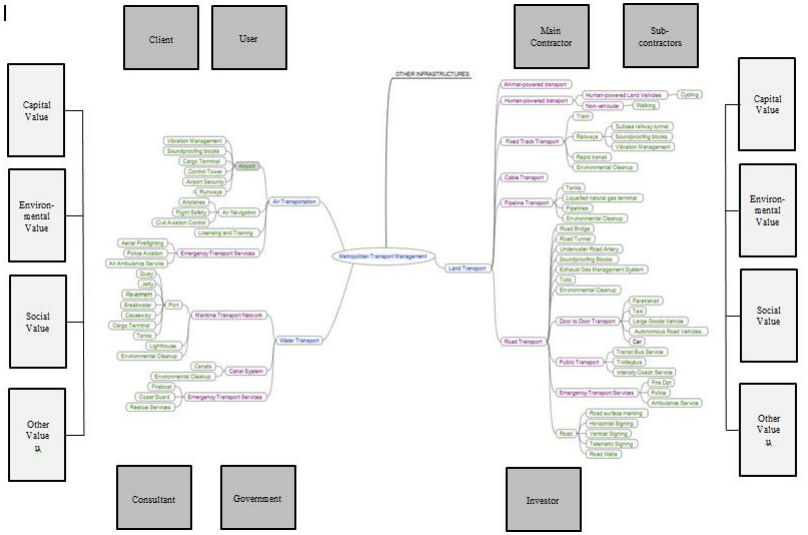
$Y_c = b_0 + b_1 \cdot X_1 + b_2 \cdot X_2 + \ldots + b_v \cdot X_v$ (*Giannopoulos, 2002*), where

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 III, **TOMORROW 11:00-12:00**)
  - Sigmoid functions:

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

- Business Model



Infrastructure Interdependencies

Empirical Data

	A	B	AS	AT	AU	AV	BB	BC	BD	BE	BF	BG	BL	BM	BN	BO	BV
1	2010 Input-Output Analytical Tables																
2	Input-Output table (domestic use, basic prices, product by product)								716	7	960						
3	£ million		62 878				1 454		13 657	1 030	489	1 449					
4	**MENU**		43	109	3 164	3 316	579		19								181
5			Product							Product			Product				Product
6			29	30.1	30.3	30OTHER	35.1	35.2-3	36	37	38	39	49.1-2	49.3-5	50	51	61
7		Product	Motor vehicles, trailers and semi-trailers	Ships and boats	Air and spacecraft and related machinery	Other transport equipment - 30.2/4/9	Electricity, transmission and distribution	Gas; distribution of gaseous fuels through mains; steam and air conditioning supply	Natural water; water treatment and supply services	Sewerage services; sewage sludge	Waste collection, treatment and disposal services; materials recovery services	Remediation services and other waste management services	Rail transport services	Land transport services and transport services via pipelines, excluding rail transport	Water transport services	Air transport services	Telecommunications services
50	29	Motor vehicles, trailers and semi-trailers	5 406	2	4	13	30	8	10	12	11	0	1	10	1	0	1
51	30.1	Ships and boats	0	3	0	0	0	0	0	0	0	0	0	0	1	0	0
52	30.3	Air and spacecraft and related machinery	8	1	322	0	0	0	0	0	0	0	0	1	0	78	1
53	OTHER	Other transport equipment - 30.2/4/9	0	0	0	76	0	0	0	0	0	0	1	0	0	0	0
59	35.1	Electricity, transmission and distribution	314	116	126	21	16 278	5 785	355	25	37	3	185	385	41	75	265
60	35.2-3	Gas; distribution of gaseous fuels through mains; steam ar	149	42	36	13	5 244	3 368	17	7	6	0	22	111	9	18	32
61	36	Natural water; water treatment and supply services	19	4	6	1	28	24	18	2	44	0	0	12	0	1	4
62	37	Sewerage services; sewage sludge	5	2	4	0	3	2	7	860	146	10	5	13	6	5	8
63	38	Waste collection, treatment and disposal services; materia	7	5	2	1	7	6	12	340	898	0	13	56	22	48	25
64	39	Remediation services and other waste management servic	0	0	0	0	0	0	0	0	0	30	0	0	0	0	
69	49.1-2	Rail transport services	5	1	2	2	1	1	0	1	4	0	8	2	1	1	3
70	49.3-5	Land transport services and transport services via pipeline:	53	5	8	11	5	7	8	32	954	4	44	1 083	19	30	165
71	50	Water transport services	13	1	3	2	0	1	0	1	9	0	6	9	1 881	11	9
72	51	Air transport services	2	0	3	1	0	0	0	0	2	0	0	2	2	65	2
79	61	Telecommunications services	4	3	17	4	59	32	27	55	52	2	31	294	69	92	982
135		Total consumption	19 151	1 245	5 576	1 306	35 740	19 028	1 723	1 935	5 544	130	5 618	16 611	7 422	5 949	12 028
136		Imported goods and services	8 472	675	5 303	151	7 339	5 140	217	57	787	10	314	4 159	1 953	3 496	8 600
137		Taxes less subsidies on products	127	12	64	8	662	289	63	42	270	25	90	1 177	188	804	233
138		Taxes less subsidies on production	143	30	43	9	637	589	442	82	126	1	- 528	517	13	1	522
139		Compensation of employees	6 680	1 200	3 509	570	3 178	2 779	930	1 573	2 239	106	3 667	14 134	3 223	3 505	10 698
140		Gross Operating Surplus	1 660	28	266	64	5 614	3 628	2 554	2 794	2 515	22	687	5 529	584	1 920	9 722
141		Total output	36 234	3 190	14 762	2 107	53 170	31 452	5 929	6 483	11 482	293	9 848	42 127	13 382	15 675	41 802
142		Production															

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

	A	B	AS	AT	AU	AV	BB	BC	BD	BE	BF	BG	BL	BM	BN	BO	BY
1	2010 Input-Output Analytical Tables																
2	Input-Output table (domestic use, basic prices, product by product)								716	7	960						
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5			Product							Product				Product			Product
6			29	30.1	30.3	30OTHER	35.1	35.2-3	36	37	38	39	49.1-2	49.3-5	50	51	61
7		Product	Motor vehicles, trailers and semi-trailers	Ships and boats	Air and spacecraft and related machinery	Other transport equipment - 30.2/4/9	Electricity, transmission and distribution	Gas; distribution of gaseous fuels through mains; steam and air conditioning supply	Natural water; water treatment and supply services	Sewerage services; sewage sludge	Waste collection, treatment and disposal services; materials recovery services	Remediation services and other waste management services	Rail transport services	Land transport services and transport services via pipelines, excluding rail transport	Water transport services	Air transport services	Telecommunications services
50	29	Motor vehicles, trailers and semi-trailers	5 406	2	4	13	30	8	10	12	11	0	1	10	1	0	1
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52	30.3	Air and spacecraft and related machinery	8	1	322	0	0	0	0	0	0	0	0	1	0	78	1
53	OTHER	Other transport equipment - 30.2/4/9	0	0	0	76	0	0	0	0	0	0	1	0	0	0	0
59	35.1	Electricity, transmission and distribution	314	116	126	21	16 278	5 785	355	25	37	3	185	385	41	75	265
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61	36	Natural water; water treatment and supply services	19	4	6	1	28	24	18	2	44	0	0	12	0	1	4
62	37	Sewerage services; sewage sludge	5	2	4	0	3	2	7	860	146	10	5	13	6	5	8
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142		Production															

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

2005 version: 123 IOGs

1995 version: 138 IOGs

1990 version*: 123 IOGs

1984 version*: 102 IOGs

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

Infrastructure Interdependencies

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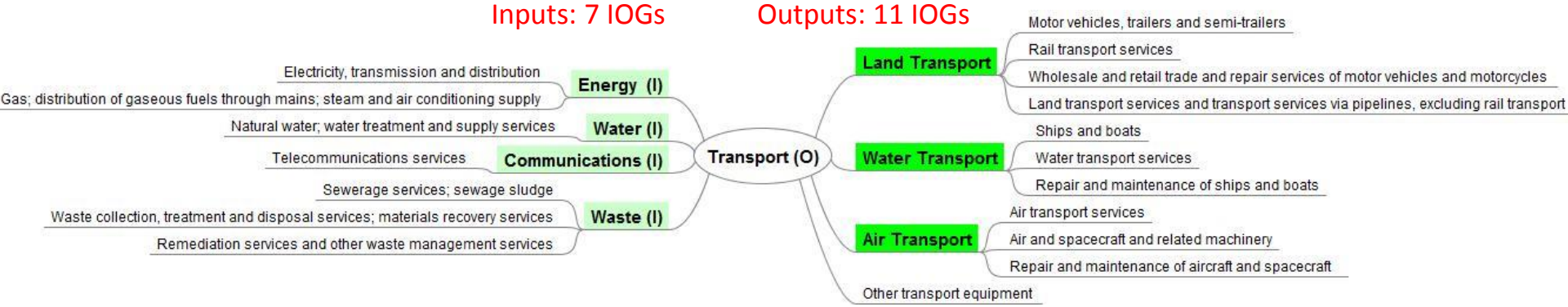
142		Production															

Infrastructure: Transport Energy Water Waste Transport Communication

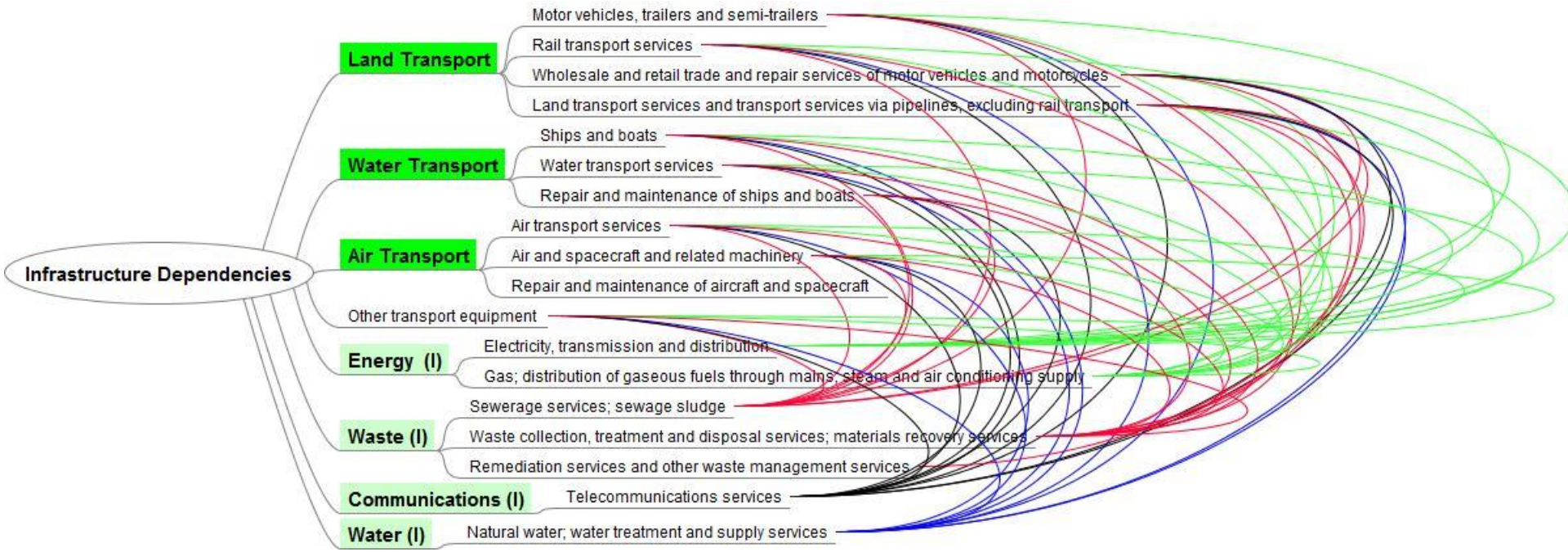


Infrastructure Interdependencies

		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	✓	✓	✓	✓	✓	✓	✓

		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
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: Five linear equations for five unknown variables can be solved with Cramer's rule:

Value added

$$\begin{bmatrix} -1{,}610 & 838 & -333 & -24 & 1 \\ -1{,}397 & 148 & -875 & -33 & 1 \\ -845 & 107 & -507 & -25 & 1 \\ -678 & 0 & -270 & -22 & 1 \\ -248 & 0 & -259 & -54 & 1 \end{bmatrix} \cdot \begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \\ b_5 \end{bmatrix} = \begin{bmatrix} 74{,}447 \\ 124{,}245 \\ 92{,}785 \\ 65{,}992 \\ 16{,}805 \end{bmatrix}$$

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

Empirical Findings and Analysis

$$Y_a = 9.80 \cdot X_1 + 14.8 \cdot X_2 - 133.81 \cdot X_3 + 1{,}62275 \cdot X_4 + 72{,}205.63$$

- X_1 : value added from Energy
- X_2 : value added from Waste
- X_3 : value added from Communication
- X_4 : value created from Water

This equation shows the economic interdependences (added value) between the different sections, but not the actual value creation.

This happens because we calculate the VALUE ADDED by each sector to Transport without considering how much value was added to each sector by Transport. The value created is the difference between the value added and the value produced.

Empirical Findings and Analysis

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

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

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

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_{cr2}: value created from Waste
- X_{cr3}: value created from Communication
- X_{cr4}: value created from Water

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

Thank you for your attention!