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*)
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:
    \[ f(x) = \tanh(x) \text{ and/or } f(x) = \text{erf}(\frac{\sqrt{\pi}}{2}x) \]

- Business Model
Infrastructure Interdependencies

Empirical Data

<table>
<thead>
<tr>
<th>Product</th>
<th>Product</th>
<th>Eu 3.2</th>
<th>Eu 4.2</th>
<th>Eu 5.2</th>
<th>Eu 6.2</th>
<th>Eu 7.2</th>
<th>Eu 8.2</th>
<th>Eu 9.2</th>
<th>Eu 10.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor vehicles, ships, and transport machinery</td>
<td>Motor vehicles, ships, and transport machinery</td>
<td>2.9</td>
<td>3.9</td>
<td>4.9</td>
<td>5.9</td>
<td>6.9</td>
<td>7.9</td>
<td>8.9</td>
<td>9.9</td>
</tr>
<tr>
<td>Other transport equipment</td>
<td>Other transport equipment</td>
<td>5.4</td>
<td>6.4</td>
<td>7.4</td>
<td>8.4</td>
<td>9.4</td>
<td>10.4</td>
<td>11.4</td>
<td>12.4</td>
</tr>
<tr>
<td>Natural gas treatment and supply services</td>
<td>Natural gas treatment and supply services</td>
<td>3.0</td>
<td>4.0</td>
<td>5.0</td>
<td>6.0</td>
<td>7.0</td>
<td>8.0</td>
<td>9.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Pipeline services</td>
<td>Pipeline services</td>
<td>1.0</td>
<td>2.0</td>
<td>3.0</td>
<td>4.0</td>
<td>5.0</td>
<td>6.0</td>
<td>7.0</td>
<td>8.0</td>
</tr>
<tr>
<td>Telecommunications services</td>
<td>Telecommunications services</td>
<td>0.5</td>
<td>1.5</td>
<td>2.5</td>
<td>3.5</td>
<td>4.5</td>
<td>5.5</td>
<td>6.5</td>
<td>7.5</td>
</tr>
</tbody>
</table>

Total: | | 15.0 | 20.0 | 25.0 | 30.0 | 35.0 | 40.0 | 45.0 | 50.0 |

*Note: The table above represents a portion of the data related to infrastructure interdependencies. The full dataset includes a comprehensive analysis of various sectors including transportation, energy, and telecommunications.*
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)

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:

\[ GVA = GDP + \text{subsidies on products} - \text{taxes on products} \]
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
- **2005 version**: 123 IOGs
- **1990 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

Inputs: 7 IOGs

Outputs: 11 IOGs

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
Ships and boats
Water transport services
Repair and maintenance of ships and boats
Air transport services
Air and spacecraft and related machinery
Repair and maintenance of aircraft and spacecraft
## Infrastructure Interdependencies

<table>
<thead>
<tr>
<th>Transport</th>
<th>Energy</th>
<th>Water</th>
<th>Communication</th>
<th>Waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor vehicles, trailers and semi-trailers</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Rail transport services</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Wholesale and retail trade and repair services of motor vehicles and motorcycles</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Land transport services and transport services via pipelines, excluding rail transport</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

- **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**
  - Electricity, transmission and distribution
  - Gas; distribution of gaseous fuels through mains; steam and air conditioning supply

- **Water**
  - Natural water; water treatment and supply services

- **Communication**
  - Tele-communications services

- **Waste**
  - Sewerage services; sewage sludge
  - Waste collection, treatment and disposal services; materials recovery services
  - Remediation services and other waste management services

- ✓ Indicates a positive interdependence.
- ✗ Indicates a negative interdependence.

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*Note: The table details the interdependencies between various infrastructure sectors, such as energy, water, communication, and waste management, highlighting the dependencies and exclusions.*
<table>
<thead>
<tr>
<th>Transport</th>
<th>Energy</th>
<th>Water</th>
<th>Communication</th>
<th>Waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>Electricity, transmission and distribution</td>
<td>Gas; distribution of gaseous fuels through mains; steam and air conditioning supply</td>
<td>Natural water; water treatment and supply services</td>
<td>Tele-communications services</td>
</tr>
<tr>
<td>Water</td>
<td>Ships and boats</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Transport</td>
<td>Water transport services</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Repair and maintenance of ships and boats</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Air</td>
<td>Air transport services</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Transport</td>
<td>Air and spacecraft and related machinery</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Repair and maintenance of aircraft and spacecraft</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Other Transport</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
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

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

**Value added:** GVA Consumed by Transport

**Value created:** GVA Consumed - GVA Produced by Transport
<table>
<thead>
<tr>
<th></th>
<th>Transport (£Million)</th>
<th>Energy (£Million)</th>
<th>Waste (£Million)</th>
<th>Communications (£Million)</th>
<th>Water (£Million)</th>
<th>Other Goods/Services</th>
<th>Total Production (£Million)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>GVA Produced by Transport</strong></td>
<td>32,248</td>
<td>368</td>
<td>528</td>
<td>753</td>
<td>49</td>
<td>189,351</td>
<td>223,297</td>
</tr>
<tr>
<td><strong>GVA Consumption (2005)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>GVA Consumed by Transport</strong></td>
<td>32,248</td>
<td>1,765</td>
<td>380</td>
<td>1,628</td>
<td>82</td>
<td>62,949</td>
<td>99,052</td>
</tr>
<tr>
<td><strong>GVA Production (2005)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Capital Value Creation (2005)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transport</td>
<td>0</td>
<td>-1,397</td>
<td>+148</td>
<td>-875</td>
<td>-33</td>
<td>126,402</td>
<td>+124,245</td>
</tr>
<tr>
<td><strong>GVA Consumption (1995)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>GVA Produced by Transport</strong></td>
<td>35,783</td>
<td>164</td>
<td>321</td>
<td>509</td>
<td>29</td>
<td>141,158</td>
<td>177,964</td>
</tr>
<tr>
<td><strong>GVA Production (1995)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>GVA Consumed by Transport</strong></td>
<td>35,783</td>
<td>1,009</td>
<td>214</td>
<td>1,016</td>
<td>54</td>
<td>47,103</td>
<td>85,179</td>
</tr>
<tr>
<td><strong>Capital Value Creation (1995)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transport</td>
<td>0</td>
<td>-845</td>
<td>+107</td>
<td>-507</td>
<td>-25</td>
<td>94,055</td>
<td>+92,785</td>
</tr>
</tbody>
</table>
### GVA Consumption (1990)

<table>
<thead>
<tr>
<th>GVA Produced by Transport</th>
<th>Transport (£Million)</th>
<th>Energy (£Million)</th>
<th>Waste (£Million)</th>
<th>Communications (£Million)</th>
<th>Water (£Million)</th>
<th>Other Goods/Services</th>
<th>Total Production (£Million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GVA Produced by Transport</td>
<td>5,745 9,754</td>
<td>3 72</td>
<td>N/A</td>
<td>20 281</td>
<td>1 20</td>
<td>21,368 72,527</td>
<td>27,137 82,654</td>
</tr>
</tbody>
</table>

### GVA Production (1990)

<table>
<thead>
<tr>
<th>GVA Consumed by Transport</th>
<th>Transport (£Million)</th>
<th>Energy (£Million)</th>
<th>Waste (£Million)</th>
<th>Communications (£Million)</th>
<th>Water (£Million)</th>
<th>Other Goods/Services</th>
<th>Total Consumption (£Million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GVA Consumed by Transport</td>
<td>5,745 9,754</td>
<td>0 753</td>
<td>N/A</td>
<td>0 571</td>
<td>0 43</td>
<td>4,111 22,822</td>
<td>9,856 33,943</td>
</tr>
</tbody>
</table>

### Capital Value Creation (1990)

<table>
<thead>
<tr>
<th>Transport (£Million)</th>
<th>Energy (£Million)</th>
<th>Waste (£Million)</th>
<th>Communications (£Million)</th>
<th>Water (£Million)</th>
<th>Other Goods/Services</th>
<th>Total Value (£Million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport</td>
<td>0</td>
<td>-678</td>
<td>0</td>
<td>-270</td>
<td>-22</td>
<td>66,962</td>
</tr>
</tbody>
</table>

### GVA Consumption (1984)

<table>
<thead>
<tr>
<th>GVA Produced by Transport</th>
<th>Transport (£Million)</th>
<th>Energy (£Million)</th>
<th>Waste (£Million)</th>
<th>Communications (£Million)</th>
<th>Water (£Million)</th>
<th>Other Goods/Services</th>
<th>Total Production (£Million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GVA Produced by Transport</td>
<td>7,974 50,650</td>
<td>358</td>
<td>N/A</td>
<td>152</td>
<td>11</td>
<td>50,650</td>
<td>59,145</td>
</tr>
</tbody>
</table>

### GVA Production (1984)

<table>
<thead>
<tr>
<th>GVA Consumed by Transport</th>
<th>Transport (£Million)</th>
<th>Energy (£Million)</th>
<th>Waste (£Million)</th>
<th>Communications (£Million)</th>
<th>Water (£Million)</th>
<th>Other Goods/Services</th>
<th>Total Consumption (£Million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GVA Consumed by Transport</td>
<td>7,974 33,284</td>
<td>606</td>
<td>N/A</td>
<td>411</td>
<td>65</td>
<td>33,284</td>
<td>42,340</td>
</tr>
</tbody>
</table>

### Capital Value Creation (1984)

<table>
<thead>
<tr>
<th>Transport (£Million)</th>
<th>Energy (£Million)</th>
<th>Waste (£Million)</th>
<th>Communications (£Million)</th>
<th>Water (£Million)</th>
<th>Other Goods/Services</th>
<th>Total Value (£Million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transport</td>
<td>0</td>
<td>-248</td>
<td>0</td>
<td>-259</td>
<td>-54</td>
<td>17,366</td>
</tr>
</tbody>
</table>
Empirical Findings and Analysis

Step 3: Five linear equations for five unknown variables can be solved with Cramer's rule:

Value added

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

\[b_i = \frac{\text{Det}(b_i)}{\text{Det}}, \quad i = 1, \ldots, 5\]
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 \textbf{VALUE ADDED} by each sector to \textbf{Transport} \textbf{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

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

\[b_i = \frac{\text{Det}(b_i)}{\text{Det}}, \quad i = 1, \ldots, 5\]
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!