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Scott Kelly, Peter Tyler & Douglas Crawford-Brown

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Exploring vulnerability and interdependency of UK infrastructure using key-linkage analysis

Scott Kelly[1], Peter Tyler[2], Douglas Crawford-Brown[3]

University of Cambridge, Department of Land Economy, 4CMR
Infrastructure Transitions Research Consortium (ITRC)

ABSTRACT

It has been argued that in the UK there has been underinvestment in critical infrastructure over the last two decades. This in turn has resulted in infrastructure that is less capable of assisting the UK economy to grow. Evidence to substantiate this claim has remained elusive. This article seeks to augment the relevant evidence by under-taking an in-depth analysis of the inter-linkages and economic contributions from infrastructure within the UK. It explores the relationship between nine infrastructure sectors and the rest of the UK economy using key-linkages. Each infrastructure sector is shown to be unique in the way it interacts with other economic sectors and in the form of contribution it makes to the economy overall. Infrastructure is a necessary and important part of economic development. The analysis finds that over the last 23 years there has been a decline in the relative economic contribution from infrastructure to UK GVA. Only two infrastructure sectors increased their relative contribution to GVA since 1992 these were the water transport sector and sewerage and sanitary services sector. Railway transport and gas distribution have had the largest relative decline in contribution towards UK GVA with relative contributions decreasing by over 50% since 1992.

1.1 INTRODUCTION

Physical infrastructure systems are integral to the proper functioning of all modern economies. However, the link between infrastructure availability, economic growth and productivity is still the subject of much uncertainty and debate within the literature (Straub, 2008). Although it is clear that infrastructure investment is a crucial factor in economic development it is less clear what forms of infrastructure are most important for different forms of economic activity to occur. There are also concerns, including from the UK Treasury itself, that the United Kingdom is under-investing in critical infrastructure (ICE, 2009; Bottini et al., 2012) .

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[1] Corresponding author: Scott Kelly, Cambridge Centre for Climate Change Mitigation Research (4CMR), University of Cambridge. Email: sjk64@cam.ac.uk, Mobile: +44 01223 764867
[2] Professor Pete Tyler. Department of Land Economy, University of Cambridge. email: pt23@hermes.cam.ac.uk
[3] Professor Doug Crawford-Brown. Cambridge Centre for Climate Change Mitigation Research (4CMR), University of Cambridge. Email: djc77@cam.ac.uk

Infrastructure such as transport systems, water, sanitation services, energy networks and telecommunications represent a large portfolio of public expenditure ranging from one-third to one-half of total public investment for most developed countries (Kessides, 1993). Yet, prior to the 1990's infrastructure as an analytic concept was absent from most economic thinking, entering only as a curious but inadequate component of the notion of capital (Prud'Homme, 2004). While most formal research studying the relationship between infrastructure and the economy since the 1990's has tended to take a macroeconomic perspective, findings are mixed with some consensus that infrastructure capital has a significant positive effect on economic output and growth (Démurger, 2001; Cain, 1997; Chakraborty and Nandi, 2011; Pradhan and Bagchi, 2013). Kessides (1993) suggests the difficulty in designating direct causal links for the economic impact of infrastructure arises because it is hard to attribute any firm conclusions from studies that take such highly aggregated measures attempting to capture all possible externalities and spillover effects that occur as a result of investment in infrastructure.

Infrastructure systems are also particularly vulnerable to the effects of disasters. It has been observed that both the frequency and intensity of natural disasters has been increasing with costs now rising year on year (The Economist, 2012; New Scientist, 2012). With increasing risks from extreme weather events caused by the onset of climate change and a concentration of populations now living in vulnerable coastal cities, river deltas and along earth quake fault-lines, the risks of damage to infrastructure systems is now an acute issue. In the event of a disaster, direct infrastructure failure may have cascading effects on other economic systems. Therefore, understanding the interconnectedness of infrastructure with the rest of economy is critical for assessing the effects of disasters and developing resiliency strategies.

Key-linkages analysis is a rigorous economic approach that allows the interdependencies between different economic sectors to be quantitatively determined and the wider systemic effects estimated. This article shows how Key-linkages analysis can be used to understand the role and purpose of nine independent infrastructure sectors within the UK economy[4]. It identifies the sectors of the UK economy that are most dependent on infrastructure for the

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provision of goods and services and estimates the economic contribution that different infrastructure sectors provide to the UK economy when both direct, indirect, employment and income effects are considered together.

The next section provides an introduction to key-linkages analysis and a formal definition of what backward and forward linkages represent. Methods and mathematical derivations are outlined. The following section describes the data along with definitions for each economic activity. Finally the results of this analysis are discussed along with the conclusions that bring together main findings.

1.2 KEY-LINKAGES ANALYSIS

In 2008 the total contribution of infrastructure to gross value added across all infrastructure sectors in the United Kingdom was 9.2%.[5] From Figure 1 it is clear that land transport[6] has contributed the largest share to gross economic activity followed by telecommunications and then electricity production and distribution. The absolute contribution towards GVA from each infrastructure sector increased between 1992 and 2008 (Figure 1). However, it is more instructive to look at the relative change in contribution from infrastructure as a percentage of final GVA in each year. Between 1992 and 2008 the change in overall GVA for the UK economy was 137%, increasing from £547.5 billion to £1,295.7 billion. However, over the same period, the combined sum contribution from all infrastructure sectors towards GVA decreased. As shown in Figure 2 the relative contribution from infrastructure towards GVA has decreased in seven out of nine infrastructure sectors. Only in water transport and sewerage and sanitary services has there been a relative increase in contribution towards GVA compared to 1992.

This information on the size of prominent infrastructure sectors in the UK does not allow us to understand how they relate to other sectors in the economy. Key-linkages analysis can be used to do this. Key-linkages analysis was first used to identify key sectors of the economy that may constrain or encourage economic growth (Chenery and Watanabe 1958). Key-linkage metrics are calculated using information contained within input output tables and therefore provides a robust source of data for identifying the economic structure and

[5] Using the final demand method the total contribution of infrastructure towards GDP is 8.16%
[6] Land transport includes all commercial land transport activities plus the sale of fuel and motor-vehicle distribution & repair.

importance of both backward and forward linkages between the economic sectors of an economy. The relative size of economic linkages can be used to highlight strengths, weaknesses and vulnerabilities within an economy. Importantly, key linkages analysis helps identify bottlenecks and vulnerabilities in supply chains so that the effects of disruptions can be avoided or minimised through new investment, better reporting and new policy. This is particularly useful for looking at the effects of disasters which may lead to cascading infrastructure failure.

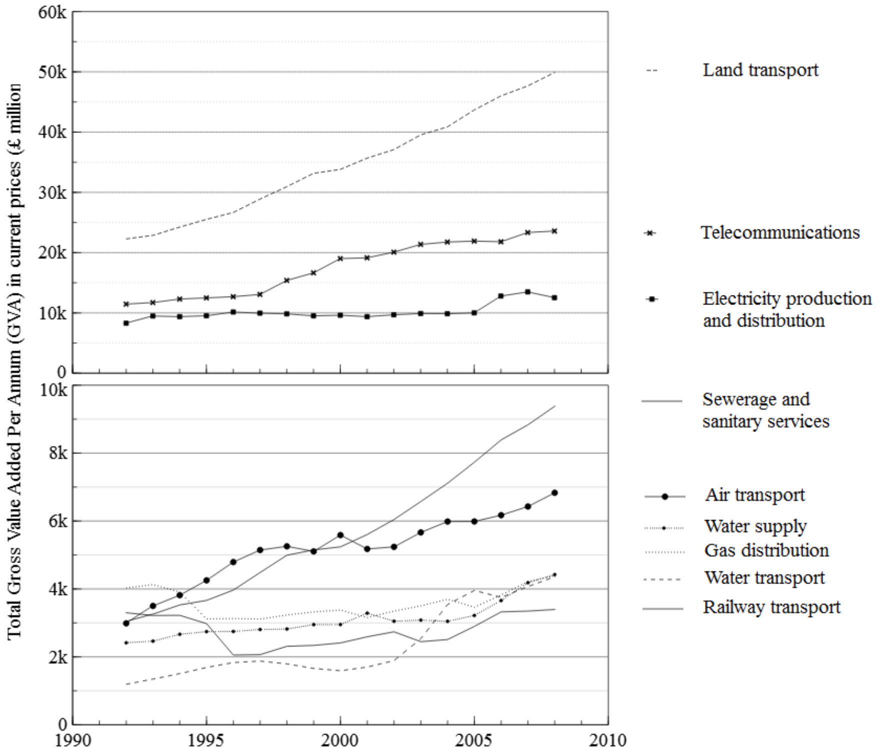

Figure 1: Total gross value added by infrastructure service type

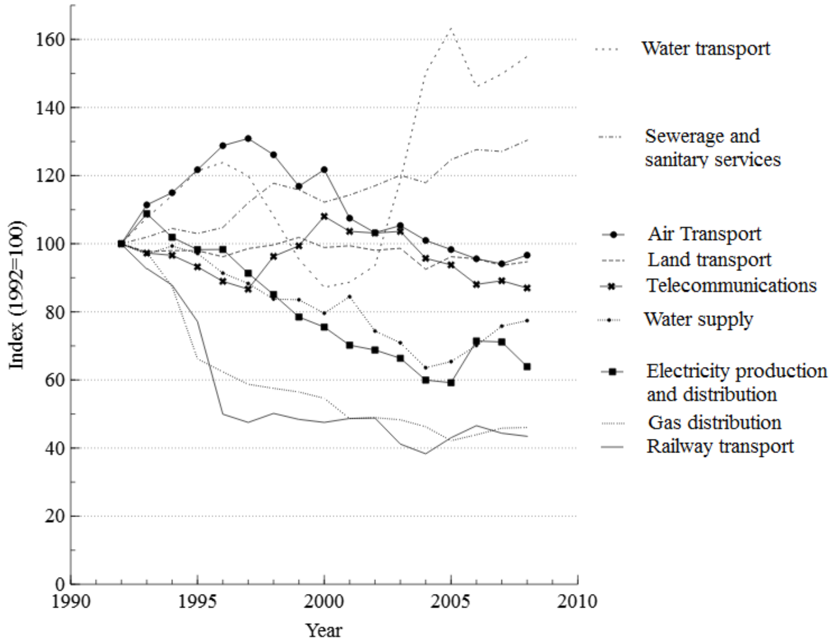

Figure 2: Change in relative contribution[1] to final GVA

1. Relative contribution refers to the percentage contribution of value added towards final GVA in any given year.

Table 1: Relative contribution of UK infrastructure to GVA between 1992 and 2008 at basic prices[1]

Infrastructure sector	GVA at basic prices (£ million)		GVA as percentage of total GVA	
	1992	2008	1992	2008
Electricity production and distribution	8,288	12,533	1.51	0.97
Gas distribution	4,026	4,386	0.74	0.34
Water supply	2,414	4,423	0.44	0.34
Land transport	22,261	49,887	4.07	3.85
Railway transport	3,301	3,394	0.60	0.26
Water transport	1,188	4,357	0.22	0.34
Air transport	2,987	6,831	0.55	0.53
Telecommunications	11,456	23,585	2.09	1.82
Sewerage and sanitary services	3,040	9,379	0.56	0.72

1. Basic prices are the amount received by the producer for the purchase of a unit of good or service produced minus any tax payable and plus any subsidy receivable. It excludes transport charges invoiced separately by the producer.
Source: (ONS, 2012)

Key-linkages analysis was developed in parallel with the advancement of input output methods and can be regarded as an important compliment to this area of research. The development of key-linkage analysis over the last forty years has contributed to important breakthroughs on international trade, the sources behind economic growth and improved understanding on the structural effects of economic development from undeveloped economies as well as providing insight into many other economic problems requiring empirical analysis on the interdependencies between economic sectors (Chenery and Watanabe 1958) .

The first practical application using the concept of economic linkages to measure the importance of different relationships amongst economic sectors was first proposed by Rasmussen in his PhD thesis titled “Studies in inter-sectoral relations” (Rasmussen, 1956). Although Leontief (1951) presented a framework for measuring the interdependence between economic sectors, the methods described by Rasmussen substantially expanded on Leontief’s original approach with a particular focus on the interdependence of prices between economic sectors. Rasmussen’s major contribution was to present what he called “summary measures of the inverse matrix” to designate a degree of importance of an individual industry within an economy, as shown by the breadth of that sector’s contribution and dependence upon all other sectors in the economy. Rasmussen described the crucial feature of a ‘key’ industry as its ability to call forth a relatively large increase in the output of other sectors when the final demand for its own products increased, while at the same time its output must expand more than average to meet the final demand on other sectors. Today these concepts are now commonly defined as backward and forward linkages within the economic supply chain.

Early pioneers in the field of key-linkage analysis such as Chenery and Watanabe (1958a) and Hirschman (1958) established the basic methodology and showed how the method could be used to study the structure of economies and for identifying key-sectors. Their main contribution was to postulate that economic development and structural change proceed through sectors with above-average linkages with other sectors of the economy acting to accelerate and amplify initially small changes and ultimately affect the whole economy (Lenzen, 2003). Several authors then started to apply these new methods to explain the constraints and opportunities for growth in developing economies (Hazari, 1970; Acharya and Hazari, 1971; Diamond, 1974; Laumas, 1975; Meller and Marfán, 1981; Andreosso-O’Callaghan and Yue, 2004; Baer et al., 1987; Beyers, 1976; Bulmer-Thomas, 1978; Clements and Rossi, 1991). The same method has also been applied in the identification of key sectors within developed economies also (Hanly, 2012; Robles Teigeiro and Sanjuán Solís, 2005; Los, 2004; Lenzen, 2003; Dietzenbacher, 1992). More recently the method has been used to study the linkage effects of specific sectors within national economies such as construction, manufacturing, and the marine sector (Morrissey and O’Donoghue, 2013; Song et al., 2006; Alcántara and Padilla, 2003; Stilwell et al., 2000). This research represents the first time that key-linkages has been used to study the relationship between infrastructure and other economic sectors. This is particularly relevant within a UK context for understanding the hidden connections and relationships between infrastructure the wider economy.

2.1. Backward and forward linkages

At the centre of the key-linkage hypothesis is the concept of backward and forward linkage indices as well as direct and indirect effects. Direct backward linkages can be straightforwardly defined as the column sum of the technical coefficient matrix A_{ij} thus representing the direct input requirements of production as a function of total output. On the other hand, total backward linkages - that is direct plus indirect effects - are defined as the column sum of the Leontief inverse L_{ij} where $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$ and represent all input requirements ad infinitum to produce one extra unit of output for sector *j*. While direct effects capture immediate changes to total output caused by adjustments occurring in one sector, indirect effects capture changes to total output due to interdependencies that occur through other sectors of the economy in the supply chain.

Direct forward linkages can be defined similarly to direct backward linkages. The key distinction here is that instead of referring to direct input requirements, forward linkages refer to the direct output requirements or sales from sector *j* directly feeding into other producing sectors of the economy. Total forward linkages – that is direct plus indirect effects – are defined as the total sales or output ad infinitum consumed by other sectors of the economy. Direct and indirect effects can therefore be estimated for both backward and forward linkages within an economy. Figure 3 schematically shows the distinction between backward, forward, direct and indirect effects.

Each sector, *i*, takes its inputs from other sectors in the economy and supplies output to each sector in the economy. Sectors are made up of firms and firms also demand and supply goods and services to and from other firms belonging to the same sector – this is referred to as intra-sectoral trade as opposed to inter-sectoral trade. Indeed, it is often found that intra-sectoral transactions represent a significant component of value within a sector's value chain. Figure 3 below shows the connections occurring across all sectors of the economy where sector $i....n \quad \forall \ i$ and *n* is the number of sectors represented by the input output table. In this schematic final demand is also shown $f_{(i)}$ and includes the final consumption of goods produced by each sector. While forward linkages capture the transactions from sectors down the supply chain demanding goods and services from sector *i,* backward linkages capture all linkages back up the supply chain that provide goods and services to sector *i*. Dashed arrows in Figure 3 represent the round by round transactions in an economy ad infinitum. Total output is therefore represented by the sum of the round by round intermediate demand plus final demand.

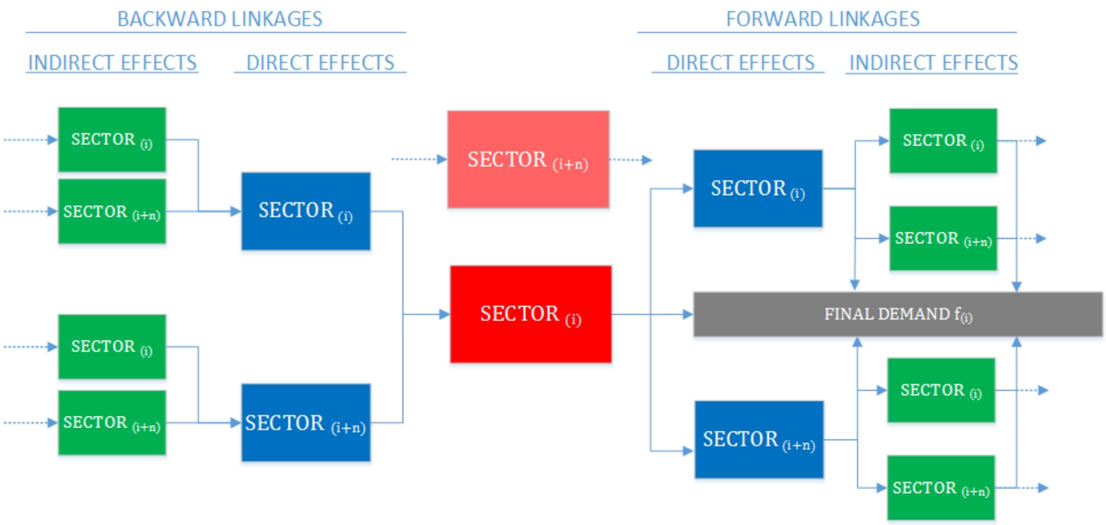

Figure 3: Backward, forward, indirect and direct effects

2.2 Estimating linkage measures

As indicated above, analysts differ as to the best approach for measuring linkage effects within an economy. There are several linkage measures that can be employed to measure the importance or 'keyness' of infrastructure sectors in the UK economy. The following section examines the main approaches. It begins by describing the Rasmussen method and its strengths and weaknesses as a measure of inter-sectoral linkage and for estimating backward, forward, direct and indirect effects within an economy. The advantages of the Ghosh model over the Leontief model for estimating forward linkages is also discussed. A definition is provided for the coefficient of variation before extending this model to use the Ghosh approach. This is then followed by a description and analysis of the hypothetical extraction approach which will be used to estimate the overall economic contribution from different infrastructure sectors in the UK economy.

The earliest work on linkage measures was completed by Rasmussen where he recommended the use of two linkage measures, these were: *the power of dispersion* and the *sensitivity of dispersion* (Hewings, 1982). Today these are similarly defined as backward and forward linkages respectively and l_{ij} is defined as a typical element of the Leontief inverse matrix $\mathbf{L}$; giving $\mathbf{i}'\mathbf{L}_j$ and $\mathbf{L}_i\mathbf{i}$ are typical column and row sums of the Leontief inverse matrix respectively and $\bar{L}$ is the average of all elements of the Leontief matrix. Normalised indices were developed as follows:

Power of dispersion: $$U_j = \frac{\mathbf{i}'\mathbf{L}_j / n}{\bar{L}} = \frac{\mathbf{i}'\mathbf{L}_j . \bar{L}}{n} \quad (1.1)$$

Sensitivity of dispersion: $$U_i = \frac{\mathbf{L}_i\mathbf{i} / n}{\bar{L}} = \frac{\mathbf{L}_i\mathbf{i} . \bar{L}}{n} \quad (1.2)$$

where n is the number of sectors in the economy and U_i and U_j are the Rasmussen indices. When U_j or $U_i > 1$ it implies that the power of dispersion U_j or sensitivity of dispersion U_i of the inverse matrix is greater than the average value of the matrix as a whole. Thus one unit change in final demand from a sector where $U_j > 1$ will generate above average increases in economic activity. On the other hand, for a sector with $U_i > 1$ it means that when output across all sectors increase uniformly, output from sector i will increase above average to meet this new demand.

The awkward interpretation given to the traditional Leontief forward linkage resulted in several authors questioning the use of the Leontief inverse for estimating forward linkages (Jones 1976). In a standard Leontief framework the sum of all the rows in one column for a particular sector j will represent the backward linkage effect in the economy, while the sum of all columns in one row i will represents the forward linkage effect in the economy. After further investigation the economic interpretation of a forward linkage in a Leontief based framework is purely hypothetical and does not have a general economic interpretation. For example the row sum giving, say a value of 2.0 for the i th industry says that if final demand in each and every industry increases by one unit, then output of the i th industry must increase by 2.0 units to meet this demand (consisting of 1.0 unit of its own delivery to final demand and 1.0 unit as inputs to other industries). This hypothetical example would never occur in reality as final demand from each and every sector would never uniformly increase by one unit. Jones (1976) criticizes this method using the Korean ‘rice’ sector as an example where it is shown to deliver less than 14 percent of its output directly to intermediate uses but leads to significant expansion of all industries ranking it as the 7th highest Leontief inverse row sum in a 340 sector model. The explanation is that 14 percent constituted a large fraction of inputs into a number of small industries which is then enlarged by the equal expansion of all industries. Jones then explains "it is not very enlightening to ask what happens to an industry if all industries, large or small, are to expand by identical unit increments. Jones then proposed that the 'output inverse' (as opposed to the Leontief 'input inverse') may produce more meaningful measures of forward linkages. This led to the development of a forward linkage measure based on the elements of the Ghosh model (Miller and Blair, 2009). In the Ghosh approach direct forward linkages can be estimated by the column sum (sum of all rows) for the ith sector of the output matrix. This is simply the value of total intermediate sales from sector i as a proportion of i's total output x_i. Similar to the calculation of the Leontief 'input inverse' derived from the input coefficients matrix, $\mathbf{A}$ (Equation 1.3), the Ghosh 'output inverse' is derived from the output coefficients matrix $\mathbf{B}$ (Equation 1.4).

$$\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1} \quad (1.3)$$

$$\mathbf{G} = (\mathbf{I} - \mathbf{B})^{-1} \quad (1.4)$$

While the input coefficients matrix (technical coefficients matrix) is derived from intermediate inputs as a share of total outputs (including value added) the output coefficient matrix is derived from intermediate sales as a share of total sales (including final demand)[7]. The economic interpretation of this new forward linkage measure can be interpreted as follows. The row sum (sum of columns) of the 'output inverse' for the ith sector represents the change in output from sector i resulting from one unit change in input from sector i.

Other contributions and adaptations to the key linkages literature have come from Chenery and Wantanabe (1958b), Yotopoulos and Nugent (1973), Laumas (1975) and Jones (1976). In its simplest form, the strength of the backward linkage of sector j (the amount by which the production from sector j depends on inter-industry inputs) is given by the sum of elements in the jth column of the direct input coefficient matrix (Miller and Blair 2009,

[7] The output inverse was first defined by Ghosh (1958) to represent supply constrained economies and marked the start of a long-running debate within the literature that continues to this day (Rose and Allison, 1989; Dietzenbacher, 1997; De Mesnard, 2007; de Mesnard, 2009; Guerra and Sancho, 2011; Oosterhaven, 2012)

p.556). Direct backward linkages for an economy can be written in matrix form as $BL(d)_j = \mathbf{i}'\mathbf{A}$ or in general form as given by Equation (1.5).

$$BL(d)_j = \sum_{i=1}^{n} a_{ij} \tag{1.5}$$

As the coefficients of the technical input coefficient matrix measure direct effects only, these are known as direct (d) backward linkages. To capture both the direct and indirect linkages of an economy (i.e. total requirements) column sums of the Leontief inverse are used. This is represented in matrix form as $BL(t)_j = \mathbf{i}'\mathbf{L}$ or in general form as Equation (1.6) .

$$BL(t)_j = \sum_{i=1}^{n} l_{ij} \tag{1.6}$$

There is some disagreement in the literature on whether the on-diagonal elements in A or L should be included or netted out of the summations. If the purpose of the study is to estimate the Hirchman's input provision (or derived demand effects) then it is normal for the on-diagonal elements to be included. Alternatively if the interest is on the sector's "backward dependence" or linkage with the rest of the economy then they should be omitted. In this analysis the on diagonal elements will be retained as intra-sectoral demand can contribute a significant component of a sector's total input or outputs requirements.

As with backward linkages there is also a definition for forward linkages. Following the argument presented above for using the Ghosh model as opposed to the Leontief model for estimating forward linkages, a similar definition can be found for forward linkages (Beyers, 1976; Jones, 1976; Miller and Blair, 1985, p.558). In this case direct and total forward linkage effects are defined by Equation (1.7) and (1.8) respectively, where b_{ij} represent the elements of the $\mathbf{B}$ matrix and g_{ij} represent the elements of the Ghosh matrix $\mathbf{G}$.

$$FL(d)_i = \sum_{j=1}^{n} b_{ij} \tag{1.7}$$

$$FL(t)_i = \sum_{j=1}^{n} g_{ij} \tag{1.8}$$

In matrix form Equation (1.7) and (1.8) are written as $FL(d)_i = \mathbf{Bi}$ and $FL(t)_i = \mathbf{Gi}$ respectively. The sum of direct forward and direct backward linkages are defined as total direct linkages (TDL) while total linkages (TL) includes both direct and indirect effects for both forward and backward linkages. The backward and forward linkages provided above give an absolute measure of a sectors dependence on other sector's in the economy.

Without a frame of reference it is difficult to know whether such links are important when compared to the rest of the economy. Using Rasmussen's framework of normalising each sector, it is possible to estimate a relative indicator that compares the 'keyness' of each sector when that sector is compared to other sectors of the economy. One limitation of the approaches identified by the literature thus far is that they only return a value of 'keyness' as an aggregate indicator for each sector. When looking at 'keyness' it is also necessary to study what sectors are contributing the most or are most important to each sectors 'keyness' within the economy. With knowledge of the relative contribution provided by different economic sectors to a single sector's overall 'keyness' it is possible to identify the potential for 'dependency risks'. In this research the five most important economic sectors to each infrastructure sector are found and ranked for both backward dependence and forward dependence. By studying the structure, size and type of the top five most important economic sectors, a more holistic picture can be painted of the interdependencies, reliance and potential propagation of risks from infrastructure failure to other sectors of the economy. In order to estimate the normalised intersectoral dependence, several new equations were developed. For backward direct and total linkages these values are respectively calculated using Equations (1.9 and 1.10) and for forward direct and total linkages these are respectively calculated using Equation (1.11 and 1.12).

$$\mathbf{BL}(d) = \frac{\mathbf{A}n}{i'\mathbf{A}i} \tag{1.9}$$

$$\mathbf{BL}(t) = \frac{\mathbf{L}n}{i'\mathbf{L}i} \tag{1.10}$$

$$\mathbf{FL}(d) = \frac{\mathbf{B}n}{i'\mathbf{B}i} \tag{1.11}$$

$$\mathbf{FL}(t) = \frac{\mathbf{G}n}{i'\mathbf{G}i} \tag{1.12}$$

The solution to Equations (1.9-1.12) result in four unique matrices that contain measures of the normalised 'keyness' indicators across different economic sectors. Using the 'keyness' values for each sector it is then possible to rank the relative 'keyness' of different economic sectors. Thus, the sum linkage measures for each infrastructure sector represent an overall measure of 'keyness' for that sector compared against all other sectors for the economy (i.e. this is the solution of Equation 1.7 and 1.8).

Although the method described above allows the calculation of both direct and indirect effects they do not give an indication of the variability of interconnectedness between sectors. It is not only the relative interconnectedness that effects supply chains but also the number of connections held between different sectors of the economy. In other words, sectors that have a large share of their sales coming from a small number of sectors will have different risks than sectors with high key linkages. A solution to the problem of sector variability was proposed by Hazari (1970) by introducing a measure of variance for each sector of the economy, namely: V_j and V_i. A high value of V_j can be interpreted as showing that a particular industry draws heavily on only a few sectors (high variance) while a low value of V_j can be interpreted as a sector drawing relatively evenly from each of the sectors in the economy (low variance). Similarly a high value of V_i suggests a particular industry supplies to a few industries while a low value of V_i suggests this industry supplies relatively evenly across all sectors. A sector that draws evenly across a greater number of sectors (low V_j) is thought to be more resilient than a sector with concentrated dependence on only a few sectors. Hazari (1970) developed two equations for estimating backward and forward variability linkages[8]. These equations were improved in this study in several important respects. As discussed forward linkages as best calculated using the Ghosh model, so the Ghosh variant of Hazari's equation was derived. Secondly, Hazari's original approach did not give a relative indicator of variability compared against other sectors. Hazari's

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[8] Hazari's equations, Backward linkages: $V_j = \sqrt{\frac{1}{m-1}\sum_{i=1}^{m}\left(l_{ij} - \frac{1}{m}\sum_{i=1}^{m} l_{ij}\right)^2} \Big/ \frac{1}{m}\sum_{i=1}^{m} l_{ij}$

Forward linkages: $V_i = \sqrt{\frac{1}{m-1}\sum_{j=1}^{m}\left(l_{ij} - \frac{1}{m}\sum_{j=1}^{m} l_{ij}\right)^2} \Big/ \frac{1}{m}\sum_{j=1}^{m} l_{ij}$

equations were therefore updated to provide a relative measure from which sectors could be compared against each other. The newly derived equations to represent relative variability are shown below in Equation (1.13) and (1.14).

$$V_j = \frac{\sqrt{\frac{1}{m-1}\sum_{i=1}^{m}\left(l_{i(j)} - \frac{1}{m}\sum_{i=1}^{m} l_{i(j)}\right)^2}}{\sqrt{\frac{1}{m^2-1}\sum_{i=1}^{m}\sum_{j=1}^{m}\left(l_{ij} - \frac{1}{m^2}\sum_{i=1}^{m}\sum_{j=1}^{m} l_{ij}\right)^2}} \qquad (i = 1,.....,m) \tag{1.13}$$

$$V_i = \frac{\sqrt{\frac{1}{m-1}\sum_{j=1}^{m}\left(g_{(i)j} - \frac{1}{m}\sum_{j=1}^{m} g_{(i)j}\right)^2}}{\sqrt{\frac{1}{m^2-1}\sum_{i=1}^{m}\sum_{j=1}^{m}\left(l_{ij} - \frac{1}{m^2}\sum_{i=1}^{m}\sum_{j=1}^{m} l_{ij}\right)^2}} \qquad (\text{j}=1,.....,\text{m}) \tag{1.14}$$

Finally, the hypothetical extraction method can be used to estimate the value a sector has within the economy by its contribution to economic output. This method was originally developed by Strassert (1968) and empirically implemented by Schultz (1977; 1976). In this approach the objective is to quantify how the total output of an economy changes if that sector were eliminated from the economy (Miller and Blair, 2009, p.563). This can be accomplished by simply removing the i th row and j th column from the $\mathbf{A}$ matrix and i th element of final demand $\mathbf{f}$ and then re-estimating the Leontief inverse. This can also be accomplished by simply replacing these elements with zeros. Using the notation of $\bar{\mathbf{A}}_{(j)}$ to represent the $(n-1)\times(n-1)$ matrix missing sector j and $\bar{\mathbf{f}}_{(j)}$ for the corresponding reduced final demand vector, output in the reduced economy is therefore found from Equation (1.15)

$$\bar{\mathbf{x}}_{(j)} = \left[\mathbf{I} - \bar{\mathbf{A}}_{(j)}\right]^{-1}\bar{\mathbf{f}}_{(j)} \tag{1.15}$$

In the original full n-sector model output is then $\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f}$ and the difference in total output between the full model $\mathbf{x}$ and the reduced model $\bar{\mathbf{x}}_{(j)}$ is therefore found using Equation (1.16) which gives an aggregate measure of the economy's overall loss if sector j was hypothetically removed.

$$T_j = \mathbf{i'x} - \mathbf{i'x}_{(j)} \qquad (1.16)$$

That is, T_j gives the difference in total output for an economy with and without sector j. Some authors argue that the first term of Equation (1.16), namely, $\mathbf{i'x}$ should exclude the original output x_j. If sector j were omitted from the total output of the full sector model, then T_j would measure $j's$ importance to the remaining sectors in the economy excluding intra-sectoral trade (Miller and Blair, 2009, p.563). As the purpose of this analysis is to determine the contribution of sector j on the economy before and after it has been extracted, x_j will not be removed and remain as part of the first term of Equation (1.16).

In either case it is possible to normalise Equation (1.16) relative to the rest of the economy. This is achieved by division of total gross output and multiplication by 100 to give an estimate of the percentage decrease in total economic activity due to the hypothetical extraction of the sector in question. This is achieved using Equation (1.17).

$$\bar{T}_j = 100\left[\left(\mathbf{i'x} - \mathbf{i'x}_{(j)}\right) / \mathbf{i'x}\right] \qquad (1.17)$$

The multiplier effects of employment and income within the nine infrastructure sectors is also considered. The structural macroeconomic effects of employment are known to be very different across different economic sectors. Income multipliers measure the change in income through compensation to employees through the economy as a result of changes to final demand. Direct income multipliers (labour-input coefficients) measure the direct contribution to employees in sector i due to a unit change in final demand in sector j. Direct impacts are thus the first round of impacts that occur on an industry to satisfy an increase in final demand from that industry.

$$a_{n+1,j} = \frac{Z_{n+1,\mathrm{j}}}{X_{\mathrm{j}}} \qquad 1.18$$

From Equation 1.18 $a_{n+1,j}$ represents the direct income generated for each unit of output from sector j and $Z_{n+1,j}$ represents the compensation to employees in sector j and X_j represents total output from sector j. The term $a_{n+1,j}$ therefore represents a measure of the direct compensation to employees due to an increase in demand from sector j. Indirect impacts or ‘simple multipliers’ are the additional economy wide impacts that must also increase to meet an increase in final demand. Type I income multipliers consider both direct and indirect flows within the economy relative to the employee compensation from the j th sector. When estimating Type I multipliers it is therefore necessary to invoke the Leontief inverse to calculate the additional requirements in production required from the rest of the economy to meet a unit increase in final demand from sector j . The simple household multiplier is shown in 1.19 and the Type I income multiplier is shown by Equation 1.20.

$$m(h)_j = \sum_{i=1}^{n} a_{n+1,\mathrm{i}} l_{ij} \qquad 1.19$$

$$m(h)_1^I = \frac{\sum_{i=1}^{n} a_{n+1,i} l_{ij}}{a_{n+1,j}} \qquad 1.20$$

The term $m(h)_j$ from Equation 1.19 gives the simple income multiplier for each sector of the economy. The term $a_{n+1,i}$ represents a row vector of direct income requirements (labour-input coefficients) and l_{ij} is the Leontief inverse. The term $m(h)_j^I$ is the term used for Type I multipliers and represents how much income from $a_{n+1,j}$ needs to expand to meet an increase in final demand. The Type I income multiplier is therefore a relative measure and depends on the existing employee compensation for each sector.

Type II multipliers are estimated similarly to Type I income multipliers but first the model needs to be closed with respect to households. This is achieved by endogenising compensation to employees as a row vector and household final demand as column vector within the direct requirements matrix. This is done to capture Keynesian based induced income effects where additional compensation to employees will lead to further expenditure on goods and services in the economy having the effect of increasing demand even further than considering indirect effects alone. Endogenising the effects of employment is therefore accomplished by augmenting the technical coefficient matrix with the household sector (employee compensation and household final demand). The Leontief inverse of the closed model is represented by the equation $\bar{L} = (I - \bar{A})$. The elements of $\bar{L}$ thus include the direct, indirect and induced effects of employment income. Estimating the induced income multiplier effects is achieved using Equation 1.21 and Type II multipliers are calculated using Equation 1.22.

$$\bar{m}(h)_j = \sum_{i=1}^{n+1} a_{n+1,i}\bar{l}_{ij} \qquad 1.21$$

$$m(h)_j^{II} = \frac{a_{n+1,i}\bar{l}_{ij}}{a_{n+1,j}} \qquad 1.22$$

The interpretation of the total income multiplier is that it measures the increase in direct, indirect and induced demand required to meet a unit increase in new demand from sector j output. Similarly, Type II income multipliers estimate the expansion of incomes relative to existing incomes including the induced effects of increased household spending as a consequence of increased income. Thus, the induced multiplier effect described by Equation 1.21 estimates the additional compensation to employees due to increases in final demand. The Type II income multiplier places this estimate relative to existing employee compensation. It is therefore worth noting that a sector with low employee compensation may expand quickly when indirect and induced effects are considered giving large Type I and Type II income multipliers but the total contribution to the economy when compared against other sectors may still be low.

In order to get a true picture for the effect of income effects from different infrastructure sectors it is necessary to employ a variation of the hypothetical extraction method. Similar to the hypothetical extraction method already employed we define a complete technical coefficient matrix $\mathbf{A}$ $(n \times n)$ and a second technical coefficient matrix $\mathbf{A}_j^*$ $(n-1 \times n-1)$ obtained by removing the row and column of the corresponding sector j. Then by defining a vector of direct employment coefficients $\boldsymbol{\lambda}$ $(n \times 1)$ and a corresponding vector where the employment coefficients for sector j have been extracted $\boldsymbol{\lambda}_j^*$ it is possible to estimate the total employment linkages of sector j with the rest of the economy. This is given by Equation (1.23).

$$TEL_j = \boldsymbol{\lambda}'\left(\mathbf{I}-\mathbf{A}\right)^{-1}\mathbf{i} - \boldsymbol{\lambda}_j'\left(\mathbf{I}-\mathbf{A}_j^*\right)^{-1}\mathbf{i} \qquad (1.23)$$

In Equation (1.23) $\mathbf{i}$ is a summation vector and $\mathbf{I}$ is the identity matrix and is the same size as its matching technical coefficient matrix. TEL_j is therefore interpreted as the total employment linkages of sector j. In other words TEL_j summarises the impact on employment income (or hours worked or number of employees) directly for sector j but also indirectly from other sectors in the economy which are also affected (Meller and Marfán, 1981). After estimating TEL_j for each sector of the economy it is then possible to estimate the percentage by which income generated in the economy would reduce if sector j were hypothetically extracted from the economy.

$$\%Lab_j = \frac{TEL_j}{TEL} \times 100 \qquad 1.24$$

1.3 Data

Data used in this analysis are from the 2005 UK Input Output Analytical Tables (IOATs) and are the most recent tables produced by the Office for National Statistics available online (ONS, 2011). The tables are consistent with the 2009 editions of the United Kingdom National Accounts: The Blue Book (ONS, 2009a) and the United Kingdom Balance of Payments: The pink book (ONS, 2009b). The Supply and Use Tables (SUTs) are used to calculate the IOATs and provide a picture of the flows of products and services in the economy for a single year. They show the composition of uses and resources across institutional sectors and the inter-dependence of industries in order to reconcile production, income and expenditure approaches to the measurement of GDP. The presentation of the SUTs and IOATs are based on the European System of Accounts which itself is based on the United Nations System of National Accounts.

The 2005 IOATs are derived using 108 sector input-output groups (IOGs) consistent with the UK's Standard Industrial Classification 2003 (SIC (03)) for industries and Eurostat's Classification for Products by Activity (CPA (02)) for products. Including components of non-market output produced by general government and non-profit institutions serving households (NPISHs) the 108 sector IOGs are expanded to 123 sectors.

Using Input-Output aggregation methods each of the 123 sectors represented within the input output tables were reduced to 38 sectors to assist with interpretation, reporting and comparison. A list of these 38 sectors can be viewed in Appendix A and are based on the NACE 1.1 section classifications. During the aggregation procedure each infrastructure sector was retained making it possible to compare each infrastructure sector against each of the other sectors within the UK economy. With the exception of land transport each infrastructure sector was identified uniquely in the 2005 UK input output tables. For the case of land transport, economic activity was split across two sectors. One of these sectors was 'other land transport' and includes all land transport used for commercial purposes including activities providing urban or suburban transport of passengers on scheduled routes following a normally fixed time schedule. In this sector transport services may be carried out with motor bus, tramway, streetcar, trolleybus, underground and elevated railways, etc. It also includes transport by taxis, operation of school buses and coaches and freight transport by road. This sector excludes auxiliary transport services such as cargo handling , warehousing, repair and maintenance of transport facilities such as railway terminals and infrastructure and the operation of airport terminals. It also excludes transport via pipelines. The sector titled 'other land transport' excludes the sale of fuel but this can be found in the sector 'motor vehicle distribution & repair, fuel' and therefore these two sectors can be added together in aggregate giving a more accurate description of the land transport sector. The sector including the retail sale of fuel also includes the retail sale, maintenance and repair of motorcycles and motor vehicles but excludes vehicle manufacture and rent.

1.4 RESULTS

Sector 'keyness' is a relative concept and dependent on other sectors in the economy. Therefore, normalising each sector's 'keyness' allows the relative linkage effect of each sector to be determined. The analysis refers to each of 38 economic sectors defined in Annex (1). Studying the bar graph in Figure 4 showing the normalised direct backward linkages it is clear that (18) Electricity production and distribution, (19) Gas distribution and (22) Land transport have above average direct backward linkage dependence with other sectors in the economy (i.e. they are directly highly reliant on other sectors of the economy for the provision of goods and services).

All remaining infrastructure sectors have below average backward dependence while (29) Telecommunications and (20) Water supply have the lowest overall direct backward dependence on other sectors for the supply of goods and services. The top five most important sectors are ranked for each infrastructure sector and represented by different colours on the stacked bar chart; white indicates the combined importance of the remaining 33 sectors with lowest linkage measures. As shown in Figure 4, the top five most important sectors for backward dependence in each infrastructure sector are able to explain over two-thirds of infrastructure's relative direct backward linkage dependence. Both (19) Gas distribution and (18) Electricity production and distribution depend heavily on (3) Coal, gas mining and extraction and (18) Electricity production and distribution[9]. For the other infrastructure sectors there are several sectors that stand out as important: (31) Business services and real estate is an important sector across all infrastructure sectors; (4) Postal and courier services is an important sector for all transport sectors and (18) Electricity production and distribution is important for (20) Water supply and (22) Land transport. Small commuter trains, trams and the London Tube are all included within (22) Land transport.

Five infrastructure sectors have above average direct forward linkage effects when compared with the rest of the economy. These are (35) Sewerage and sanitary services; (29) Telecommunications; (25) Railway transport; (19) Gas distribution and (18) Electricity production and distribution. The sectors with the lowest direct forward linkage effect in order from lowest to highest are (26) Water transport; (20) Water supply; and, (27) Air transport. The first five most important sectors are generally not as important for direct forward linkages as direct backward linkages, but still explain a large proportion of the normalized forward linkage effect. Important economic sectors that rely on infrastructure services include (31) Business services and real estate; (23) Wholesale and retail distribution; and (38) Non Profit Institutions Serving Households (NPISH's).

[9] Electricity production and distribution relies heavily on itself in the production of electricity.

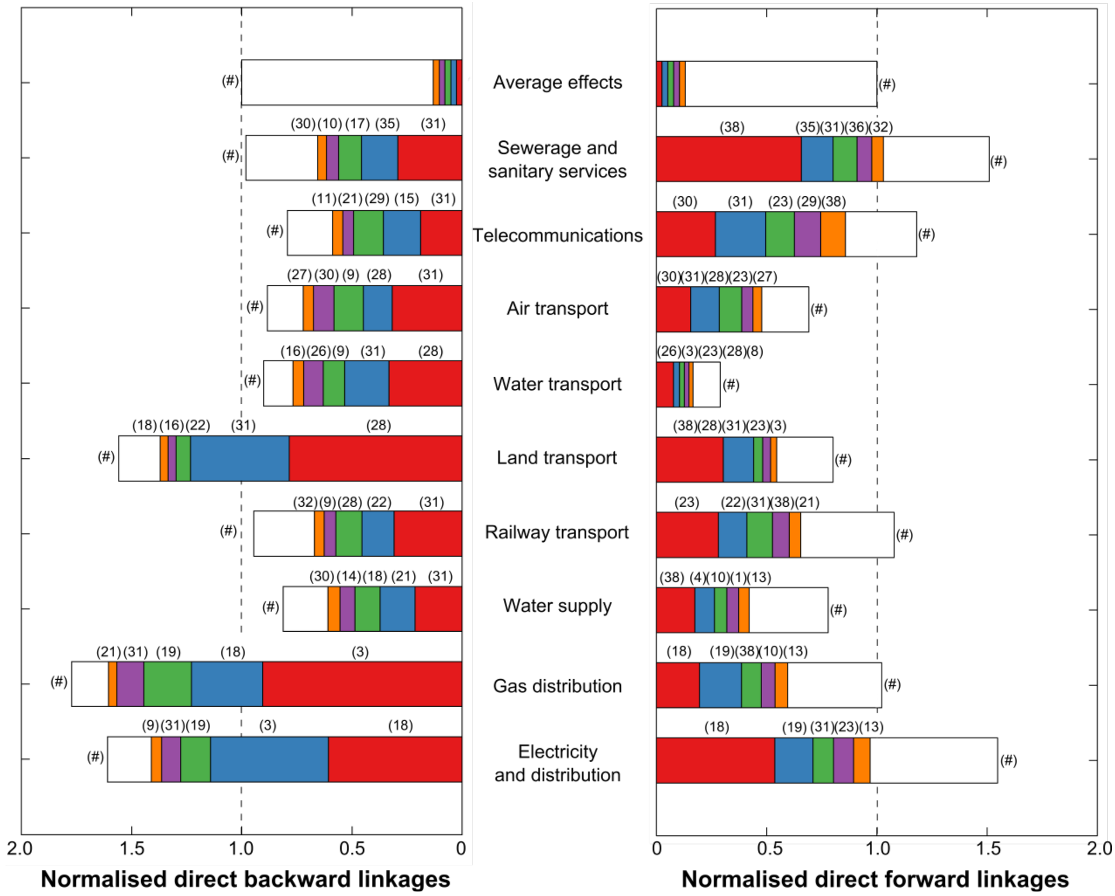

Figure 4: Normalised direct backward and forward linkage effects of infrastructure 'keyness'

Sectors with linkage effects greater than 1.0 indicate above average contribution, while sectors with linkage effects less than 1.0 represent below average contribution. The bar titled 'Average effects' has been included for comparison, and is a hypothetical example for what the average sector would look like. The average sector therefore has a backward and forward linkage effect of 1.0 and each sector linked to the average sector contributes equally (i.e. 1/38 of that sectors linkage dependence). For the remaining nine infrastructure sectors the five most important economic sectors have been ranked and given a colour based on that rank. Therefore, each infrastructure sectors total input dependence (backward linkage) and total output dependence (forward linkage) are provided. The white portion on each bar labelled with a hash tag represents the sum of all remaining sectors of the economy contributing or depending on each infrastructure sector.

Total effects on the other hand consider the round-by-round transactions that occur within an economy. Unlike direct effects total effects consider disruptions through the entire supply chain and therefore give a better indication for how the economy is affected overall. As shown in Figure 5 the total backward linkage effect is above average for (18) Electricity production and distribution; (19) Gas distribution and (22) Land transport. Total backward linkages are below average for every other infrastructure sector. When compared to direct effects the top five ranked sectors for total backward linkages explain a larger proportion of the linkage effect suggesting a few sectors have significant influence over infrastructure. When looking across all infrastructure sectors for total backward linkages, the most important sectors for infrastructure are (31) Business services and real estate, (30) Banking finance and insurance and (9) Coke ovens, refined petroleum and nuclear fuel. Once more,

(28) Postal and courier services has significant backward linkage effects across all transport sectors suggesting a sector it provides a large proportion of the revenue for transport services. For forward total linkages five infrastructure sectors have higher than average linkage effects. These are: (35) Sewerage and sanitary services, (29) Telecommunications; (25) Railway transport; (18) Gas distribution; and, (19) Electricity production and distribution. The sectors with the lowest total forward linkages with other sectors of the economy in order from lowest to highest are: (26) Water transport, (27) Air transport; (20) Water supply; and, (22) Land Transport. The most important forward linkage sectors with infrastructure are (31) Business services and real estate; (23) Wholesale and retail distribution; and, (38) Non Profit Institutions Serving Households (NPISH's).

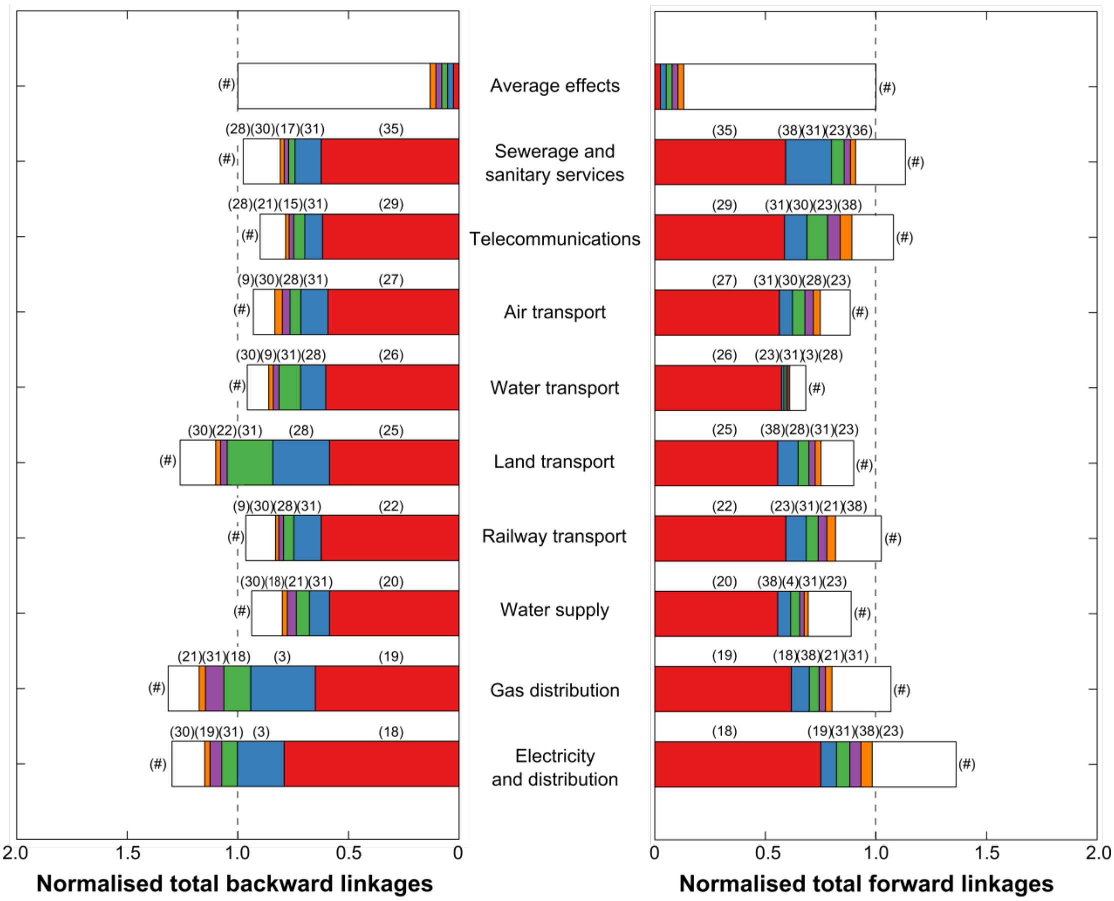

Figure 5: Normalised total backward and forward linkage effects of infrastructure 'keyness'

The variance or spread of the number of sectors purchasing or selling goods and services is an important indicator of vulnerability. If a sector sells its goods and services to a relatively small number of sectors or if infrastructure relies on goods and services from a small number of sectors then it may be vulnerable to disruptions occurring within its supply chain. In Figure 6 the backward and forward variance for each sector of the economy is shown. It is immediately obvious that far more sectors of the economy have higher forward variance than backward variance. This suggests that most sectors receive their goods and services relatively evenly from a large number of sectors in the economy (backward variance) but when it comes to the supply of goods and services, most sectors supply to a relatively small number of other sectors. Infrastructure appears to stand out as an exception to this general rule. For example (19) Gas distribution, (25) Railway transport and (26) Water transport appear to have higher backward variance when compared to forward variance. This suggests that infrastructure sectors rely on relatively few sectors of the economy to produce goods and services but then sell their goods and services to a relatively large number of other sectors of the economy.

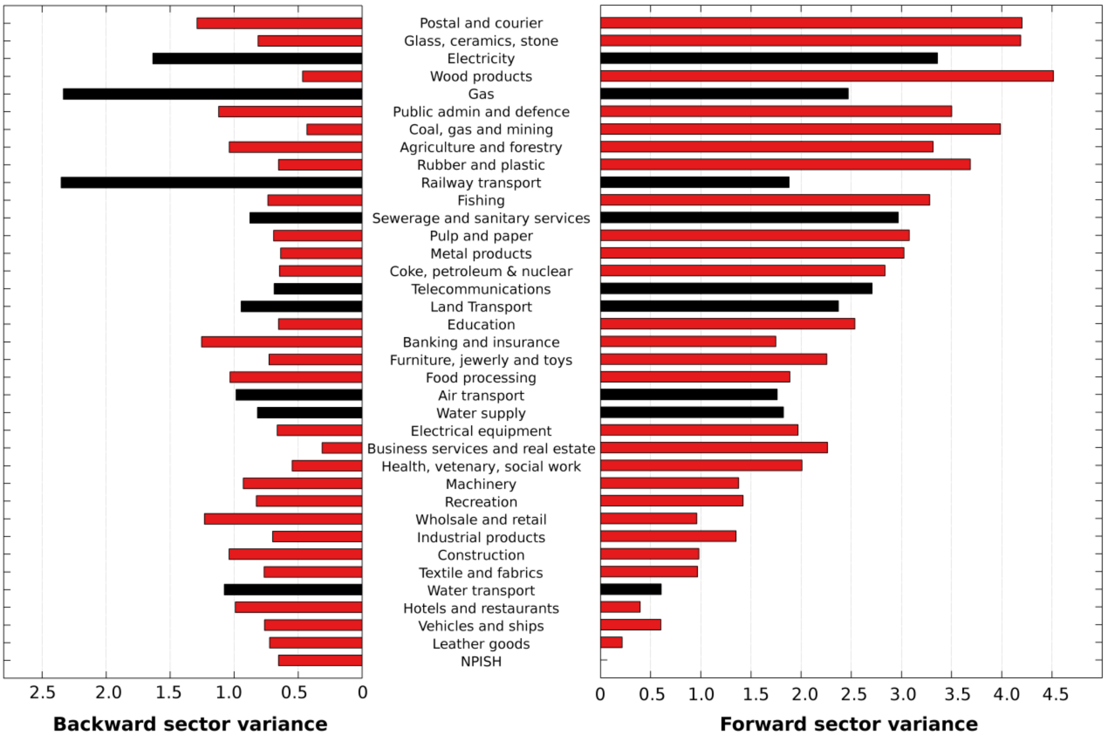

Figure 6: Backward and forward s linkage variance for multiple sectors

Relative variance is an indicator of diversity for both the demand (backward linkage) and supply (forward linkage) of goods and services in the economy. Values greater than 1.0 indicate above average variance relative the variance across the whole economy. Intra-sectoral demand and supply, that is the provision and supply of goods and services within a single sector have been netted out. This is because we are interested in understanding the diversity of trade external to each sector. A sector with high variance indicates significant trade across only a few sectors while low variance indicates trade that is spread relatively evenly across different sectors. The sum of backward variance and forward variance have been ranked from highest to lowest.

The economic contribution from infrastructure is calculated using the hypothetical extraction method. This process involves hypothetically removing a specific sector from the UK economy and then re-estimating total output. The subsequent decrease in total output can then be attributed as the value that sector provides to the economy overall. Estimating the relative value of final demand and intermediate demand is achieved by also hypothetically removing final demand for the sector being analysed and comparing this with the overall decrease in output. As shown in Table 2 the value that each infrastructure sector provides to the economy varies significantly. (22) Land transport provides the largest economic value to the economy followed by (35) Telecommunications and (18) Electricity production and distribution. Caution must be used when interpreting these results as the round by round effects of extracting a single sector from the economy will lead to decreases in economic output that are much greater than the output from the sector when considered on its own. As a consequence, if the total economic value from every sector in the economy were summed in this way it would equate to a number greater than the total output of the economy. Nevertheless it does provide a good summary measure of the round by round contributions made to the economy.

Table 2: Estimated economic value of infrastructure systems as function of total output

	Estimated value to economy based on final demand	Estimated value to economy based on intermediate demand	Total value to the UK economy	Value as percentage of total output
	(£billion)	(£billion)	(£billion)	%
(18) Electricity production and distribution	8.77	44.41	53.18	2.36
(19) Gas distribution	10.22	29.63	39.84	1.76
(20) Water supply	2.99	4.58	7.57	0.34
(22) Land transport	43.06	92.11	135.6	5.99
(25) Railway transport	5.14	12.64	17.78	0.79
(26) Water transport	8.39	7.04	15.43	0.68
(27) Air transport	10.45	13.86	24.30	1.08
(29) Telecommunications	17.05	38.91	55.96	2.48
(35) Sewerage and sanitary services	3.29	14.55	17.84	0.79

Direct, indirect and induced income multipliers are shown in Figure 7. Direct income multipliers represent the direct increase in compensation to employees if final demand in that sector increased by one unit. For example, (35) Sewerage and sanitary services has a direct income multiplier of 0.36. If final demand for Sewerage and Sanitary Services were to increase by £100 then £36 of that £100 increase would go towards compensating employees in the Sewerage and Sanitary Services sector. Indirect income multipliers consider how other sectors of the economy must increase production to meet additional final demand in the Sewerage and Sanitary Services sector. The indirect income multiplier for Sewerage and Sanitary Services is 0.19 therefore £19 will be generated in the economy and spent on additional compensation for employees. If induced effects are also taken into account (additional expenditure on goods and services due to increased incomes going to employees) then output in the economy will increase, and an additional 0.31 or £31 will be spent on compensation to employees. Thus the total compensation to employees including all effects is the amount of increase estimated by the closed input output model. For Sewerage and Sanitary Services this will be 0.86 or £86.

The closed model representing induced effects probably over-estimates the income multiplier effect because not all additional income earned is spent in the economy. On the other hand, a model that only represents indirect effects probably underestimates the benefits to the economy as higher incomes will lead to additional expenditure. Oosterhaven, Piek and Stelder (1986) recommend using indirect and induced multipliers as the upper and lower bounds of the true indirect effect on the economy. Figure 7 shows the direct, indirect and induced increase in incomes for a unitary increase in final demand from each sector of the economy.

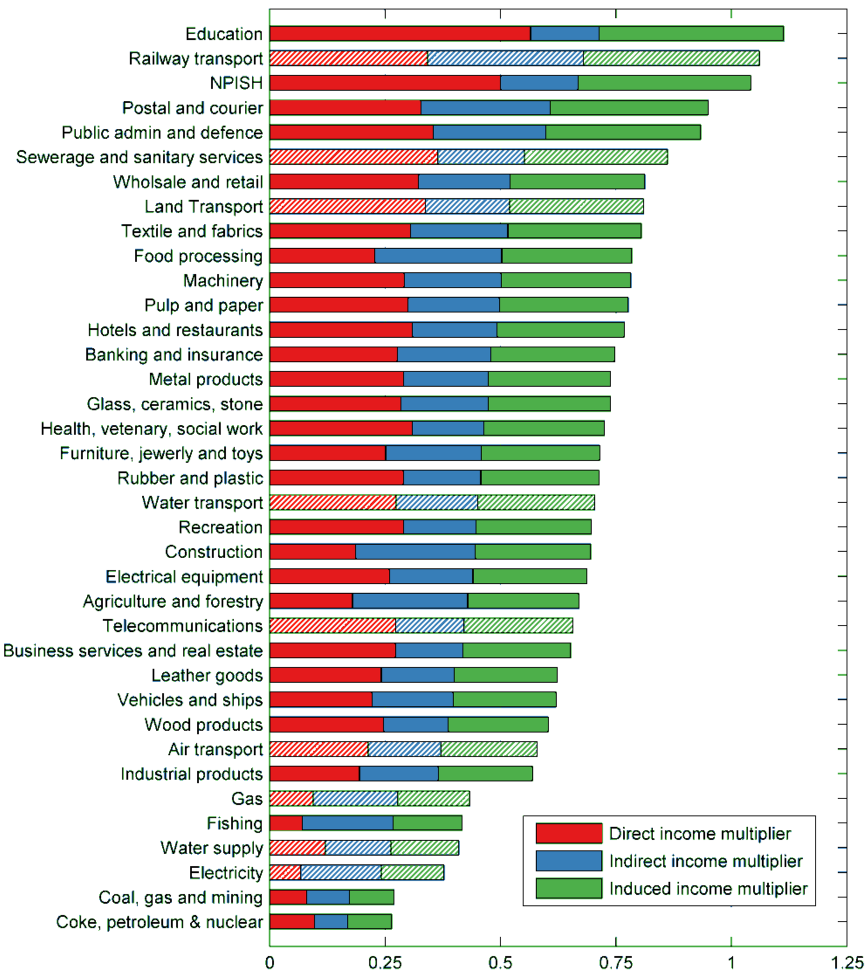

Figure 7: Direct, indirect and induced income multipliers for 38 economic sectors in the UK

In contrast to the simple multipliers shown in Figure 7, Type I and Type II multipliers estimate how much direct incomes expand due to an increase in final demand. As Type I and Type II multipliers are relative to the direct income multiplier they do not provide an account of the absolute quantity that incomes will expand in the economy but instead how much incomes will expand relative to that sectors existing output. It is therefore possible for sectors with low direct income multipliers to expand appreciably giving a large increase to indirect and induced incomes elsewhere thus giving a large Type I or Type II multiplier. Type I and Type II multiplier effects are shown in Table 3 for each infrastructure sector.

It is notable that (18) Electricity Production and Distribution and (19) Gas Distribution have some of the lowest simple multiplier effects suggesting a smaller share of increases to final demand goes on compensation to employees, but these two sectors also have some of the largest Type I and Type II multipliers when compared with other sectors in the economy. This implies that increases occurring to final demand in (18) Electricity Production and (19) Gas Distribution expand incomes disproportionately in the rest of economy (indirect and induced effects) than increases in income occurring directly in these sectors alone. The average income multiplier across all infrastructure sectors is higher than the average income multiplier across all sectors in the economy. This suggests infrastructure has larger indirect and induced effects on income than the average induced and indirect effects of the economy as a whole.

Using the hypothetical extraction method, it is possible to determine how much employment income in the whole economy would decrease if sector j were removed from the economy. This is therefore a measure of how important a particular sector is at generating employment income in the economy. This analysis is completed for each infrastructure sector of the economy. As indicated by the last column in Table 3, (22) Land Transport has the most significant effect on employment income followed by (25) Railway Transport (35) Sewerage and Sanitary services and (29) Telecommunications. The highest value sectors across the whole economy in generating employment income are (31) Business Services Real Estate sector responsible for 13.68% of income, followed by (28) Postal and Courier Services with 8.03% and (23) Wholesale and Retail with 7.44%.

Table 3: Income multiplier effects from infrastructure

	Type I income multiplier	Type II income multiplier	Hypothetical decrease in employment income (%)

(18) Electricity production and distribution	3.56	5.56	2.39
(19) Gas distribution	2.93	4.57	2.19
(20) Water supply	2.17	3.38	1.61
(22) Land transport	1.54	2.40	6.35
(25) Railway transport	2.00	3.10	4.26
(26) Water transport	1.65	2.57	2.71
(27) Air transport	1.74	2.71	2.40
(29) Telecommunications	1.54	2.41	3.46
(35) Sewerage and sanitary services	1.52	2.36	3.69
Average for Infrastructure	**2.07**	**3.22**	**3.23**
Average for all sectors	**1.84**	**2.88**	**3.98**

1.5 CONCLUSION

In this article an in-depth analysis of the inter-linkages and economic contributions from infrastructure within the UK has been explored. Over the last 23 years there has been a decline in the relative economic contribution from infrastructure to UK GVA. The only infrastructure sectors to increase their relative contribution to GVA since 1992 were (26) Water and (35) Sewerage and Sanitary services. (25) Railway transport and (19) Gas Distribution have had the largest relative decline in contribution towards UK GVA with relative contributions decreasing by over 50% since 1992.

This relative decline may be because the UK economy has evolved in such a way that it depends less on infrastructure systems for providing economic output. Alternatively, it could simply reflect that there has been a serious under investment in critical infrastructure over the last two decades. This in turn has resulted in deteriorating infrastructure that is less capable of keeping pace with economic output. In order to understand the function of infrastructure within an economy, it is necessary to explore its economic linkages and that has been the objective of this article.

For direct backward linkages (19) Gas Distribution, (18) Electricity Production and (22) Land Transport are ranked as the three highest sectors for backward dependence in the entire economy. For forward direct effects (18) Electricity Production is ranked 5th most important in the economy and (35) Sewerage and Sanitary Services is ranked 6th. The top five most important economic sectors that contribute to economic output account for more than two-thirds of all economic transactions from each infrastructure sector. Five infrastructure sectors have higher than average direct forward linkages. These are in order of size: (35) Sewerage and Sanitary Services, (18) Electricity Production, (29) Telecommunications, (25) Railway Transport and (19) Gas Distribution.

When analysing total linkages, (18) Electricity Production, (19) Gas Distribution and (22) Land Transport once again have higher than average backward linkages with other sectors of the economy. Similarly, for total forward linkages the same five infrastructure sectors have higher than average forward linkage effects but their order has changed to the following: (18) Electricity Production, (35) Sewerage and Sanitary Services, (29) Telecommunications, (19) Gas Distribution and (25) Railway Transport. Once again, the five most important sectors for each infrastructure sector explain the majority of economic activity. Across all sectors, intra-sectoral demand accounts for the highest proportion of economic activity when total linkages are considered.

When considering linkage variance, an interesting pattern starts to emerge. Unlike other sectors of the economy, infrastructure appears to have higher backward sector variance than forward sector variance implying that infrastructure relies heavily on only a few sectors for the provision of goods and services and sells goods and services across a larger number of other sectors within the economy. This is in contrast to the majority of other economic sectors where the reverse is true and suggests that infrastructure sectors are highly dependent on the provision of goods and services from a few sectors but have demand for goods and services spread relatively evenly across all sectors of the economy.

Using the hypothetical extraction method it is possible to estimate the economic value that different UK infrastructure sectors may contribute to the UK economy taking into consideration both direct and indirect effects. The hypothetical contribution made by the top four infrastructure sectors from highest to lowest is: (22) Land Transport (£135.6b), (29) Telecommunications (£55.96b), (18) Electricity Production (£53.18b) and (19) Gas Distribution (£39.84).

Closing the model with respect to households allows us to estimate the effect of household income on economic output. Using simple income multipliers the sectors that contribute the most to income effects include (25) Railway Transport, (35) Sewerage and Sanitary Services and (22) Land Transport. Including both indirect and induced effects a £1 increase in final demand in any one of these sectors will lead to an increase of more than £0.75 in additional employment income in the economy. Estimating Type I and Type II multiplier effects for each infrastructure sector provides an estimate for how much direct incomes will expand (multiply) by an increase to final demand. Using this estimate (18) Electricity Production and (19) Gas Distribution have the highest Type I and Type II multiplier effects when compared against other infrastructure sectors. When compared against other sectors of the economy, infrastructure has above average indirect income effects on the economy. Using the hypothetical extraction method for looking at the income effects of infrastructure shows the relative decrease in income if a particular sector were hypothetically extracted from the economy. This type of analysis shows that (22) (22) Land transport and (25) Railway Transport contribute the largest share of employment income to the economy.

This study explored the relationship between nine infrastructure sectors and the rest of the UK economy. Using key-linkages analysis it has been possible to show what sectors of the economy demand from infrastructure for the provision of goods and services and what sectors supply goods and services to infrastructure. Each infrastructure sector is shown to be unique in the way it interacts with other economic sectors and in the form of contribution it makes to the economy overall. Infrastructure is therefore a necessary and important part of economic development. Although it is difficult to quantify the true value that infrastructure provides within an economy this paper provides a good first attempt at quantifying the structure of relationships between different infrastructure sectors and its overall contribution to output. In conclusion, infrastructure remains an integral component of the UK economy. Further research is required to understand how infrastructure may co-evolve with the economy in the near and distant future.

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Table 4: Infrastructure categories

1	Agriculture and forestry	14	Machinery	27	Air transport
2	Fishing	15	Electrical equipment	28	Postal and courier services
3	Coal, gas mining extraction	16	Motor vehicles, ship building and repair	29	Telecommunications
4	Food processing	17	Furniture, jewellery, sports equipment, toys	30	Banking finance, insurance
5	Textile and fabrics	18	Electricity production and distribution	31	Business services and real estate
6	Leather goods	19	Gas distribution	32	Public administration and defence
7	Wood and wood products	20	Water supply	33	Education
8	Pulp paper and paperboard	21	Construction	34	Health, vetenary, social work
9	Coke ovens, refined petroleum & nuclear fuel	23	Wholesale and retail distribution	35	Sewerage and sanitary services
10	Industrial products, fertilisers, dyes, soaps, toiletries	24	Hotels and restaurants	36	Recreational and other services
11	Rubber and plastic products	25	Railway transport	37	Private households
12	Glass, ceramics, stone	22	Land transport	38	NPISH
13	Metal products	26	Water transport		

Derived from: (ONS, 2012)