How do UK regional commuting flows relate to spatial configuration?

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Abstract

The benefits of living in cities are well documented and can be generalized to include capitalising on agglomeration benefits in triggering productivity gains. However cities cannot be approached as stand-alone places but rather as a system of city regions and national urban hierarchy. Despite the connected nature of city regions, research on spatial configurations beyond cities is limited. The majority of spatial configuration research focuses on the city. This can be attributed to the lack of interdisciplinary research with large geographic model and the technological limitations in computing nation-wide models. The need for research on urban agglomeration benefits from regional infrastructure and the advent of large scale open source data and software, raises an opportunity to examine regional issues such as commuting behaviour from the spatial configuration perspective.

Based on the theoretical propositions, where spatial configuration is a determinant of movement, this research examines to what extent spatial configuration relate to commuting behaviour at the regional and national scale. In order to approach this research question, we first describe and introduce the commuting flow and spatial network dataset used in this study. Next, we describe the association between the commuting flow variables and spatial configuration variables through an exploratory correlation analysis. Third, we define an initial classification of commuting flows based on three specific urban agglomerations. To conclude, we compare how the configuration perspective in using angular distance compares with the geographical perspective in using metric distance to model commuter flows through a gravity model.

This study showed that spatial configuration in the form of integration is able to capture cities as concentrations of people and workplaces and as attractors of commuter flows. Although this attraction of commuters towards cities is obvious, the characteristics of this attraction are complex. City size, spatial density, regional integration, metric and angular proximity seem to affect commuter flows in city regions and can be described using spatial integration at different radii. The difference between being a commuter city (Wigan), a city that attract commuters from nearby (Oxford) or a city that attracts commuters from afar (Norwich) appears to be influenced by the balance of city size, density and its regional connectivity. Re-interpreting the gravity model from a spatial configuration perspective produces significant result in explaining commuting flows. However a comparison of different commuter models based on metric and angular impedance shows that metric rather than angular proximity associate more strongly to commuter flow between city regions. Whilst, Space Syntax research argues the importance of spatial configuration influences pedestrian behaviour at the local scale, this research argues distance and configuration influences our behaviour in a more complex manner at the regional scale.

Keywords

Space syntax, commuting flows, UK, regional network models, gravity model.
1. Background

Recent planning discussions in the United Kingdom are focused on city regions at a national level. The introduction of High Speed 2 for example, the fast train connection between London, Birmingham and in later stages to Manchester and Leeds has sparked many controversies regarding its regional spatial impacts. Cities served by this connection wonder whether HS2 will make them subservient to London or whether a symbiotic relation can be formed. Would these rail links create system of highly interconnected cities in the north of England that can start to rival with London? In order to understand the impact of interventions on a regional and national scale we must first need to clarify what forces govern system of cities.

The benefits of living in cities are well researched and it can be generalised to include capitalising on accessing a wider and deeper pool of labour, supplier, goods and customers, reduction in transportation costs and technological spillover. Generally, large, dense urban markets help create more specialisms, can trigger productivity gains and foster innovation activities. (Lucci and Hildreth 2008; Krugman 1991; Glaeser 2011) However cities cannot be approached as stand-alone places. Rather, they sit within a wider regional and national urban hierarchy. (Hildreth 2006) Their success in attracting and retaining firms and workers, and generating jobs, depends as much, if not more, on the linkages that exist between them and with their wider region (Turok 2004) as their own economies. What than constitutes a city region? One way the city-region can be defined is by the ways people live their lives and how the economy operates between cities and the towns and areas that surround them (Harding et al 2006). It is a dynamic concept expressed in terms of connections and flows from home to work, home to shop, home to home in housing moves, home to cultural entertainment, as well as the way businesses relate to their customers and suppliers. Within the landscape one can find a network of cities; small or large, grouped or isolated, dense or sparsely structured.

Despite the connected nature of city regions, research into studying how these city regions work from a spatial configuration perspective have been limited. The majority of space syntax research has focus solely on the scale of the city and of its buildings. This micro-focus stems from firstly its architectural roots, second the lack of inter-disciplinary research with large scale geographical models and third technological limitation in computing large scale regional models. With the demand in looking at agglomeration benefits from regional infrastructure such as HS2 and with the advent of large scale open source data such as Open Street Maps, open source platform such as QGIS and PostGIS and technological advancements in computing large graph indices using depthmap (Varoudis et al 2012; Hanna et al 2012), an opportunity has arisen to examine regional issues from the spatial configuration perspective and validating Space Syntax analysis empirically at the national level.

In order to understand how cities operate within regions, this research will examine commuting behaviour from the spatial configuration perspective. Commuting flows are traditionally modelled under the Newtonian-inspired Gravitational models where flow is a function positively proportional to the size of attractions and inversely proportional to some impedance (Hansen 1959; Carrothers 1956; Tinbengen 1962; Wilson 1967). However limited research has looked at how spatial configuration influences commuting flows.

Based on the theoretical propositions where spatial configuration is a determinant of movement and transactions, this research aims to extend this proposition in looking at the extent spatial configuration relate to commuting pattern at the national scale. Specifically, to what extent do spatial integration at different scales associate with commuter flow distributions and to what extent does angular distance compares with metric distance in explaining commuter flows.

In order to answer these research questions, the paper is structured into five parts:

- in the first part we introduces the dataset and the methodology;
- in the second part we describe the commuting flow dataset and the spatial network dataset;
- in the third part we analyse the dataset through exploratory correlation data analysis between both commuting flow variables and spatial configuration variables;
- in the fourth part we look at the commuting flows for three local agglomerations in the UK;
in the fifth part we report the regression results comparing the traditional approach and a spatial configuration approach to the commuter gravity model. More specifically comparing the use of metric distance and angular distance as impedance to modelling commuting flows;

2. Methodology

This study is framed within the area of Great Britain, containing England, Wales and Scotland (see figure 01a). In order to investigate the relation between spatial configuration and commuting flows, two datasets have been collected. The first data set contains information on population and travel to work behaviour per Local Authority (see figure 1b) produced by the Office of National Statistics (ONS). Second is a spatial model of the motorways, A-roads, B-roads and minor roads across the UK derived from the Ordnance Survey Meridian 2 data set (see figure 1c).

Figure 1:
1a United Kingdom Study Area
1b Local Authorities
1c Meridian 2 layer
This first part of the study will visualize the data using QGIS and explored statistically through a bivariate correlation analysis. The table below illustrates all the variables studied. The second part of the study will model commuting flows by comparing the traditional gravity model with the spatial configuration interpretation of the gravity model.

<table>
<thead>
<tr>
<th>Space Syntax Integration</th>
<th>Spatial configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Segment Length</td>
<td>Spatial configuration</td>
</tr>
<tr>
<td>Population</td>
<td>Socio-economic</td>
</tr>
<tr>
<td>Workplaces</td>
<td>Socio-economic</td>
</tr>
<tr>
<td>Population Density</td>
<td>Socio-economic</td>
</tr>
<tr>
<td>Workplace Density</td>
<td>Socio-economic</td>
</tr>
<tr>
<td>Total Commuters</td>
<td>Commuting variables</td>
</tr>
<tr>
<td>Average Commuting Distance</td>
<td>Commuting variables</td>
</tr>
<tr>
<td>Average Distance Decay</td>
<td>Commuting variables</td>
</tr>
<tr>
<td>Commuting flows</td>
<td>Commuting variables</td>
</tr>
</tbody>
</table>

**Table 1:** variables

### 2.1 Commuting flows

Commuter flow can be described as a number of people traveling from their residence to their workplace. This information was gathered by the Office for National Statistics for all local authorities in the UK. This study analyses these flows in relation to their origin and destination and as an aggregate commuter flow to and from specific local authorities. Commuter flows are linked to the spatial distribution of population and workplaces. The numbers of workplaces have been calculated by combining the commuters living and working in the same Local Authority as locals and total number of commuters following this equation;

\[
\text{Workplaces} \times \text{Commuters} \times \text{Locals}
\]

**Equation (1)**

This research also explores population and workplace density. The absolute population and workplace data has been normalized by area (ha) in order to better compare differently sized local authorities. The travel-to-work data set includes the amount of commuters from every Local Authority to any other Local Authority resulting in more than 160000 different flows. For each of the flow the distance between the origin and the destination has been calculated by defining the ‘centroid’ of each Local Authority boundary. The Euclidean distance between two centroid points defines the distance of the specific commuter flow. The distance and the amount of commuters between each combination of Local Authorities have been used to analyse the relation between the flow and the spatial characteristics of its origin and destination. Data on commuter flows to each Local Authority have been aggregated in order to calculate total number of incoming commuters, the average commuting distance and average distance decay. The average commuting distance is calculated by dividing all traveled distances by the number of commuters to a certain destination. It is defined by the following formula;

\[
\text{Average Commuting Distance} = \frac{\Sigma (\text{Commuters} \times \text{Distance})}{\Sigma \text{Commuters}}
\]

**Equation (2)**
With information on number of people traveling at certain distances, the attraction force to a certain workplace destination can be determined by calculating its distance decay. The function of the decay of commuters per unit of distance away from the workplace destination is defined by the following formula;

\[
\text{Average Distance Decay} = \frac{\sum \left( \frac{\text{Commuters}}{\text{Distance}} \right)}{\sum \text{Commuters}}
\]

Equation (3)

2.2 Spatial measures

This study investigates how spatial configuration can help to explain the distribution of commuter's flows. The spatial network that forms the base of the spatial configuration analysis has been created using the Ordnance Survey Meridian 2 Layer; a simplified road centre line model of more than 2 million segments that included motorways, A-roads, B-roads and minor streets across the whole of Great Britain. The spatial measures of Segment Angular Integration and Total Segment Length have been calculated for each segment of the spatial network model using the computer software DepthmapX developed by Alasdair Turner (Turner 2004) and Tasos Varoudis (Varoudis, 2012). Segment Angular Integration or simply Integration, is a close derivative of angular closeness centrality in network science literature. (Hillier and Iida 2005; Hillier and Hanson 1984; Hillier and Yang 2012). To calculate Integration, we first measure for each segment the Total Depth (TD). TD is the sum of the shortest angular path between every origin segment (i) to every destination (j) segment.

\[
\text{TD}_i = \sum_d \text{dij}
\]

Equation (4)

Segment Angular Integration can then be calculated by dividing node count (NC) squared by its total depth.

\[
\text{INT}_i = \frac{(\text{NC}^2)_i}{\text{TD}_i}
\]

Equation (5)

Average Segment Angular Integration for each local authority is then calculated by taking the mean of segment angular integration for all segments in each local authority.

\[
\text{AvgINT}_i = \frac{\sum \text{INT}}{N}
\]

Equation (6)

2.3 Gravity models

Tobler’s first law of geography states: “Everything is related to everything else, but near things are more related than distant things.” (Tobler, 1970) From the configuration perspective, little exploration has been done to look at how nearness is measured geographically or geometrically. Limited research can be found on how configuration distance actually influences commuting flow and the workplace destination we choose. This section illustrates the methodology of applying the gravity model using the traditional approach and the spatial configuration approach.

Commuting flows are traditionally modelled under the Newtonian-inspired Gravitational models where flow is a function positively proportional to the size of attractions(Mass) and inversely
proportional to impedance (Imp) between them (Hansen 1959; Carrothers 1956; Tinbengen 1962; Wilson 1967). Impedance in this case is measured as the shortest metric or angular path between each local authority.

\[ CF_{ij} = F(Mass_i, Mass_j, Imp_{ij}) \]

Equation (7)

This study will adopt this framework and will test to what extent the traditional metric distance as impedance differs from the angular distance derived from spatial configuration research. Interpreting the space syntax measure of angular integration in a gravitation modelling context, the mass of its origin and destination region is implicitly modelled by the origin and destination spatial density when computing the routes between all segments to all segments. Applying this notion into a gravity model, the mass can be interpreted in the spatial configuration perspective as a function of spatial density (SD) and the impedance by it angular distance (Ang).

\[ CF_{ij} = F(SD_i, SD_j, Ang_{ij}) \]

Equation (8)

Empirically, this study will, by applying Tinbingen (1962) international trade statistical framework, compare the traditional gravity model (equation 7) with one substituted by spatial configuration measure (equation 8). A multiple variable regression model is specified where the log of the commuting flow (CF) is regressed against the logged population (Pop i) at origin, logged population (Pop j) at destination and logged shortest metric distance between origin and destination (MetDij). This will form the first model or base model of this comparison.

\[ \log(CF_{ij}) = \beta_0 + \beta_1 \log(Popi) + \beta_2 \log(Popj) + \beta_3 \log(MetDij) + \varepsilon \]

Equation (9)

In the second model, total segment length (TSL) for both the origin and destination local authority will be used while retaining the metric distance impedance.

\[ \log(CF_{ij}) = \beta_0 + \beta_1 \log(TSL_i) + \beta_2 \log(TSL_j) + \beta_3 \log(MetDij) + \varepsilon \]

Equation (10)

Total segment length is simply the sum of all segment length for each local authority.

\[ TSL = \sum SL \]

Equation (11)

In the third model, average space syntax integration (Int) for both origin and destination is used at each local authority while retaining the metric distance impedance.

\[ \log(CF_{ij}) = \beta_0 + \beta_1 \log(Int_i) + \beta_2 \log(Int_j) + \beta_3 \log(MetD) + \varepsilon \]

Equation (12)

In the fourth model, the population for both its origin and destination is retained but we substitute shortest metric distance with shortest angular distance (AngD) between each local authority.

\[ \log(CF_{ij}) = \beta_0 + \beta_1 \log(Popi) + \beta_2 \log(Popj) + \beta_3 \log(AngD) + \varepsilon \]

Equation (13)

A least square estimation is applied for the regression model where tests statistics and goodness of fit are reported in the empirical section.

3. Key findings

The research of this paper consists of four parts. First a general overview is given of the spatial distribution of population and workplaces. Second, the relation between spatial integration and aggregate commuter flow is explored. Thirdly, we define an initial classification of commuter flow attraction based on three specific urban agglomerations. Lastly, we compare how the configuration perspective in using angular distance compares with the geographical perspective in using metric distance to model commuter flows through a gravity model.
3.1 Population and workplaces

Economic activity tends to concentrate due to the many benefits of interaction between people and firms. It allows firms to operate on a larger scale, capitalising on a wider and deeper pool of workers, suppliers and customers, create more specialisms, can trigger productivity gains and foster innovation activities. (Lucci and Hildreth 2008; Krugman 1991; Glaeser 2011) The works of Bettencourt and West (2007) illustrate universal evidence of the beneficial relation between population concentration and productivity, salary, innovation and employment. Within big cities, governmental, financial and business services but also medicine, law, arts, higher education, culture and the provision of both luxury and mass-produced goods converge (Hall, 2000; Florida, 2002; Polèse, 2005). Given the concentration of all these services, cities and city regions, not surprisingly, attract population.

Table 2 describes the size, the population and its density, the workplace and its density, number of commuters, average distance decay and average commuting distance from the UK Census 2011 dataset. There are a total of 374 local authorities in the United Kingdom. Each local authority has an average an area of 60,000 sqm, 166,000 residence, 63000 workplace and therefore a population density of 14.65 person per sqm and 5.65 workplace per sqm.

<table>
<thead>
<tr>
<th></th>
<th>Area (m²)</th>
<th>Population (p)</th>
<th>Workplaces</th>
<th>Population density (p/ha)</th>
<th>Workplace density (w/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>average</strong></td>
<td>60965</td>
<td>165950</td>
<td>63009</td>
<td>14.65</td>
<td>5.65</td>
</tr>
<tr>
<td><strong>std dev</strong></td>
<td>162287</td>
<td>112289</td>
<td>41205</td>
<td>22.41</td>
<td>8.78</td>
</tr>
<tr>
<td><strong>max</strong></td>
<td>2648437</td>
<td>1092330</td>
<td>357433</td>
<td>145.13</td>
<td>59.16</td>
</tr>
<tr>
<td><strong>min</strong></td>
<td>1239</td>
<td>34320</td>
<td>10133</td>
<td>0.09</td>
<td>0.03</td>
</tr>
<tr>
<td><strong>count</strong></td>
<td>374</td>
<td>374</td>
<td>374</td>
<td>374</td>
<td>374</td>
</tr>
</tbody>
</table>

Table 2. Descriptive statistics for ONS population and travel-to-work dataset

The figures below describes population density mapped in GIS from light red to red and workplace density mapped in GIS from light blue to blue for each local authority in the UK.

![Population density in the UK](image1)

![Workplace density in the UK](image2)

Figure 2. Left Population density in the UK; Right Workplace density in the UK.
The result reveals the UK population is concentrated in a number of metropolitan regions such as London, Manchester, Liverpool and Leeds in the north of England, Birmingham in the midlands, Newcastle Upon Tyne in the north-east and Glasgow and Edinburgh in Scotland plus a lot of smaller cities near the coast and between these major regions. The workplace density distribution strongly overlaps with population density distribution. The scatterplot below describes the positive linear association between population density and workplace density. Residence and workplace are expectedly interrelated and are concentrated in cities.

Figure 3 Correlation between workplace and population density for each Local Authority

3.2 Commuter attraction

As cities grow in size and physically spread, costs rise due to increasing land costs, increasing congestion, commuting costs and rising wages (Hildreth, 2006). Smaller cities within the city region become more attractive places to live than big cities. When these smaller cities are not part of the big city region and cannot compete in terms of employment opportunities, commuting patterns towards the big city emerge (Cheshire et al 2004). Medium sized cities that are part of a city region will benefit from the economic success of other cities within the region (Hildreth, 2006). These places will attract workers themselves creating city regions surrounded by smaller cities creating a constellation of cities. The table below describes statistics for commuters, average commuting distance and average distance decay from the Census 2011 dataset. Of the 63000 people working in Local Authorities on average, 30000 commute and 33000 live within the Local Authority. The average commuting distance is 37000 metre and average distance decay is 5 p/m.

<table>
<thead>
<tr>
<th></th>
<th>Commuters</th>
<th>Average Commuting Distance</th>
<th>Average Distance Decay</th>
</tr>
</thead>
<tbody>
<tr>
<td>average</td>
<td>29387</td>
<td>36990.06</td>
<td>5.09</td>
</tr>
<tr>
<td>std dev</td>
<td>51154</td>
<td>21725.62</td>
<td>12.63</td>
</tr>
<tr>
<td>max</td>
<td>867615</td>
<td>231167.73</td>
<td>215.32</td>
</tr>
<tr>
<td>min</td>
<td>2692</td>
<td>13572.97</td>
<td>0.06</td>
</tr>
<tr>
<td>count</td>
<td>374</td>
<td>374</td>
<td>374</td>
</tr>
</tbody>
</table>

Table 3 descriptive statistics for commuter measures
The figure below describes the journey to work volume mapped in GIS using lines from light yellow to dark yellow between each local authority in the UK. Thicker lines indicate greater frequency of commutes between local authority and thinner lines describes lesser frequency of commutes between local authorities.

Figure 4. Journey to work flows in the UK in 2014

The result reveals a network of concentrated commuter flows around London and other constellations of cities regions around the country. This network isn’t exclusive for the larger metropolitan regions such as London, Manchester and Birmingham but also around smaller cities such as Exmouth in Cornwall and Norwich in Suffolk. These smaller cities also attract commuters from adjacent regions. In general flows to adjacent regions are stronger than to regions further away.

Segment Angular Integration has been calculated for each segment of the spatial network model using the computer software DepthmapX developed by Alasdair Turner (Turner 2004) and Tasos
Varoudis (Varoudis, 2012). The radii calculated for this study includes 800m, 2000m, 5000m, 10000m, 20000m, 50000m, 100000m, 250000m, 500000m. The measure is aggregated as means to each local authority area. Total segment length for each local authority have been calculated in the open source software QGIS. Table 04 describes the sum of segment length, and average space syntax integration for the local authorities.

<table>
<thead>
<tr>
<th></th>
<th>Length</th>
<th>Int800</th>
<th>Int2k</th>
<th>Int5k</th>
<th>Int10k</th>
<th>Int20k</th>
<th>INTr50k</th>
<th>INTr100k</th>
<th>INTr250</th>
<th>INTr500k</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean</td>
<td>925896</td>
<td>25</td>
<td>72</td>
<td>222</td>
<td>1161</td>
<td>3244</td>
<td>6933</td>
<td>17668</td>
<td>25941</td>
<td></td>
</tr>
<tr>
<td>std dev</td>
<td>906911</td>
<td>12</td>
<td>49</td>
<td>187</td>
<td>471</td>
<td>1037</td>
<td>2117</td>
<td>3346</td>
<td>7187</td>
<td>6730</td>
</tr>
<tr>
<td>max</td>
<td>7609930</td>
<td>95</td>
<td>346</td>
<td>1200</td>
<td>2791</td>
<td>5528</td>
<td>9107</td>
<td>12851</td>
<td>31532</td>
<td>36190</td>
</tr>
<tr>
<td>min</td>
<td>141926</td>
<td>11</td>
<td>19</td>
<td>40</td>
<td>54</td>
<td>78</td>
<td>240</td>
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<tr>
<td>count</td>
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<td>374</td>
<td>374</td>
<td>374</td>
<td>374</td>
</tr>
</tbody>
</table>

Table 4 Max, Min, Avg, Std dev for sum of segment length and Segment Angular Integration

As illustrated in the figure below, average integration scales linearly as its radius increases.

Figure 5 Scatterplot between space syntax integration and its radius

The figure below describes the Segment Angular Integration for the different radii in the UK.
Maps in figure 6 show integration of the country at different radii where blue indicate low centrality and red indicate high centrality. At local scale, between Radius 800m – 5,000m, the integration measure shows the core of the cities in the UK such as London and Manchester in red. Smaller towns and villages are also highlighted within these scales. At the meso scale at Radii 10000m – 50000m, the integration measure shows the metropolitan regions in the UK. It shows large metropolitan regions such as Greater London, Greater Birmingham and Greater Manchester. These metropolitan
regions overlap with the commuting flows indicated on the flow map in figure 04. At the macro scale, between radius 100000m – 500000m, the integration measure shows centrality at a national scale. At this scale, rather than cities, the connections between cities have high levels of integration. Integration at radius 100km shows how London, Birmingham, Manchester and Leeds act as a singular city systems. At the radii beyond the 100km, integration gravitates towards the Midlands which form the topographical centre of the country.

<table>
<thead>
<tr>
<th>Integration</th>
<th>800</th>
<th>2000</th>
<th>5000</th>
<th>10000</th>
<th>20000</th>
<th>50000</th>
<th>100000</th>
<th>250000</th>
<th>500000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population (p)</td>
<td>16%</td>
<td>19%</td>
<td>23%</td>
<td>24%</td>
<td>20%</td>
<td>11%</td>
<td>6%</td>
<td>1%</td>
<td>1%</td>
</tr>
<tr>
<td>Workplaces (job)</td>
<td>17%</td>
<td>20%</td>
<td>24%</td>
<td>25%</td>
<td>22%</td>
<td>13%</td>
<td>7%</td>
<td>2%</td>
<td>1%</td>
</tr>
<tr>
<td>Population density</td>
<td>63%</td>
<td>74%</td>
<td>83%</td>
<td>82%</td>
<td>74%</td>
<td>45%</td>
<td>23%</td>
<td>7%</td>
<td>6%</td>
</tr>
<tr>
<td>Workplace density</td>
<td>61%</td>
<td>72%</td>
<td>81%</td>
<td>80%</td>
<td>72%</td>
<td>44%</td>
<td>23%</td>
<td>7%</td>
<td>6%</td>
</tr>
<tr>
<td>Logged commuters</td>
<td>34%</td>
<td>42%</td>
<td>50%</td>
<td>51%</td>
<td>48%</td>
<td>42%</td>
<td>39%</td>
<td>21%</td>
<td>20%</td>
</tr>
<tr>
<td>Logged average</td>
<td>24%</td>
<td>24%</td>
<td>25%</td>
<td>26%</td>
<td>29%</td>
<td>34%</td>
<td>37%</td>
<td>27%</td>
<td>33%</td>
</tr>
<tr>
<td>commuting distance</td>
<td>52%</td>
<td>61%</td>
<td>71%</td>
<td>73%</td>
<td>70%</td>
<td>58%</td>
<td>47%</td>
<td>23%</td>
<td>23%</td>
</tr>
</tbody>
</table>

Table 5 Correlation matrix

The correlation matrix in table 05 summarises the Pearson correlation coefficients between spatial integration and density, commuting variables and socio-demographic variables. Firstly, strong associations are found between population density, workplace density and integration at a radius of 5000m with a coefficient of determination ($R^2$) of 83% and 82%. Similar results are reported between total segment length with both population and workplace density. It achieves an $R^2$ of 88% and 86% respectively. The number of commuters per flow and average distance decay correlate well with levels spatial integration/density at a similar local radius of 10000 m. This suggests similar to residents, commuters are drawn towards dense, vibrant and urban cities and prefer to live near their workplace. Average commuting distance correlates negatively with regional integration at 100000 m. Commuters travelling towards workplace centres in less urbanised areas with low levels of integration have to thus cover greater distances. Inversely cities with high levels of regional integration are more attractive to live in or close to, thus minimising commuting distance. Please see appendix B for details of the scatterplots.

The chart below summarises the coefficient of determination ($R^2$) along the Y axis between various commuting variables and space syntax integration at increasing radius along the X axis. Population density and workplace density have a similar trajectory with their peak correlation at radius 5000 m and declining rapidly at larger radii. Average distance decay and total commuters shows a similar correlation distribution but peak at radius 10000 m.
How do UK regional commuting flows relate to spatial configuration?

The correlations show a strong relation between population density, workplace density, commuter flows and spatial integration. Can these relations explain different roles cities play in city regions? Can they explain why certain cities attract commuters and why other cities have an outflow of commuters? What determines the distance commuters travel to work? In order to make this clear the net commuter flows for each pair of cities are examined.

\[ NCF(i, j) = \sum CF_{ij} - \sum CF_{ji} \]  

Equation (14)

Net Commuter Flow (NCF) is the net difference between total commuter outflows between City i and City j (CFij) and total commuter inflows between City i and City j (CFji). A detailed view overlapping integration at different radii and net commuting flows starts to reveal relations in more detail (see figure 8, 9 and 10). The sign represents the dominant direction of the commuting flow. If, for example, there is a thick line that points from City i and City j, it means there is a greater net flow from City i to City j. The cases of Wigan, Milton Keynes, Oxford and Norwich showcase how proximity, density, and spatial integration can help to describe different commuter patterns and thus give an insight in how cities relate with each other.

**Wigan**

The city of Wigan is located between Liverpool and Manchester. Regional Integration at radius 100000 m shows that Wigan is embedded in the regional city network spanning Liverpool and Manchester. However, its levels of Integration at radius 5000 m, which correlates closely with population and workplace density, are low compared to the city of Manchester. The combination of high levels of regional integration and low levels city-wide Integration compared to surrounding urban areas, seems to result in a workplace dependency on larger and denser cities in close proximity.
The cities of Oxford and Milton Keynes are respectively located to the west and north of London. As the largest city in the UK, London has the largest commuter inflow. The correlation studies have shown, distance decay of commuter flows is on average greater in larger cities. Oxford and Milton Keynes attract commuters from their immediate context with relatively more independence from London then other more nearby commuting hubs. This greater independence of the two cities can be attributed to high levels of regional integration, high levels of city-wide integration, and being metrically further way from London. When compared to Oxford, Milton Keynes has more commuters to London which is likely the result of both better railway connectivity and economic dependency.
Norwich

The city of Norwich is located along the east coast of England. The region around Norwich has low levels of regional integration due to scarcity of urban areas. Norwich which sits within a low density region attracts commuters from afar. The majority of commuter flows converge in Norwich making it the only workplace centre in its wide region. The negative correlation between regional integration and commuter distance found in this study underpins these findings. Residents of areas with low population density and low workplace density have few choices of workplace in close proximity resulting in long commutes.
These case studies illustrate the underlying association between spatial integration and population density, workspace density and commuter behaviour which is far more complex than it seems. This description allows an initial classification where the difference between being a commuter city (Wigan), a city that attract commuters from nearby (Oxford) or a city that attracts commuters from afar (Norwich) appears to be influenced by the balance of city size, density and its regional connectivity. Further research is required to quantitatively classify different commuting cities with respect to morphological, network and economic indicators.

3.3 Gravity Model

Commuting flows are traditionally modelled using gravity models where flow is a function positively proportional to the size of attractions and inversely proportional to some distance impedance (Hansen 1959; Carrothers 1956; Tinbengen 1962; Wilson 1967). This research confirms these results and also re-interprets the gravity model from a spatial configuration perspective.

The table below illustrates the regression results for the four models as specified in the methodology section. Model 1 is the gravity model from the traditional economic perspective where the mass is measured by population at each local authority and metric distance as its impedance between them. Model 2 and Model 3 and Model 4 are gravity models from the spatial configuration perspective. Model 2 interprets the mass as spatial density or average segment length in each local authority and...
metric distance as impedance. Model 3 interprets the mass with average space syntax integration in each local authority and metric distance as impedance. Model 4 interprets the mass as population at each local authority and angular distance as impedance.

All four models are statistically significant at the Prob > F 0.05 level. For all four models, both the origin and destination mass variable have positive estimates whilst the impedance variable has negative estimates. Model 1 achieves the highest goodness of fit with an R-square of 64.5%. Model 2 achieves the second highest goodness of fit with an R-square of 58.2%. Model 3 achieves the third highest goodness of fit with an R-square of 57.6%. Model 4 achieves the weakness goodness of fit with R-square of 52.5%. Model 1 which measures impedance by metric distance achieves a significant better fit than Model 4 which measures impedance by angular distance.

<table>
<thead>
<tr>
<th>Estimates</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
</tr>
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<tbody>
<tr>
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<td>-1.44</td>
<td>-1.34</td>
<td>-1.8</td>
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<tr>
<td>Log Ang</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<tr>
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<td></td>
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<tr>
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<td></td>
<td></td>
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<tr>
<td>Log Dest Seg Length</td>
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<td>5.77</td>
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<td><strong>58.16%</strong></td>
<td><strong>57.58%</strong></td>
<td><strong>52.53%</strong></td>
</tr>
<tr>
<td><strong>RSquare Adj</strong></td>
<td><strong>64.49%</strong></td>
<td><strong>58.16%</strong></td>
<td><strong>57.58%</strong></td>
<td><strong>52.53%</strong></td>
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<tr>
<td>Root Mean Square Error</td>
<td>0.362</td>
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<td>0.418</td>
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<tr>
<td>Mean of Response</td>
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<td>0.809</td>
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<tr>
<td>F Ratio</td>
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<td>61,771</td>
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<tr>
<td>Prob&gt;F</td>
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<td>&lt;0.0001*</td>
<td>&lt;0.0001*</td>
<td>&lt;0.0001*</td>
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<tr>
<td>Observations</td>
<td>136,530</td>
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<td>136,530</td>
<td>136,530</td>
</tr>
</tbody>
</table>

Table 7 Regression results

The results confirm previous research suggesting commuting flows between two areas are explained by the impedance between the origin and destination and the size of their attraction. The spatial configuration perspective of the gravity model was less strong in explaining commuting flows than the geographical perspective. Attraction as measured by population had stronger explanatory power than total segment length and space syntax integration. Impedance as measured by metric distance had stronger explanatory power than angular distance. Spatial density is thus an efficient correlate and supplement to population while flows between two areas can be better explained by metric distance more so than angular distance. This finding suggests a more complex interaction on how distance influences pedestrian behaviour. These results require further validation but suggest potentially how we choose commuting destinations differs from which routes we choose.
4. Conclusion

The benefits of living in cities are documented and it can be generalised to include capitalising on accessing a wider and deeper pool of labour, supplier, goods and customers, reduction in transportation costs and technological spill overs. (Lucci & Hildreth 2008; Krugman 1991; Glaeser 2011). This study extends on this notion and showed that spatial configuration in the form of integration is able to capture cities as concentrations of people, workplaces and commuter attractors. Although this attraction of commuters towards cities is obvious, the characteristics of this attraction are complex where city size, spatial density, regional integration, metric and angular proximity all seem to influence commuter flows between city regions.

To explore further, an initial classification of city commuting typologies was undertaken through examining three case studies on a regional scale. The difference between being a commuter city (Wigan), a city that attract commuters from nearby (Oxford) or a city that attracts commuters from afar (Norwich) appears to be influenced by the balance of city size, density and its regional connectivity. Spatial integration over multiple radii suggest why certain cities attract commuters and others repel. Large cities such as London seem to attract commuters in relative close proximity. This finding is supported by the positive correlation between integration and distance decay. Wigan which sits within a large urban agglomeration is a commuter city dependent on Manchester and Liverpool. Oxford which is far enough from London attract commuters from nearby. Norwich which sits within a low density region attracts commuters from afar. Commuting distance is a function of regional connectivity and city size. Commuter from small cities in low density rural areas with low regional integration need to travel further than similar sized cities embedded in dense city regions.

This research also explored different gravity models. In these models metric and angular impedances were related to the UK commuter flow dataset. Re-interpreting the gravity model from a spatial configuration perspective produces significant results in explaining commuting flows. However a comparison of different commuter models based on metric and angular impedance shows that metric proximity is more strongly associated to commuter flow between local authorities than angular proximity. Whilst, Space Syntax research argues the importance in how configuration influences pedestrian behaviour at the local scale. This research argues distance and configuration influences our behaviour in a more complex manner at the regional scale.

This study has a number of limitations. Firstly, the spatial model used for this study does not contain a multi-modal multi-country spatial network. This is unrealistic as significant amount of commuting today is made by rail and air and across national borders. Second, the use of the local authority boundary as an areal unit suffers from the typical modifiable areal unit problem. Third, the study uses the centroid of local authority in calculating distances between them, which is insensitive to the actual proximity between places. This requires more detailed research for validation. This study only found initial relations and classification of commuter flows in city regions. More research of city regions from a morphological, network and an economical perspective is needed.

References

National Records of Scotland, (2011) Census: Digitised Boundary Data (Scotland) [computer file]. UK Data Service Census Support. Downloaded from: http://edina.ac.uk/census


Appendix A

<table>
<thead>
<tr>
<th>Data Item</th>
<th>Explanation</th>
</tr>
</thead>
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<tr>
<td>OS Meridian 2</td>
<td>Minor roads, A roads, B roads and motorways within Great Britain. Ordnance Survey 2014</td>
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<tr>
<td>WU03UK</td>
<td>Location of usual residence and place of work by method of travel to work. ONS Crown Copyright Reserved, 2014</td>
</tr>
<tr>
<td>MYE3</td>
<td>Components of population change for local authorities in the UK, mid-2013</td>
</tr>
<tr>
<td>Infuse Local Authorities 2011</td>
<td>Local authorities for England, Wales, Scotland and Northern Ireland merged by UK Data Service Census Support, 2014</td>
</tr>
</tbody>
</table>

Appendix B

Scatterplot between Logged commuting distance and Logged integration R100,000m

Scatterplot between Logged population density and Logged integration R5,000m
Scatterplot between Logged Workplace Density and Logged integration R5,000m

Scatterplot between Logged total commuters and Logged integration R10,000m

Scatterplot between Logged average commuting distance decay and Logged integration R10,000m