Modelling and visualising the impacts of increasing fuel costs on the UK spatial economy

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1. Introduction

In the UK, over four million business organisations rely on a web of spatial connections to other establishments. Each connection has its own cost in energy and time to move goods and services across space. It is possible to theorise how a change in costs may affect a single firm, but system-wide effects also occur, which to be seen and understood require a detailed picture of the spatial structure of the UK economy as a whole.

Lacking good spatial economic data, it is difficult to develop insights into the future spatial economy: what will happen as costs change and the UK undergoes an energy transition? Currently, views here are polarised. There are qualitative, 'common-sense' arguments that distance will become more expensive as energy costs increase, and thus localism must be a policy priority (e.g. Glasmeier 2007, North 2010). On the other hand, quantitative analyses all too often ignore the distance factor entirely (cf. Krugman 2010), treating transport as a normal production input, or minimising its importance since the cost of moving goods is a small percentage of overall costs (Glaeser & Kohlhase 2004). IO models are able to investigate the multiplier effects of changing a single cost on the whole production matrix (for an energy-cost example see Kerschner & Hubacek 2009) but they do not model what will happen as distance costs between all business organisations change.

The research presented here is part of a larger project (GRIT: http://geo-grit.org) that has two broad aims: (i) creation of a fine-grained picture of the current spatial structure of the UK economy and (ii) simulating how changing fuel prices could alter that structure over the long term. This paper presents two aspects of this research; first a proof of concept using synthetic data to show how a detailed spatial picture of the economy will be generated. Secondly, how the resulting 4-D matrix will be visualised – how to visualise complex spatio-temporal data sets is an increasingly important issue facing researchers. (NB: Results showing the real spatial network using data from the Business Structure Database will be shown at the conference).

2. Real and Synthetic Data

The real data to be used to construct a picture of the spatial structure of the UK economy comes from two sources; the Business Structure Database (BSD) and ONS Supply and Use tables. The BSD database contains records of the location and turnover for over 99% of UK businesses. Access to this data is tightly controlled, hence we present details of our methodology using a synthetic data set. The Supply and Use tables include a ‘combined use’ matrix describing intermediate demand between 110 SIC-coded sectors (e.g. retail, manufacturing, industrial etc), with the most recent trade flows for 2010. These two data sets will be linked together to generate an accurate spatial picture of the UK economy.

In the `proof of concept’, we use a synthetic version of the BSD sector aggregations to NUTS 3 geographies (133 zones in the UK, each zone containing details of the presence each sector has). This is linked to the real ‘combined use’ matrix data of UK trade flows and, using a spatial decay function (see below) a synthetic estimation of UK spatial trade flows is made. The NUTS-3 scale was chosen to strike a balance between robustly testing the methodology at a useful spatial resolution, keeping within BSD disclosure requirements and keeping the data at a level that can produce useful outputs.

The following sections will detail how the matrix was constructed from the synthetic data before briefly showing how this network is visualised.

3. Methodology

The first issue to be addressed is to allocate (non-geographical) flow data between SIC codes described in the Supply and Use ‘combined use’ table. How do those flows map to the geography of the UK? Where does it originate and where is it spent? Monetary amounts between each SIC sector must be allocated between many pairs of zones; the number of possible permutations is huge and must be constrained in some way. We employ a method that has two distinct stages: (1) turn each individual money flow in the `combined use' matrix between two sectors into a ‘budget’ for each zone. This means that each zone’s SIC sector will have up to 110 separate budgets, one for each sector it is buying from. (2) treating each zone as a `representative agent’, it will spend that budget across the UK, according to a constrained budget function. These two steps are carried out as follows.

3.1 Creating a demand matrix for each SIC sector, for each NUTS 3 zone:

The first requirement is to find the demand level for each NUTS 3 zone, for each of its SIC sectors. From the Supply and Use table, demand is known at the UK level from/to each sector. This stage requires that amount to be split between each zone, using a demand proxy to apportion it. The proxy used here is total turnover for each zone’s SIC sector. Zone totals were then normalised to one, thereby keeping actual turnover information anonymous (an important consideration for the real data). The resulting fractions were then used to split demand.

3.2 Estimating demand spend for each SIC sector across the UK to create an IO matrix:

The result of 3.1 is that each zone’s separate SIC sector now has a demand amount set proportional to turnover, constrained so that the total across all zones equals the figure in the Supply and Use table. To apportion demand, each zone SIC sector was treated as a separate economic `representative agent’ with a budget for each other sector they buy from. A budget constraint was then used to allot that agent’s spend across the rest of the UK. To achieve this, a ‘Constant Elasticity of Substitution’ (CES) approach was used as given in Equation 1:

$$c_j = \frac{p_j^{\frac{1}{\rho-1}} Y}{\sum_{i=1}^{n} p_i^{\frac{\rho}{\rho-1}}}$$

Where c_j is the quantity of j demanded, Y is the budget, rho is the `elasticity of substitution' parameter, p_j is the cost of j and p_i is the cost of all others being demanded.

The CES approach has been used successfully at a more aggregate level to produce analyses of international trade costs (see e.g. Anderson & van Wincoop 2003; Anderson & van Wincoop 2004). This allows an allocation of demand that easily keeps them within a set 'budget' for each zone SIC sector; and the importance of distance can be controlled very finely through its elasticity parameter and the cost of distance itself (Olner 2012).

4. Visualising

4.1 Static network

In the example given below, the flow of money from [SIC 25OTHER] `Fabricated Metal Products' in Sheffield to [SIC 24.1-3] `Basic Iron and Steel' are calculated using the CES function outlined above. Figure 1 shows the resulting synthetic spatial pattern, assuming almost every other NUTS3 zone has some presence for basic iron and steel production. This is an unrealistic assumption chosen to illustrate how the method distributes trade flows spatially.

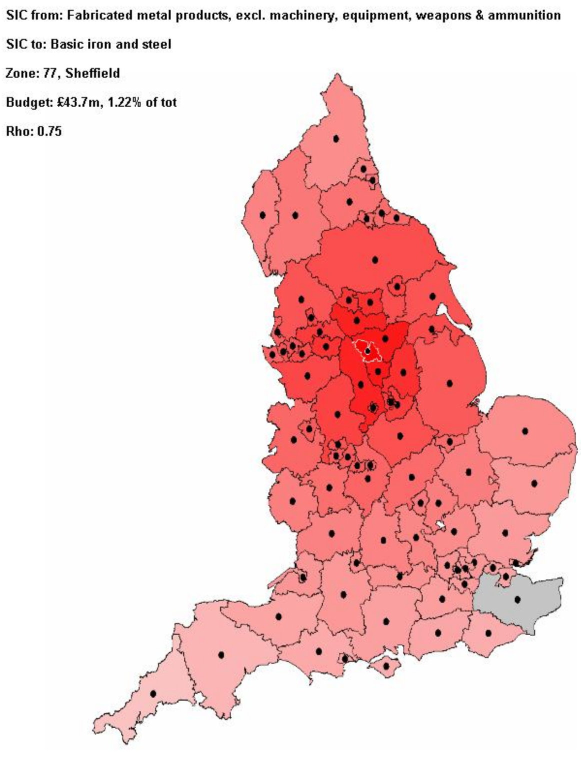

Figure 1. Resulting spatial pattern of the flow of money from Sheffield to all NUTS3 zones.

4.1 Dynamic network

Whilst one key challenge of this work is to create a matrix that can accurately represent the dynamics of the flows of money between different sectors spatially, another is how to dynamically visualise the data. Figure 2 presents snapshots of how the UK trade network represented in the `combined use' matrix can be visualised. A dynamic version of this visualisation will be demonstrated at the conference, and can be seen at http://www.personal.leeds.ac.uk/~geodo/grit/SupplyUseNetworkViz/.

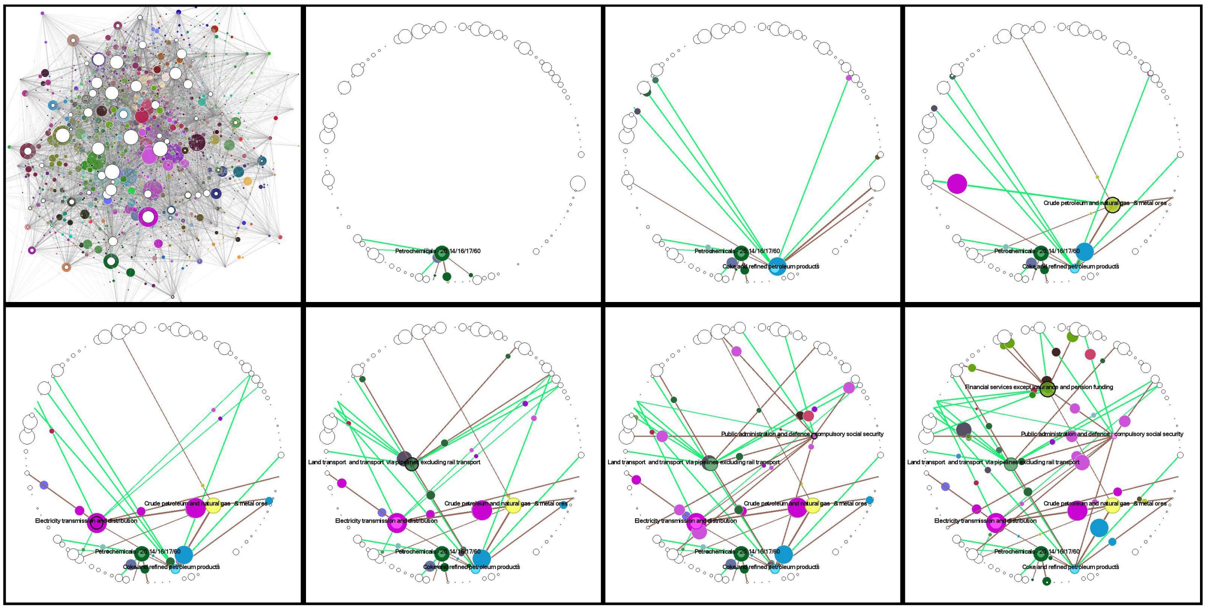

Figure 2. Intra-UK trade flows as a network diagram. From left to right: force-based layout for whole network; then singling out sectors showing largest connections: petrochemicals, coke & petroleum; crude petrol, gas & metal ores; land transport inc. pipelines; public administration; financial services.

5. Discussion

Once constructed, the project's spatial trade matrix can be used to simulate the impacts on the economy of changing energy usage under a range of scenarios. For example, will changing costs mean a substantive spatial reconfiguration of the entire economy or will the changes prove less significant, relative to other economic shifts? As EU carbon emission costs are embedded further into the economy, how will changing production costs amplify tensions in the UK's industrial networks, and drive spatial relocation? Further details on the methodologies and results generated using the real data will be presented at the conference.

6. Acknowledgements

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Biography

Dan Olner is a researcher at the School of Geography, University of Leeds. In his PhD work, Dan has been developing agent-based modelling ideas to re-examine location theory questions about how spatial economies change. The challenges posed by climate change and rising energy prices are breathing new life into this field.

Alison Heppenstall is a lecturer in Geocomputation at the School of Geography, University of Leeds. AH has a background in development of novel computational tools, in particular, agent-based modelling. Her current work is focused on integrating agent-based models with microsimulation and behavioural frameworks. She was recently an editor on the book Agent-based Models of Geographical Systems.

Gordon Mitchell (C.Env, MIEMA) is a lecturer in resource and environmental management, with interests in application of spatial analysis tools to forecasting and planning for sustainable development.