GREATER MANCHESTER INDEPENDENT PROSPERITY REVIEW

ECONOMIC COMPLEXITY ANALYSIS

A technical report for the research on
Innovation & Global Competitiveness

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The Bennett Institute for Public Policy at the University of Cambridge seeks to rethink public policy in an era of turbulence and growing inequality. Its research, teaching and policy engagement are guided by the need to devise sustainable solutions to some of the most pressing problems of our time.

The views expressed in this report are those of the authors and, as usual, errors and omissions in this report remain the responsibility of the authors alone.

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The Greater Manchester Independent Prosperity Review was commissioned to provide a detailed and rigorous assessment of the current state, and future potential, of Greater Manchester's economy. Ten years on from the path-breaking Manchester Independent Economic Review, it provides a fresh understanding of what needs to be done to improve productivity and drive prosperity across the city region.

Independent of local and national government, the Prosperity Review was carried out under the leadership of a Panel of six experts:

Professor Diane Coyle
Bennett Professor of Public Policy, University of Cambridge, and
Chair of the Greater Manchester Independent Prosperity Review

Stephanie Flanders
Head of Bloomberg Economics

Professor Ed Glaeser
Fred and Eleanor Glimp Professor of Economics, Harvard University

Professor Mariana Mazzucato
Professor in the Economics of Innovation & Public Value and Director of UCL Institute for Innovation and Public Purpose

Professor Henry Overman
Professor of Economic Geography, London School of Economics, and
Director of the What Works Centre for Local Economic Growth

Darra Singh
Government and Public Sector Lead at Ernst and Young (EY)

The Panel commissioned studies in four areas, providing a thorough and cutting edge analysis of key economic issues affecting the city region:

- Analysis of productivity, taking a deep-dive into labour productivity performance across Greater Manchester (GM), including a granular analysis of the 'long tail' of low-productivity firms and low pay;
- Analysis of education and skills transitions, reviewing the role of the entire education and skills system and how individuals pass through key transitions;
- Exploration of the city region's innovation ecosystems, national and international supply chains and trade linkages; and sources of global competitiveness, building on the 2016 Science and Innovation Audit; and
- Work to review the infrastructure needs of Greater Manchester for raising productivity, including the potential for new approaches to unlock additional investment.

A call for evidence and international comparative analysis, developed in collaboration with the Organisation for European Cooperation and Development (OECD) and European Commission, also supported this work.

All of the Greater Manchester Independent Prosperity Review outputs are available to download at **www.gmprosperityreview.co.uk**.

This technical report is one of a suite of Greater Manchester Independent Prosperity Review Background Reports.

Contents

1. Introduction and scope

What are places currently good at doing, and what might they be able to be good at doing in the future? These questions are central to an effective industrial strategy, but it can often be difficult to assess rigorously a place's key areas of competitiveness and future opportunities for economic development. The economic complexity framework is a new network-based empirical methodology to study a place's current comparative advantage and future growth potential. It provides a new tool for visualising differences in places' productive capabilities (or 'know-how') and industrial structures, and it has also provided new insights into development patterns and the growth potential of countries and regions.[1]

This report for the GM Prosperity Review applies the analytical framework of economic complexity to study Greater Manchester's industrial strengths and future development possibilities. Drawing on detailed employment data from the UK Business Register and Employment Survey (BRES), this report:

1) Examines GM local authorities' current sectoral comparative advantages in terms of their ***economic complexity***, a measure which has been shown to be linked to future growth potential;

2) Constructs the ***UK Industry Space***, a network perspective that helps visualise structural differences between UK local authorities, both in terms of current industrial specialisations and future development possibilities;

3) Identifies possible ***future industrial opportunities*** for the 10 local authorities in Greater Manchester that are (i) well aligned with current industrial strengths and (ii) could be advantageous in terms of higher value growth and capability upgrading.

Not surprisingly, the 10 authorities differ considerably in their current degrees of complexity and network structures, as described below. The key results for the purposes of the Local Industrial Strategy concern the future potential of each authority for developing higher value activities by building out from their existing relative strengths.

[1] Key research includes Hidalgo et al 2007, Hidalgo and Hausmann, 2009; Hausmann et al 2014; Neffke et al 2011; Balland & Rigby, 2017; Mealy et al 2018a; 2018b; Bishop et al 2018.

2. The Economic Complexity of UK Local Authorities and Industries

The Economic Complexity Index (ECI) and Product Complexity Index (PCI) are measures of economic activity that have been shown to provide useful insights into the type of activities that distinguish prosperous from less prosperous places. Originally developed by Hausmann and Hidalgo (2009) to understand cross-country differences in productive capabilities from export data, the measures have since proved to be particularly successful at explaining variation in per capita GDP and predicting future growth rates across countries (Hausmann et al 2014a). Similar findings have been shown to apply to regional data (Gao & Zhao, 2018; Mealy et al 2018a, 2018b). In the regional setting, the ECI and PCI provide a useful way of understanding differences in local authorities' industrial strengths.

Industrial strengths are measured using *location quotients*. Location quotients analyse the concentration of industrial employment in defined geographic areas. An industry j's location quotient in a given area i is calculated as the ratio of the *industry's share of employment* in that location to its share of employment nationally. So if we define E_{ij} as the number of people employed in industry j in local authority i, then the location quotient for industry *j* in area *i* (denoted LQ_{ij}) is given by

$$LQ_{ij} = \frac{E_{ij} / \sum_j E_{ij}}{\sum_i E_{ij} / \sum_i \sum_j E_{ij}}$$

If a local authority has a location quotient greater than 1 (which indicates that the local authority's employment share in that industry is the greater than the national average), the local authority is said to be 'competitive' or have 'revealed comparative advantage' (RCA) in that industry.

Here we apply the Hausmann et al (2014a) algorithm to the location quotients to calculate the economic complexity metrics (ECI and PCI) for UK local authorities and industries.

The ECI and PCI measures are calculated based on local authorities' industrial strengths (see box). It is intuitive to think of the ECI and PCI as being related to the industrial diversity (the number of industries a particular local authority has a comparative advantage in) and the industry's ubiquity (the number of local authorities that have an advantage in a given industry). However, a more accurate way to think about the ECI is as a measure that captures the most variation in the different dimensions of local authority industrial profiles. It provides a *ranking* that places local authorities with similar industrial profiles close together in the ordering, and local authorities with different industrial profiles far apart (Kemp-Benedict, 2014; Mealy et al 2018a).

This ECI ranking is particularly interesting from an economic perspective because it is strongly correlated with UK local authorities' earnings per capita (see Figure 1) and is significantly predictive of earnings growth (see the regression results reported in Table 1). The right hand side panel of Figure 1 highlights that local authorities with high ECI tend to be urban areas or cities, while local authorities with low ECI are more likely to be rural areas.

Figure 1: Relationship between Local Authorities' Economic Complexity and average annual earnings

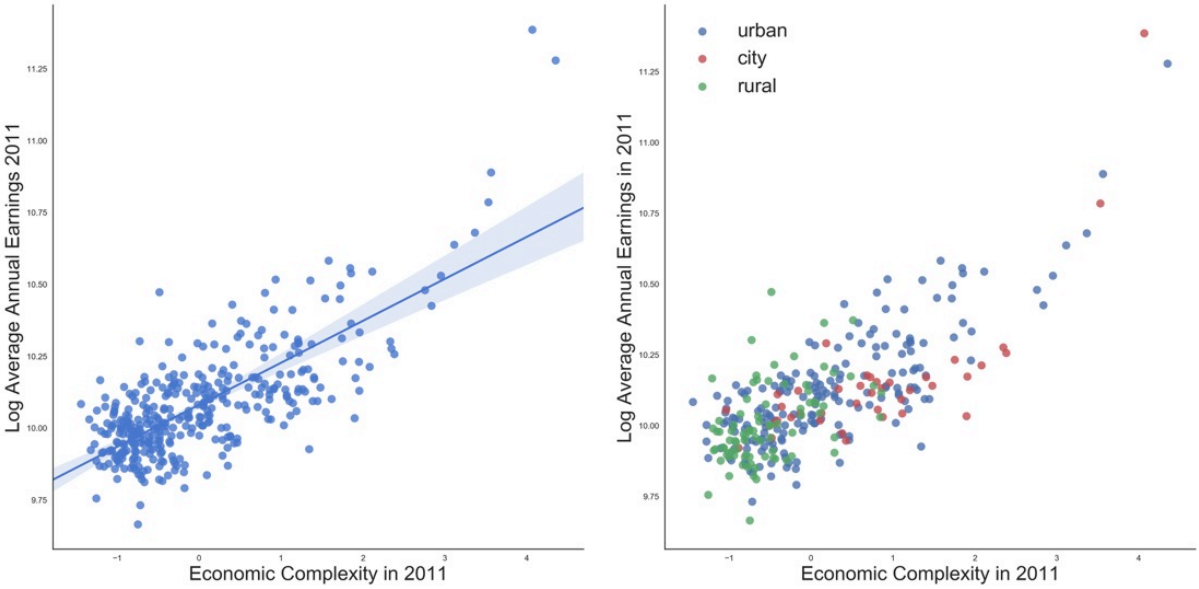


Table 1: Regression analysis of the relationship between growth in local authorities' annual earnings and economic complexity

Variables	Annualised growth rate in average annual earnings (2011 – 2016)
Economic Complexity in 2011	0.004***
	(0.001)
Log average annual earnings in 2011	-0.053***
	(0.005)
Intercept	0.555***
	(0.056)
Observations	369
Adjusted R-squared	0.238

*** p-value <0.001, standard errors in parenthesis
Workplace earnings data is sourced from the ONS Annual Survey of Hours and Earnings. Not all workplace earnings data was available for all 380 local authorities

Table 2 shows the top and bottom ranked local authorities in terms of their ECI for the year 2015. High ECI ranked local authorities like the City of London, Tower Hamlets and Islington not surprisingly have similar industrial profiles to each other and different industrial profiles from the more rural areas like East Staffordshire, Sedgemoor, and Falkirk.

Table 2: Top and bottom ranked Local Authorities by ECI

ECI Rank	Local Authority	Rank	Local Authority
1	City of London	371	Neath Port Talbot
2	Tower Hamlets	372	Pendle
3	Islington	373	Telford and Wrekin
4	Westminster	374	Rotherham
5	Southwark	375	South Derbyshire

6	Camden	376	Dudley
7	Hammersmith and Fulham	377	North Lincolnshire
8	Kensington and Chelsea	378	East Staffordshire
9	Hackney	379	Sedgemoor
10	Lambeth	380	Falkirk

However, we can get more information about how these local authorities' industrial profiles differ by looking at the corresponding PCI measure. It provides a particularly useful indicator of what competitive strengths local authorities at either end of the ECI ranking have in common. As shown in Table 3, showing the 10 top and bottom 10 industries ranked in terms of their PCI, almost all the highest PCI industries are skilled professional, financial or information-related sectors that tend to be concentrated in cities and urban areas. The bottom ranked industries largely relate to manufacturing activities that are more likely to be located outside major urban centres.

Table 3: Top and bottom ranked industries by PCI

PCI Rank	SIC (3-digit) Industry	Rank	Local Authority
1	Reinsurance	249	Manufacture of bodies (coachwork) for motor vehicles; manufacture of trailers and semitrailers
2	Fund management activities	250	Manufacture of products of wood, cork, straw and plaiting materials
3	Television programming and broadcasting activities	251	Manufacture of basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in primary forms
4	Trusts, funds and similar financial entities	252	Processing and preserving of meat and production of meat products
5	Motion picture, video and television programme activities	253	Manufacture of articles of concrete, cement and plaster
6	Advertising	254	Preparation and spinning of textile fibres
7	Market research and public opinion polling	255	Manufacture of cement, lime and plaster
8	Other information service activities	256	Manufacture of basic iron and steel and of ferro-alloys
9	Management consultancy activities	257	Mining of hard coal
10	Computer programming, consultancy and related activities	258	Manufacture of coke oven products

An important advantage of the ECI and PCI is that they do not require any prior knowledge about the type of industries that distinguish different places. The methodology allows the data to reveal how to distinguish local authorities on the basis of their industrial profiles.

Figure 2 and 3 respectively show the aggregate picture of the average local authority ECI values within each UK region, and the average industry PCI values falling into broader SIC 2-digit categories. (In both cases the black line represents the error bars showing the 95% confidence interval.) Figure 2 shows that on average, local authorities in London have industrial structures that are most similar to local authorities in the South East, and most different from local authorities in Yorkshire and the Humber and Wales. Not surprisingly, Figure 3 shows the industries that tend to be more concentrated in London and the South

East relate to finance, insurance, ITC and professional activities, while agricultural and manufacturing industries more likely to be concentrated in local authorities in Yorkshire and the Humber and Wales.

Figure 2: Average ECI of Local Authorities in UK Regions

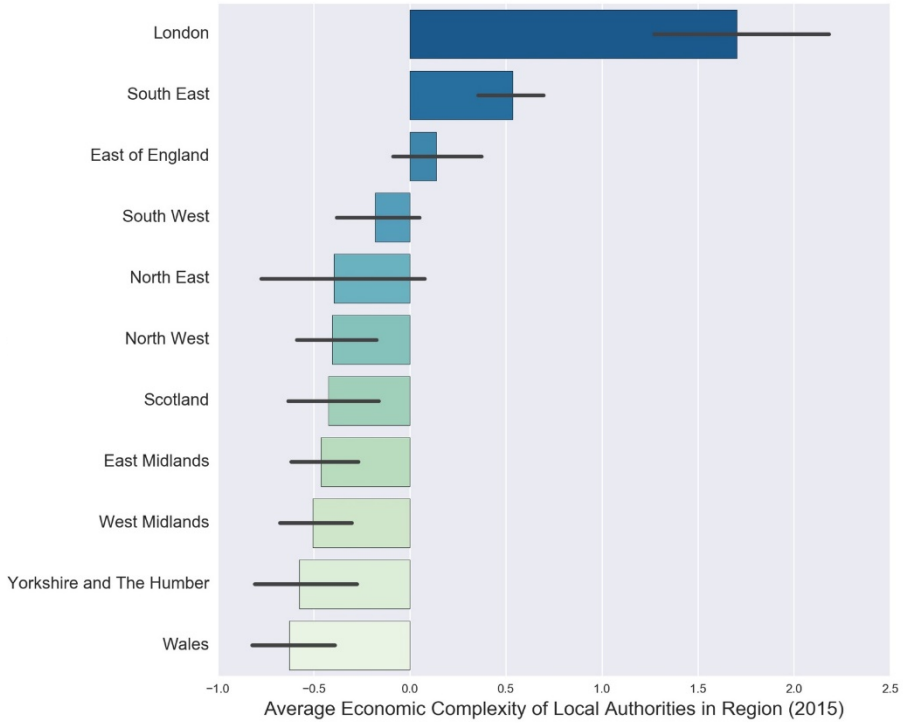


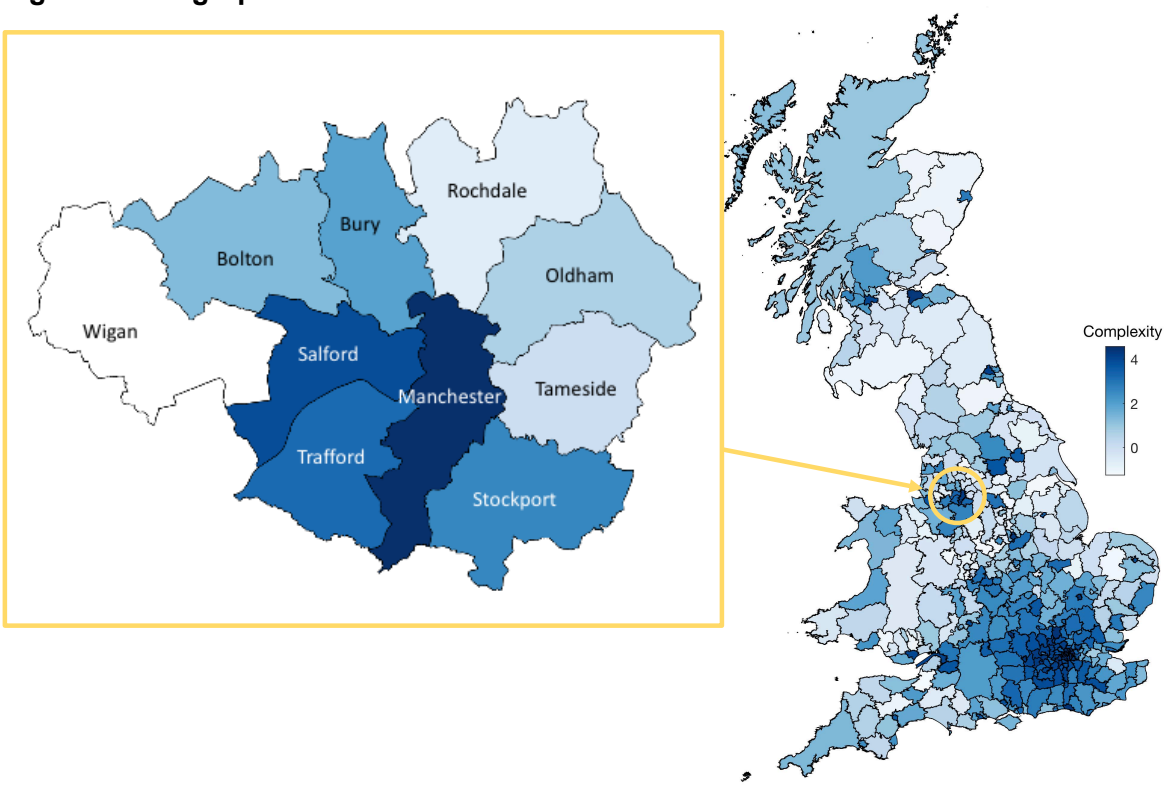
Figure 3: Average PCI of SIC 3 digit industries for broader 2-digit SIC categories

Black lines represent error bars showing 95% confidence interval

3. Economic Complexity of the GM Districts

Turning to Greater Manchester, Figure 4 shows the geographical distribution of local authorities' ECI across the UK, with an inset highlighting the Greater Manchester city-region. Despite their relatively close geographic proximity, this inset highlights the stark differences between the GMCA boroughs. Manchester and Salford have the highest ECI, followed by Trafford and Stockport, which indicates they have relatively similar industrial profiles concentrated in higher-skilled service industries. In contrast, Wigan, Rochdale and Tameside have much lower ECI values, suggesting they have quite different areas of competitiveness, more concentrated in manufacturing activities. An effective industrial strategy needs to take account of these differences, as the realistic possibilities for future growth are likely to look very different across these different areas.

Figure 4: Geographical Distribution of ECI across the UK



3.1 Mapping regional comparative advantage in the UK industry space

To understand each GM district's economic strengths and growth prospects in more detail this section turns to a networks-based lens.

The UK Industry space is a network that helps visualise different types of industrial clusters that agglomerate together geographically. It represents industries as nodes linked to other nodes if they are more likely to cluster (be geographically co-located) within a local authority.

Figure 5. The UK Industry Space

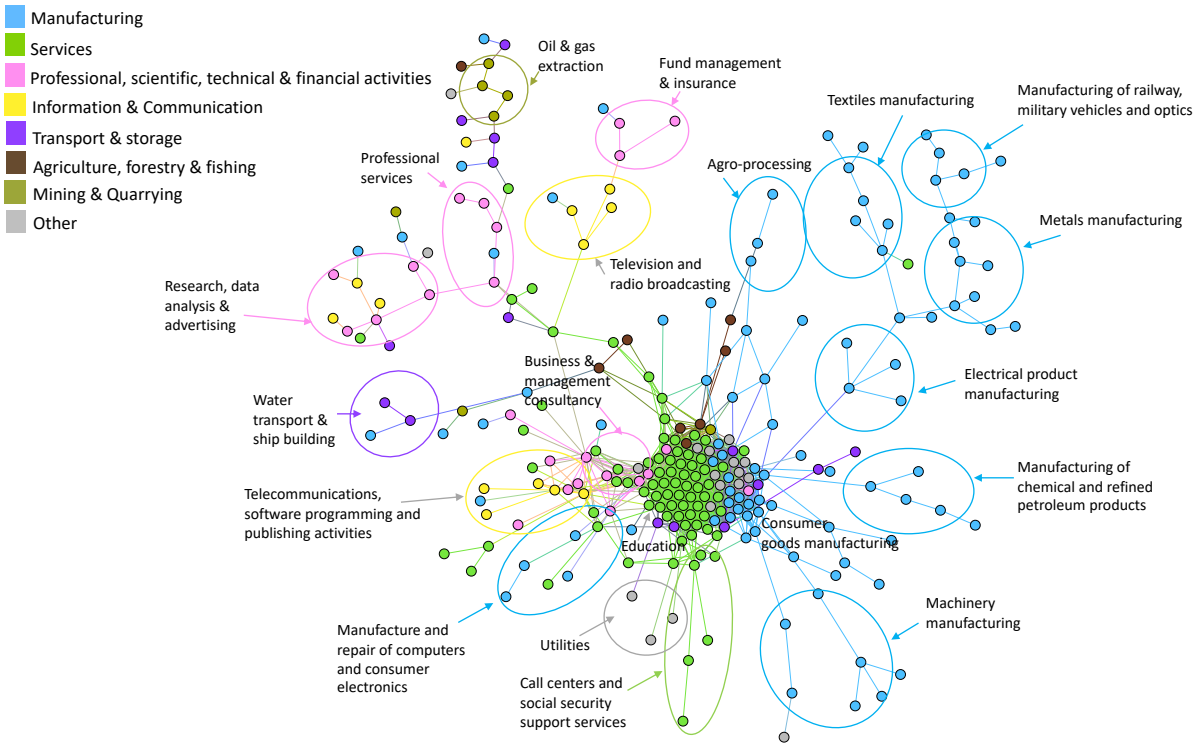


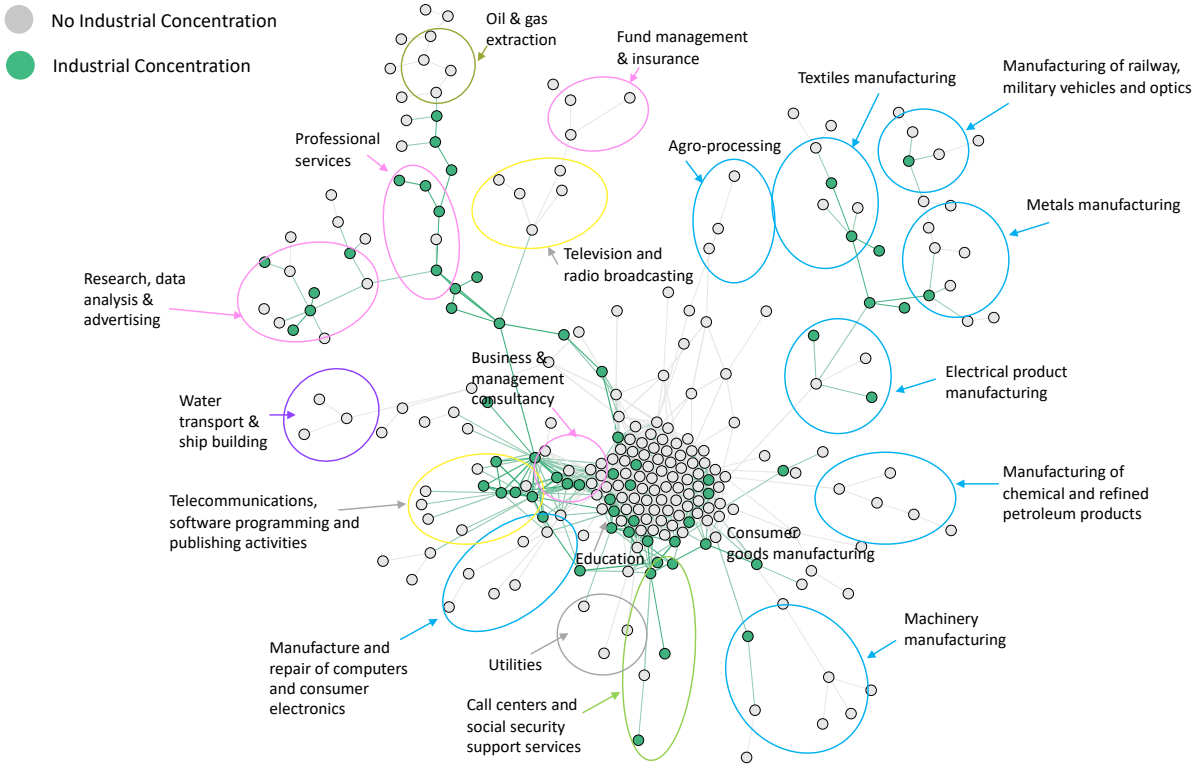
Figure 5 shows the UK Industry Space constructed from BRES data for the year 2015.[2] Manufacturing industrial clusters (shown in blue) will often locate together to take advantage of lower transport costs. Skilled service industries such as professional services and research institutes (shown in pink) will tend to cluster in areas where there is a pool of highly skilled labour. Oil and gas industries (shown in yellow) tend to be located close to where natural resources are concentrated. The UK Industry Space also shows a densely connected 'core' of non-tradable service industries (shown in green) at the centre of the network. These industries include retail, restaurants, schools and hospitals, in which employment tends to increase in proportion with the population in a place.

3.2 Mapping Places in the UK Industry Space

We can visualise differences in local authorities' industrial structure by plotting the industries for which they have a comparative advantage in the UK Industry Space. For example, in Figure 6, we show the city of Manchester's position in the UK Industry Space. Industries that Manchester is competitive in (that is, LQ >1) are coloured green. Here one can see that Manchester has a number of strengths in the area of the Industry Space which relates to research and professional services. It is also concentrated in a number of more densely connected industries relating to telecommunications, computer programming and management consultancy services. These service-oriented strengths are not surprising, perhaps, but the Figure shows that central Manchester also has a number of manufacturing related strengths on the right hand-side of the Industry Space, which relate to textiles and chemicals.

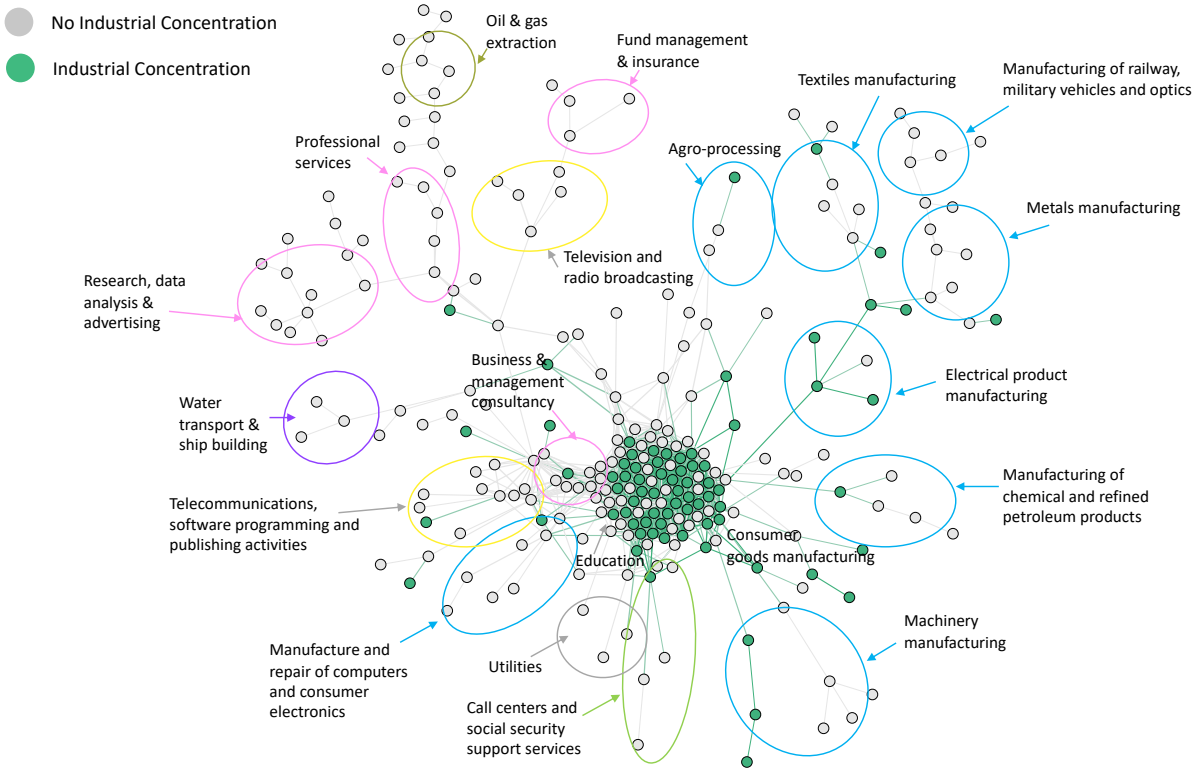
[2] The UK industry space is constructed using a very similar methodology to the approach developed by Hidalgo et al (2007) to construct the Product Space. The Product Space nodes are products linked to each other on the basis of their probability of being co-exported.

Figure 6: Manchester's position in the UK Industry Space



In Figure 7, we show Wigan's position in the UK Industry Space. This allows us to see how different its strengths are from central Manchester. Wigan has few competitive strengths on the area of the UK industry space relating to research, finance and professional services. Instead it has a lot more employment concentrated in the centre of the network, in industries relating to construction, warehousing and storage, and wholesale and retail activities. Wigan also has areas of comparative advantage in a number of different types of manufacturing, such as textiles, chemicals, plastics and machinery.

Figure 7: Wigan's position in the UK Industry Space

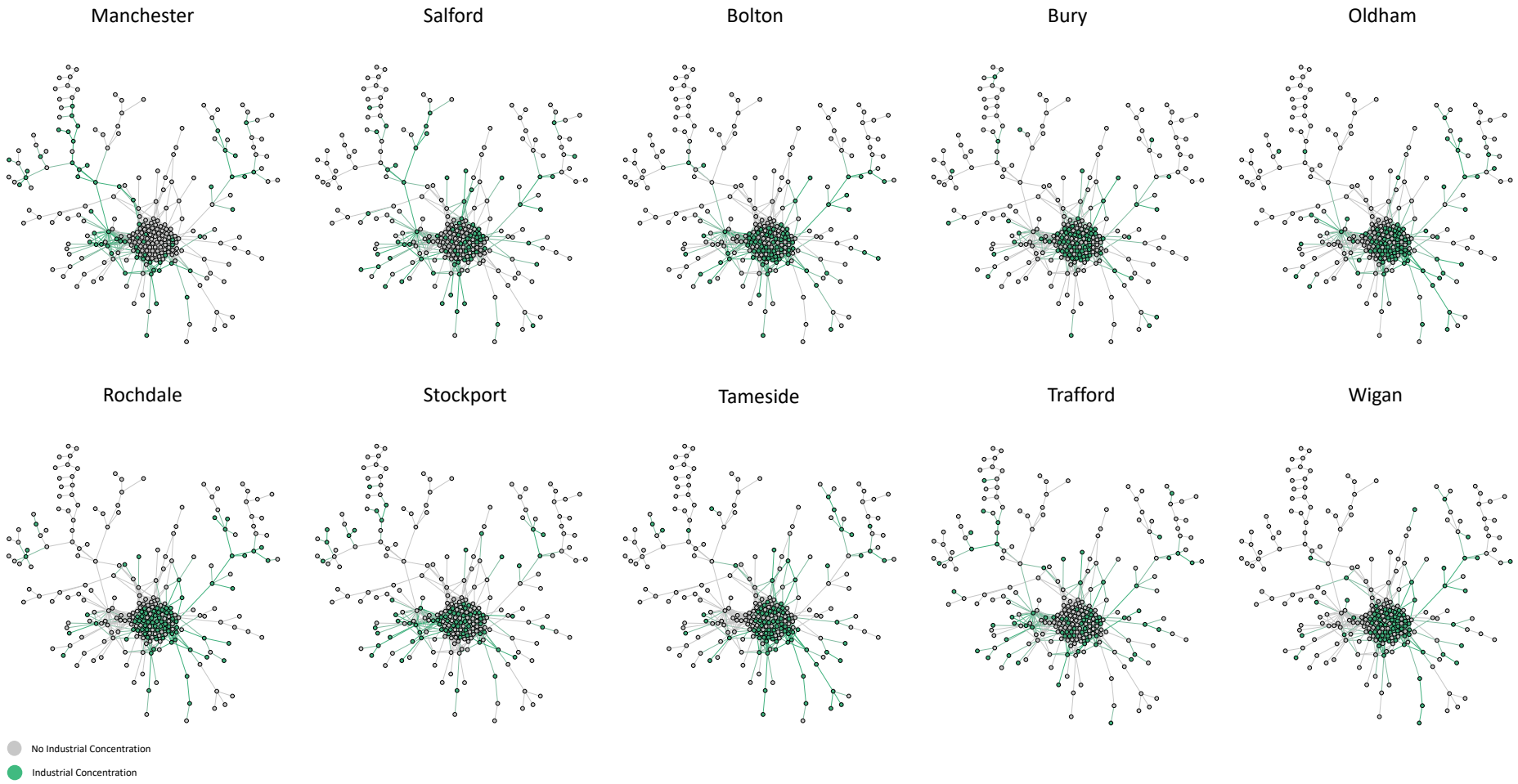


These differences in industrial structure are particularly important when considering industrial strategy. The UK Industry Space provides a useful visual tool for showing industries that local authorities are more likely to be able to build up in future given their present competitive strengths. Just as it is easier to make trousers if you already know how to make T-shirts, countries and regions are more likely to be able to diversify into products or industries that are 'related' (or require similar knowledge or inputs) to those they currently possess[3]. So for example, since Manchester already has a number of competitive strengths in skilled professional services in the top left hand professional services area of the UK industry space, it would most likely find it easier to develop further industries in that cluster that can take advantage of the existing network of skilled professionals and knowledge already located in the city. In contrast, developing a research institute in Wigan may be more difficult – at least in the near-term – given Wigan's current set of competitive strengths. However, manufacturing industries that can benefit from Wigan's existing supply chains, storage and logistical capabilities could represent a more feasible development opportunity.

In Figure 8, we show all 10 GMCA boroughs in the UK Industry Space. These plots provide a sense of the variation across industrial profiles within the city-region, and help give an indication of the types of industrial clusters that are present in each local authority. In the next section, we show how both the economic complexity measures and the network analysis presented here can be combined to identify potential future opportunities for industrial growth and development.

[3] See for example Hidalgo et al 2018

Figure 8: GMCA Boroughs Positions in the UK Industry Space



4. Identifying potential strategic opportunities for the ten Greater Manchester Boroughs

Drawing on information about what UK local authorities are currently good at, we can identify new industrial opportunities that:

(i) Are well aligned with the place's current industrial strengths, and
(ii) Have higher PCI, which could be advantageous in terms of growth and capability upgrading.

To measure how well aligned a growth opportunity is with a place's current industrial strengths, we consider a measure of 'proximity density'.[4] By considering the probability that any two industries will be concentrated in a particular local authority, the proximity density metric captures the likelihood that a new industry could develop there, given its current industrial structure. So for example, if a place is already competitive in industries like accounting, tax consultancy and management consulting, its competitive strengths are likely to be more well-aligned or 'proximate' to the development of new industries such as insurance and fund management activities, and less well-aligned to say agro-processing or pulp and paper manufacturing.[5]

Figure 9 shows the 10 GMCA boroughs. In these plots, green dots represent the local authority's current industrial strengths, while grey dots are industries in which it is not yet competitive. The horizontal axis shows the distance (calculated as 1 minus proximity density) between a given industry and the local authority's existing industrial strengths. The vertical axis plots each industry's complexity (measured by PCI).

The plot for Manchester city for instance (top left of Figure 9), shows a number of green industries in which it is already competitive including advertising, management consulting and computer programming. Industries shaded in purple represent new industrial possibilities that could be advantageous areas of competitiveness in the future. These industries, including market research and public opinion polling, trusts and fund management activities, and motion pictures, video and television, are not only well-aligned to Manchester's current industrial strengths, they also have higher PCI. As discussed in section 1, higher PCI industries are concentrated in places with higher average earnings and growth performance.

Such growth possibilities are sometimes referred to as 'strategic bets' (Hausmann et al 2014b). Although the probability of development in these areas is lower, their industrial success could stimulate significant future benefits in terms of greater diversification and growth opportunities in the longer term. Of course, given this greater risk of failure, promotion of these industries needs to be underpinned by careful feasibility analysis and a rigorous assessment of current binding constraints – such as availability of enough people with appropriate skills, or suitable space – that presently restrict development in these areas.

A similar exercise can be carried out for the other Greater Manchester local authorities.

Owing to its different existing set of capabilities, Stockport (top right plot of Figure 9) has a number of proximate opportunities that have low PCI, such as pre-primary education, landscape services, and residential care activities, but also higher some with PCI such as management consulting, software publishing and head-office activities.

The plots for Wigan and Rochdale shown in the next two panels of Figure 9 both show a distinctly different pattern again. Wigan and Rochdale's nearest future possibilities have low

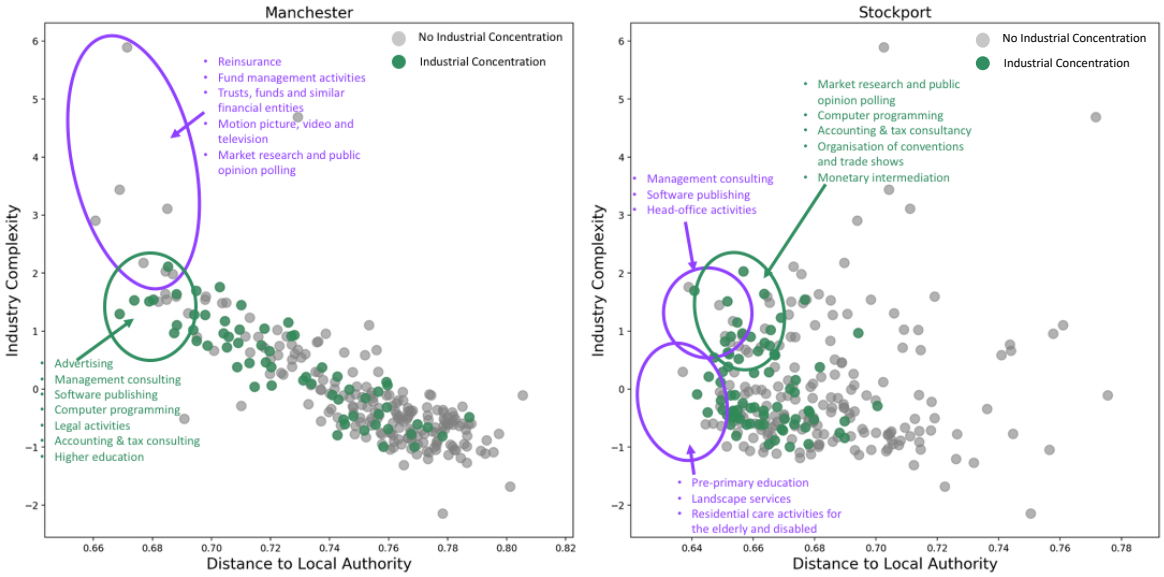
[4] Originally developed by Hidalgo et al (2007)
[5] More information about the proximity density measure can be found in the Technical Appendix

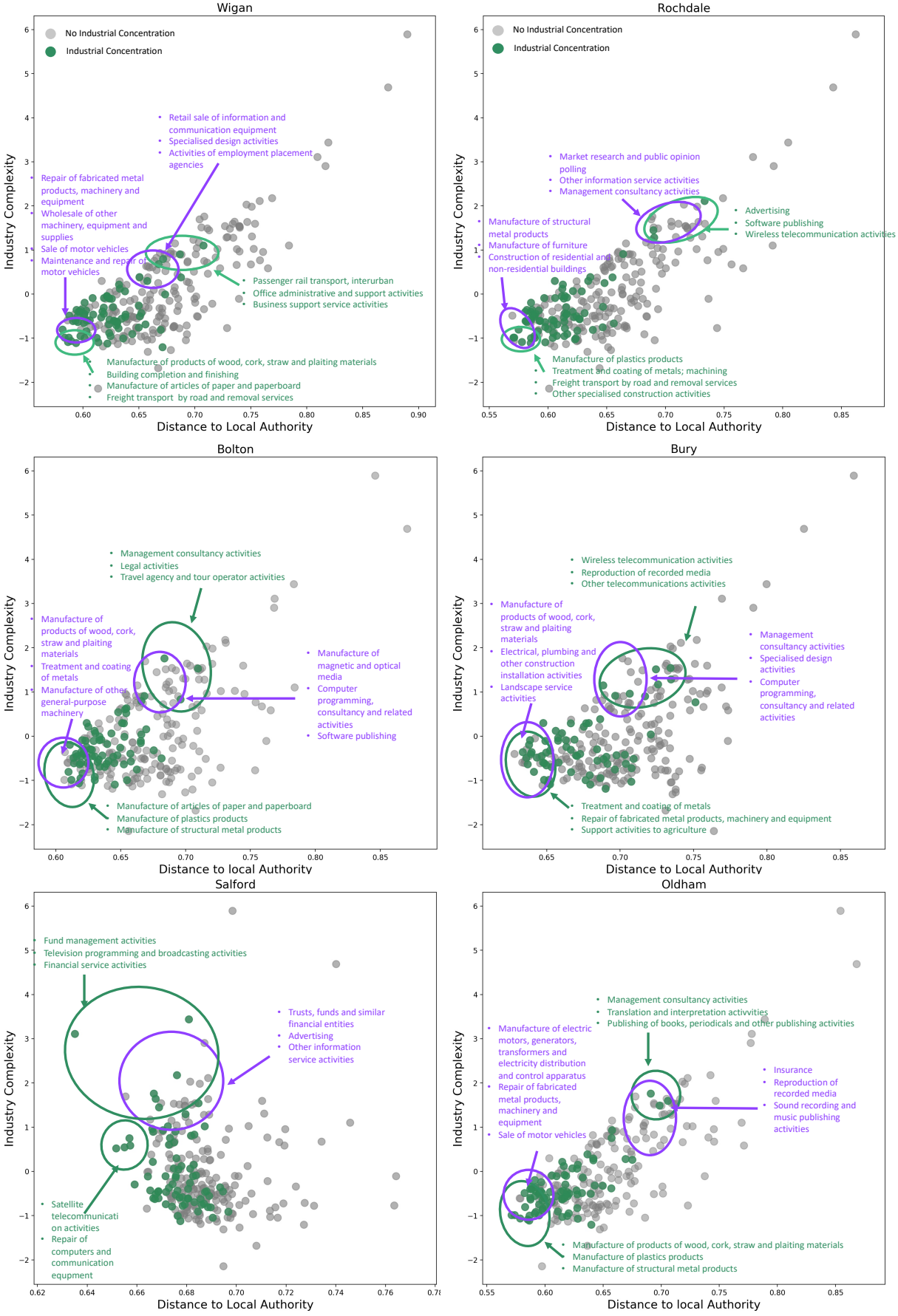
PCI. For example, Wigan's closest industrial opportunities include the sale, maintenance and repair of motor vehicles, repairing fabricated metal, machinery and equipment, and wholesale activities. Rochdale's nearby industrial possibilities include manufacturing structural metal products and furniture, and construction activities. However, Wigan and Rochdale also have competitive strengths in a few industries that are more complex and less typical for their set of industrial capabilities. For example, Wigan has employment concentrations in office administration and business support service activities, while Rochdale has them in advertising, software publishing, and wireless telecommunication activities. The presence of these industrial concentrations could represent an opportunity for Wigan and Rochdale to build on these areas as a kernel of activity allowing them potentially to diversify beyond their traditional, low value, manufacturing-oriented industrial base.

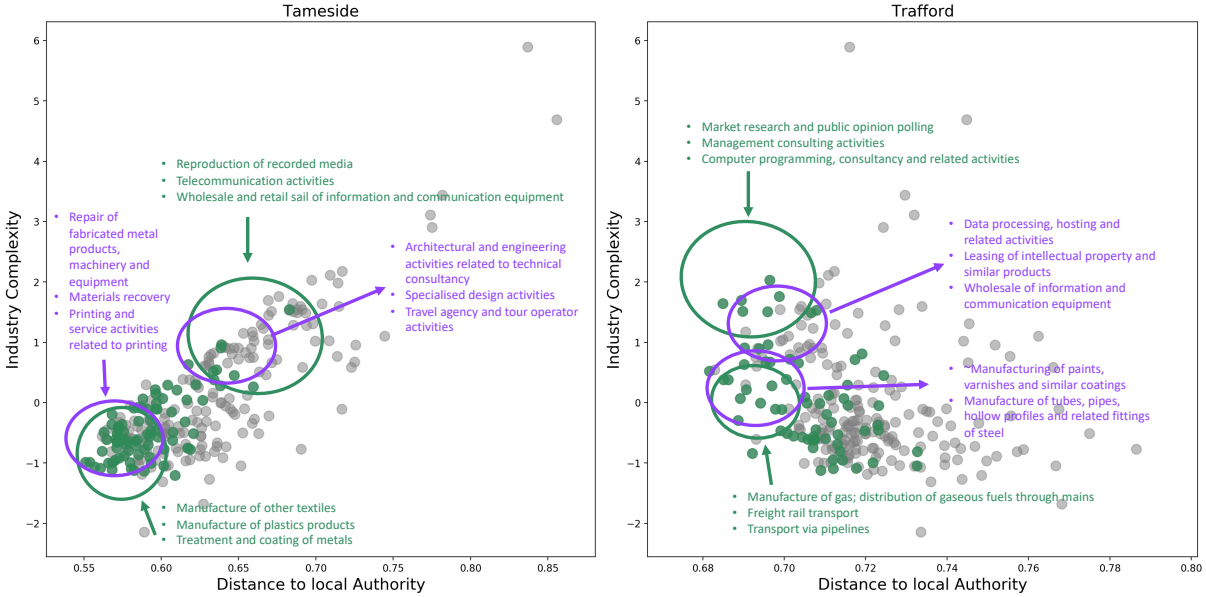
Bolton, Bury, Oldham and Tameside similarly have fairly industrial productive bases, with existing strengths and nearby growth opportunities tending to relate to less complex manufacturing activities. However, each of these local authorities also has a few key strengths in more complex, high-value areas such as management consultancy and telecommunications-related activities.

Salford and Trafford have a more diverse portfolio of competitive strengths, with greater ability to leverage existing capabilities in market research, computer programming and financial services into more complex, higher skilled activities relating to data processing, information services, advertising and financial management.

Figure 9: Identifying new industrial possibilities for the 10 GMCA boroughs




Wigan
No Industrial Concentration
Industrial Concentration
Retail sale of information and communication equipment
Specialised design activities
Activities of employment placement agencies
Repair of fabricated metal products, machinery and equipment
Wholesale of other machinery, equipment and supplies
Sale of motor vehicles
Maintenance and repair of motor vehicles
Passenger rail transport, interurban
Office administrative and support activities
Business support service activities
Manufacture of products of wood, cork, straw and plaiting materials
Building completion and finishing
Manufacture of articles of paper and paperboard
Freight transport by road and removal services
Industry Complexity
Distance to Local Authority
Rochdale
No Industrial Concentration
Industrial Concentration
Market research and public opinion polling
Other information service activities
Management consultancy activities
Manufacture of structural metal products
Manufacture of furniture
Construction of residential and non-residential buildings
Advertising
Software publishing
Wireless telecommunication activities
Manufacture of plastics products
Treatment and coating of metals; machining
Freight transport by road and removal services
Other specialised construction activities
Industry Complexity
Distance to Local Authority
Bolton
Management consultancy activities
Legal activities
Travel agency and tour operator activities
Manufacture of products of wood, cork, straw and plaiting materials
Treatment and coating of metals
Manufacture of other general-purpose machinery
Manufacture of magnetic and optical media
Computer programming, consultancy and related activities
Software publishing
Manufacture of articles of paper and paperboard
Manufacture of plastics products
Manufacture of structural metal products
Industry Complexity
Distance to local Authority
Bury
Wireless telecommunication activities
Reproduction of recorded media
Other telecommunications activities
Manufacture of products of wood, cork, straw and plaiting materials
Electrical, plumbing and other construction installation activities
Landscape service activities
Management consultancy activities
Specialised design activities
Computer programming, consultancy and related activities
Treatment and coating of metals
Repair of fabricated metal products, machinery and equipment
Support activities to agriculture
Industry Complexity
Distance to Local Authority
Salford
Fund management activities
Television programming and broadcasting activities
Financial service activities
Trusts, funds and similar financial entities
Advertising
Other information service activities
Satellite telecommunication activities
Repair of computers and communication equipment
Industry Complexity
Distance to Local Authority
Oldham
Management consultancy activities
Translation and interpretation activvities
Publishing of books, periodicals and other publishing activities
Manufacture of electric motors, generators, transformers and electricity distribution and control apparatus
Repair of fabricated metal products, machinery and equipment
Sale of motor vehicles
Insurance
Reproduction of recorded media
Sound recording and music publishing activities
Manufacture of products of wood, cork, straw and plaiting materials
Manufacture of plastics products
Manufacture of structural metal products
Industry Complexity
Distance to local Authority



Finally, it is important to emphasise that this analysis only represents an initial exploration of these places' industrial strengths and future possibilities. Further analysis would need to analyse:

(i) Whether efforts to encourage the development of a new area of activity in any specific location makes sense in terms of that sector's broader growth prospects and demand profile;

(ii) Whether there are binding constraints limiting growth in more complex areas of activity (such as skill shortages, lack of infrastructure or unfavourable regulatory environments) that policy will need to address if such industrial strategy policies building out from current specialisms to more complex activities are to succeed;

(iii) The extent to which the activity is *tradable* and can serve markets beyond the local authority's domestic demand. Tradable industries tend to have a stronger influence on a region's growth and development, because unlike non-traded activities (such as barber shops, grocery stores, retail and other services, which tend to grow in proportion with the size of a local authority's population), tradable industries are competing with other regions or overseas. As a result, tradable industries tend to have higher wage growth, higher productivity and patenting rates as they grow.[6]

[6] See for example Porter (2003)

Technical Appendix

Calculating the ECI and PCI

The ECI and PCI are calculated on the basis of the following steps.

First, we construct a binary M matrix based on local authorities' location quotients in different industries. In this M matrix, rows represent local authorities, columns represent industries and $M_{ij} = 1$ if local authority i has an LQ in industry $j > 1$, and $M_{ij} = 0$ otherwise. Summing across the rows of M gives a local authority's *diversity* (the number of industries it is competitive in), while summing across the columns of M gives an industry's *ubiquity* (the number of local authorities that it is concentrated within).

Second, we calculate a local authority similarity matrix $\widetilde{M}$, which is given by

$$\widetilde{M} = D^{-1}MU^{-1}M',$$

where D is the diagonal matrix formed from the vector of local authority diversity values and U is the diagonal matrix formed from the vector of product ubiquity values. The $\widetilde{M}$ matrix captures how similar one local authorities' industrial strengths are to another (see Mealy et al 2018a for more information on how to interpret this matrix).

The ECI is defined as the eigenvector associated with the second-largest right eigenvalue of the matrix $\widetilde{M}$. The PCI is symmetrically defined by transposing the binary M matrix and finding the second largest right eigenvalue of an industry similarity matrix $\widehat{M}$, given by

$$\widehat{M} = U^{-1}M'D^{-1}M.$$

Constructing the Industry Space

We construct the UK Industry Space from the binary M matrix based on local authorities' location quotients in different industries (defined above). Drawing on the methodology introduced by Hidalgo et al (2007), we first calculate the *proximity* ϕ_{jk} between two industries j and k, which is based on their pairwise conditional probability of co-locating in a local authority and is given by

$$\phi_{jk} = \min\left(\frac{\sum_i M_{ij}M_{ik}}{\sum_i M_{ij}}, \frac{\sum_i M_{ij}M_{ik}}{\sum_i M_{ik}}\right).$$

Here we take the minimum of these terms to symmetrise the proximity measure and ensure $\phi_{jk} = \phi_{kj}$.

Two industries that have a very high proximity to each other have a very high probability of co-locating in a local authority, while two industries that have a low proximity to each other rarely appear in the same local authority.

Two industries that have a very high proximity to each other have a very high probability of co-locating in a local authority, while two industries that have a low proximity to each other rarely appear in the same local authority.

The UK industry space is essentially a network visualisation of this measure. Nodes in the industry space are industries, which are linked together on the basis of their proximity. However, if we were to visualise all links between all industries, it would be difficult to see any network structure. To create the network diagram shown in this report we follow Hidalgo et al's (2007) approach and first construct the backbone of the network by calculating a *maximum spanning tree* from the ϕ_{jk} values. A maximum spanning tree of a given network

is a tree (i.e. contains no cycles) that connects all vertices with the minimum possible number of edges having maximum weight. So the maximum spanning tree based on the ϕ_{jk} values will ensure all industries are connected to each other using the minimum number of edges of maximal proximity. We then add additional links to this network backbone that have a higher weight (or proximity) than a given threshold. The threshold used in this [Report/Chapter] is 0.38[7], but alternative thresholds give similar results. We then used a force-directed algorithm to visualise the position of nodes and links.

Proximity density (and distance)

To calculate how aligned a new industry is with a local authority's current industrial strengths, we draw on Hidalgo et al's (2007) proximity density measure. Drawing on the proximity metric (described above), the proximity density ω_{ij} measure calculates the average proximity of a new industry k to all the other industries local authority i is currently concentrated in. It is given by

$$\omega_{ik} = \frac{\sum_j M_{ij}\phi_{jk}}{\sum_j \phi_{jk}}$$

The distance measure shown on the x-axis of Figure 9 is calculated as 1 - ω_{ik}

[7] This represents 1.7 standard deviations above the mean of the distribution of proximity values

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