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The development of an index of rural deprivation: A case study of Norfolk, England

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ABSTRACT

Geographical deprivation indices such as the English Index of Multiple Deprivation (IMD) have been widely used in healthcare research and planning since the mid-1980s. However, such indices normally provide a measure of disadvantage for the whole population and can be inflexible to adaptation for specific geographies or purposes. This can be an issue, as the measurement of deprivation is subjective and situationally relative, and the type of deprivation experienced within rural areas may differ from that experienced by urban residents.

The objective of this study was to develop a Rural Deprivation Index (RDI) using the English county of Norfolk as a case study, but with a view to adopting a flexible approach that could be used elsewhere. It is argued that the model developed in this research gives clarity to the process of populating an index and weighting it for a specific purpose such as rural deprivation. This is achieved by 'bundling' highly correlated indicators that are applicable to both urban and rural deprivation into one domain, and creating a separate domain for indicators relevant to the setting of interest, in this case rural areas. A further domain is proposed to account for population differences in rural areas. Finally, a method was developed to measure variability in deprivation within small areas. The RDI results in more rural areas in Norfolk falling in the most deprived quintile, particularly those classified as 'Rural town and fringe in sparse settings'; these areas also have high levels of heterogeneity of deprivation when using the variability measure created.

This model proposed has the potential to provide a starting point for those who wish to create a summary deprivation measure taking into account rurality, or other local geographic factors, and as part of a range of approaches that can be used to allocate, or apply for, resources.

1. Introduction

Deprivation indices have been widely used in healthcare research and planning since the mid-1980s, typically measuring components of material and social disadvantage of residents of small geographical areas (e.g. Davey-Smith et al., 2001). Many countries have a commonly used index; an example is the English Index of Multiple Deprivation (IMD). The various deprivation indices used internationally provide a useful indication of which areas are more or less disadvantaged, and can be used to assist with the planning of services, and assess demand for health and social care (Farmer et al., 2001; Carstairs, 1995). However, they have been criticised as being much more appropriate for representing disadvantage in urban compared to rural areas (Martin et al., 2000).

One problem with deprivation indices is that there is no universal measure of 'deprivation', which is subjective and situationally relative. Deprivation experienced by the residents of rural areas may differ from that experienced by urban residents (Commins, 2004), for example, poor access to services such as healthcare, or shops and amenities (Higgs and White, 1997).

A second problem is that deprivation indices provide an aggregate measure of disadvantage within the geographical areas for which the index is calculated, and may hide variations in disadvantage (Schuurman et al., 2007). Rural deprivation may present in small pockets (for example a few isolated houses on the edge of a village) (Cloke, 2013) and the effect is to fail to capture these small pockets in the measures as they are subsumed into area scores (see Huby et al., 2009).

As a consequence of the various limitations of existing widely-used deprivation indices, there is a danger that rural areas can become 'overlooked' when measuring health service need using such indices. Overall health comparisons suggest that, on average, the health of rural people is better than their urban counterparts, but that there are some clear problems, including the ageing population, road traffic accidents

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and possibly excess winter deaths (Smith et al., 2008). Further, the costs of providing services for rural residents may be considerably higher than for their urban counterparts (Peterson et al., 2017).

1.1. Existing work to measure rural deprivation

In England, Hodge et al. (2000) aimed to identify 'bundles' of indicators which could be used to assess disadvantage in rural areas. They specifically noted that in previous work, no one, single (direct and unequivocal) indicator could be used to accurately identify rural deprivation. They therefore proposed sets of indicators that combine aspects of disadvantage (similar to IMD) into bundles. As a result, six exploratory bundles were created:

- **Access to employment:** numbers unemployed, hidden unemployed, out-migrants of working age in previous year
- **Quality of employment:** numbers working long hours in low pay sectors, numbers in seasonal employment, excess numbers in part-time work
- **Low incomes:** number in low-earning Standard Occupational Qualification occupations, number unemployed, pensioners, economically active
- **Housing accessibility:** number for whom (housing costs/earnings > 0.25), number in social housing
- **Housing quality:** households with more than one person per room, households in temporary accommodation, households with no central heating
- **Access to services:** numbers living in parishes with no local food shop and no doctor's surgery and no daily bus service, and living in households with no car.

The ability of these bundles to provide a useful measure of disadvantage was investigated in three counties (Durham, Lincolnshire and Suffolk) where local authority members were requested to comment on the appropriateness of the scores derived by the bundles for their local area. The authors suggested that the bundles might be a useful tool during resource allocation due to their ability to be applied across both urban and rural settings, whilst acknowledging that not all aspects of disadvantage, such as physical isolation in rural areas, were encompassed in the bundles. In addition, the bundles were not designed to be used as a composite tool and therefore it is not appropriate to combine the bundle scores to provide an overall estimation of disadvantage. One limitation of implementation was a lack of robust local data.

In France, Havard et al. (2008) developed a socioeconomic deprivation index, the Havard index, with the aim of identifying health inequalities in the country. The index is constructed of 19 components that were obtained from the French Census. The authors indicated that the index was appropriate for use across both urban and rural populations and had good internal and external validity. It was however, highly correlated with both existing Townsend ($0.97\ p < 0.01$) and Carstairs ($0.96\ p < 0.01$) indices, suggesting that the use of this comparatively more detailed and complex index may not add anything over existing indices unless the differences are related specifically to enhanced identification at the rural level. More recently, Bertin et al. (2014) assessed the applicability of four deprivation indices to be used in relation to healthcare in both urban and rural settings using Brittany, France, as an example location. The four indices investigated were; Townsend and Carstairs along with two developed using principal component analysis specifically for the French population. These were the Havard (Havard et al., 2008) and Rey indices (Rey et al., 2009). The Rey index is comprised of four indicators; the mean household income, the percentage of high school graduates in the population > 15 years old, the percentage of blue-collar workers in the active population (in British indices this is often represented by indicator of social class) and the unemployment rate.

The external validity of the indices was assessed using data from a colorectal cancer screening initiative with the premise that screening uptake is lower in areas with higher deprivation. Using simple and multiple regression (adjusting for level of urbanisation) significant negative associations with the level of screening attendance were reported for all indices. However, the strongest goodness-of-fit were reported for the Carstairs and Rey indices ($R^2 = 0.216$ and 0.170 respectively). From this the authors concluded that both the Carstairs and Rey indices may be used to assess disadvantage in rural and urban settings in relation to healthcare, although this contrasts the general consensus in the UK that Carstairs is insensitive to rural deprivation (Martin et al., 2000). There therefore remains the need for further work to identify a set of indicators that may be used to better identify rural deprivation, and this is explored using a case study location of Norfolk, UK.

1.2. Norfolk – the case study setting

The research presented in this manuscript uses the case study of the county of Norfolk, a predominantly rural county in the East of England. In 2016 it had a population density of 166 persons per kilometre square, compared to 424 in England, and 321 in the East of England (Norfolk Insight, 2016). Around 40% of the population live in four urban areas: Norwich, Great Yarmouth, King's Lynn and Thetford. Norfolk's rural population is more elderly than its urban population, with 34% of those living in the most rural settings aged over 64 years compared to 19% in urban areas (ONS, 2016).

1.3. Classification of deprivation and rurality in England

The English Indices of Multiple Deprivation (IMD) measures relative deprivation in small areas and is the official measure of multiple deprivation in England. The IMD is based on data for small geographic areas known as Lower Layer Super Output Areas (LSOAs). LSOAs are part of a hierarchical geographical system used for reporting by the UK government; an LSOA in England and Wales had on average 1614 persons in 2011.

The IMD has seven domains (Income; Employment; Health and disability; Education, skills and training; Crime; Barriers to housing and services; Living environment). Weightings for the domains are 22.5%, 22.5%, 13.5%, 13.5%, 9.3%, 9.3% and 9.3% respectively. Three of the domains have sub-domains (Indoor and Outdoor for Living environment; Geographical barriers and Wider barriers for Barriers to housing and services; Children and young people and Adult skills for Education, skills and training). Each domain is weighted before being combined into an overall composite measure. The domain weightings, which were predominately determined by reference to theory (Smith et al., 2015), were re-examined by Dibben et al. (2007) whose findings generally support the existing weightings, however the weightings were not tested for specific applications such as the measurement of rural deprivation.

The degree of rurality of LSOAs in England can be identified using the UK Government's Rural and Urban Area Classification (RUC11) (Bibby and Brindley, 2015). RUC11 classifications are based on the type of settlement (dispersed dwellings, hamlet, village, small town, urban fringe and urban) and on a population sparsity measure (the number of households in the surrounding area). There are eight RUC classes at LSOA level (four urban and four rural), but only one of the four urban classifications applies to Norfolk (Table 1). Due to the low number of LSOAs in 'sparse settings' in Norfolk, this classification has in some instances been combined with the equivalent 'non-sparse' settlement type in this report. This creates three RUC categories in Norfolk; 'Urban city and town', 'Rural town and fringe' (sparse and non-sparse) and 'Rural village and dispersed' (sparse and not sparse).

Table 1
Number of LSOAs falling in RUC11 classifications for England and for Norfolk.

RUC11 Classifications	LSO England No.	LSOA England %	LSO Norfolk No.	LSOA Norfolk %
Urban city and town	14456	44.0%	267	49.6%
Rural town and fringe	2937	8.9%	110	20.4%
Rural town and fringe in a sparse setting	119	0.4%	15	2.8%
Rural village and dispersed	2361	7.2%	135	25.1%
Rural village and dispersed in a sparse setting	181	0.6%	11	2.0%
(Other urban)	12790	38.9%	0	0%
Total	32844		538	

Table 2
Average scores for subdomains within Barriers to Housing and Services and Living Environment domains (higher scores = higher deprivation).

Row Labels	Barriers to Housing and Services		Living Environment	
	Wider	Geographical	Indoors	Outdoors
Rural village and dispersed in a sparse setting	8.6	74.4	77.0	1.5
Rural village and dispersed	7.6	64.3	41.7	5.2
Rural town and fringe in a sparse setting	13.2	24.0	35.8	2.5
Rural town and fringe	9.7	26.6	17.2	6.5
Urban city and town in a sparse setting	16.1	25.0	33.5	3.2
Urban city and town	16.7	20.8	18.4	17.1
Urban major conurbation	18.4	15.1	15.9	28.1
Urban minor conurbation	34.5	12.6	22.4	34.6

1.4. The IMD and rural deprivation

Fig. 1 shows the average IMD rank for each domain by rural-urban classification. A lower rank indicates a higher level of deprivation. Domain ranks are more variable for rural than for urban areas. Areas classified as 'Rural village and dispersed' are significantly more deprived on two domains - Barriers to housing and services and Living environment.

For each of the sub-domains within the Barriers to housing and

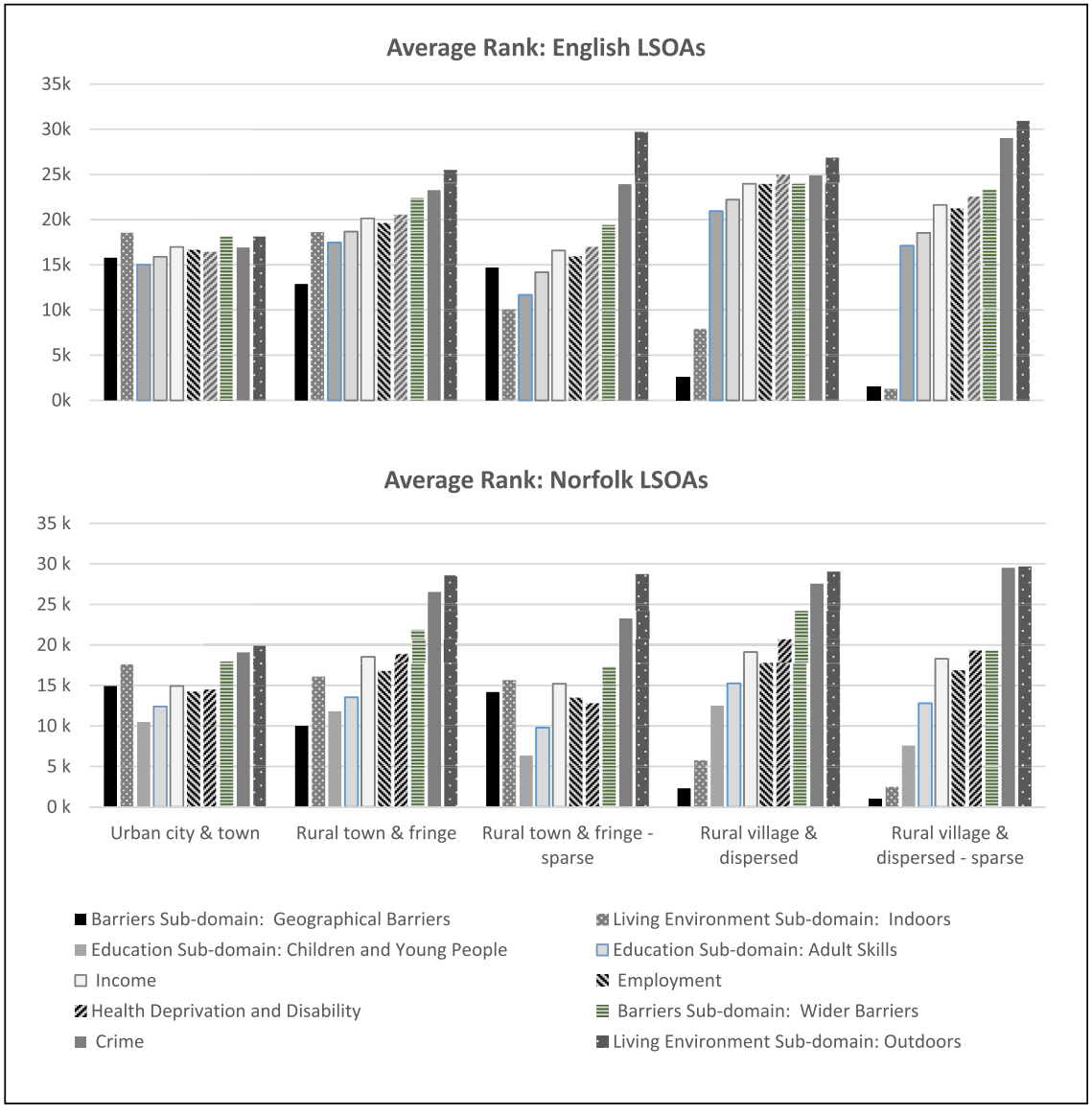

Fig. 1. Average rank of LSOAs by RUC11 classifications for England and for Norfolk. Lower ranks equate to higher deprivation.

services and Living environment domains, rural areas are significantly more deprived on one than the other (Table 2). These sub-domains, Geographic barriers and Indoor living environment, account for 10.8% of the IMD weighting and one approach to developing a measure for rural deprivation might be to adjust their weightings.

Data tables are provided to enable the re-weighting of IMD domains for specific applications such as this (DCLG, 2015). The tables are required because domain scores are exponentially transformed prior to being combined into the composite indicator, and the tables provide the transformed scores. The transformations are applied to mitigate against a high score in one domain cancelling a low score in another (Smith et al., 2015). This is, in effect, a method of differential weighting because the scores for the most highly deprived areas are amplified. Transformed scores are only available for domains, not sub-domains. This is because sub-domain scores are themselves exponentially transformed prior to being combined into the domain score, which is then also exponentially transformed. Separating the sub-domains would result in this second transformation being removed.

The two-stage transformation for sub-domains makes it difficult to identify how each sub-domain contributes to the overall weighting of the IMD. In order to explore this, the IMD was recalculated without the second exponential transformation on the Barriers to housing and services domain and the Living environment domain. This resulted in a fall in mean deprivation scores for LSOAs classified as 'Rural village and dispersed' from 14.3 to 12.7 ($p < 0.001$) and 'Rural village and dispersed in a sparse setting' from 20.0 to 16.9 ($p < 0.001$). Thus, while the two subdomains for which rural areas are most deprived in the IMD account for just 10.8% of the overall weighting, the double transformation appears to amplify the influence they have. Opacity around the effects of the exponential transformations used within the IMD was an issue raised by Deas et al. (2003).

2. Developing a Rural Deprivation Index

2.1. Approach

The process of developing a Rural Deprivation Index (RDI) was guided by the OECD Handbook on constructing composite indicators (Nardo et al., 2005). This suggests ten steps, starting with the development of a theoretical framework to provide a basis both for the selection of indicators, and to guide how these indicators might be combined into a composite index. Other recommended steps include the use of multivariate analysis to justify methodological choices such as aggregation, and the comparison of the resulting index with other published indicators.

2.2. Developing a theoretical framework

The theoretical framework suggested in the OECD guidance (Nardo et al., 2005) as the first step for constructing a composite indicator 'should clearly define the phenomenon to be measured and its sub-components' (p.22). Deprivation for the purposes of this work is therefore defined as the characteristics of material and social deprivation as it affects rural areas. Rurality is defined as any area categorised as rural using the UK government's RUC11 classifications (Bibby and Brindley, 2015) with priority given to 'Rural village and dispersed' settings.

There have been a range of approaches to developing sub-components of rural deprivation. For example, Hodge et al. (2000) based their six 'bundles' on areas of policy, Haase and Pratschke (2012) their three 'dimensions' on analysis of other deprivation indices and the literature, Thomson et al. (2014) their five 'domains' on governmental strategic outcomes, and the five themes of Farmer et al. (2001) are based on a review of the literature. A model for rural deprivation devised by Shaw in 1976 is still widely referred to in the context of rural deprivation (Cloke, 2013; Haase and Walsh, 2007; OCSI, 2012). Its structure is driven by theory about the underlying drivers of rural deprivation, rather than policy, which may be transient. For this reason, it was adopted as a useful starting point for the development of the theoretical framework for this project.

Shaw's model contains three dimensions of rural deprivation; household deprivation (such as low income), opportunity deprivation (availability of services), and mobility deprivation (barriers to transport). Mobility and opportunity deprivation may lead to a narrowing of choice and poor uptake of services in rural areas (Wilson, 2017). Distance from services also results in increased cost of living due to transport and other costs such as heating where there is no main gas (DEFRA, 2011). In 2013, those living in rural English villages spent 25% more than the England average, and those living in hamlets and isolated dwellings 33% more (DEFRA, 2011). While average income levels are higher overall in rural areas of England classified as 'Rural village and dispersed' (DEFRA, 2011), those on benefits, or close to the benefits thresholds, may face greater financial strain than their urban counterparts on similar levels of income. Thus, the relationship between Shaw's (1976) opportunity and mobility deprivation dimensions on one hand, and household deprivation dimension on the other, matters, as a lack of locally available services potentially disproportionally affects those that are materially and socially disadvantaged (Lucas, 2012) such as those who are on low incomes, in poor health, or lack social capital.

Rural populations are generally older (Age UK, 2013), and may therefore place increased demand on health and social care. The Institute for Fiscal Studies (Luchinskaya et al., 2017) estimates that a 65 year old costs double in terms of health spending when compared to a 30 year old, and a 90 year old eight times more. While relative health is generally better in rural areas (Gartner et al., 2008), indicators for health deprivation are normally age standardised, as is the case with the IMD. This means that they measure health and disability in relation to what one might expect for a population of a particular age, not actual levels of poor health and disability. This issue does not apply to health alone; using the Older People Income Deprived supplementary index of the IMD, some of the most deprived LSOAs in Norfolk on this measure have many fewer older people income deprived than some of the least deprived. Therefore, whilst the IMD measures relative deprivation, the user may not be alert to the need to consider population structure, and this may result in misuse of the measure if, for example, it was used to allocate resources without this knowledge.

The final factor considered when developing the theoretical framework for this work was that of spatial scale. Rural LSOAs are physically much larger than urban LSOAs due to having lower population densities, and their populations may be less homogenous. A number of authors have suggested that, because of this, rural deprivation is more dispersed and is more likely to occur in small pockets (OCSI, 2012; Haase and Walsh, 2007; Woods, 2005), and that this may make it difficult to identify rural deprivation using area-based measures unless the geographic unit used is very small.

The theoretical framework, with its four dimensions, is represented in Fig. 2. The first is 'Relative Household Deprivation' and contains indicators typically associated with material and financial deprivation that are not polarised to either urban or rural areas. The second dimension contains deprivation indicators relevant, or polarised, to rural areas (including Shaw's concepts of mobility and opportunity deprivation) and is named 'Locality Related Deprivation'. The third dimension, 'Population Characteristics', is present to account for an older rural population, and the fourth and final dimension for possible issues of 'spatial scale'. The model provides a flexible method for grouping and weighting variables within an index in order to test their applicability in measuring rural deprivation.

2.3. Populating the theoretical framework

Decisions about what indicators to select to in order to populate the

Fig. 2. Conceptual model enabling deprivation to be adjusted for local factors/characteristics.

Table 3
Indicators selected for inclusion in the RDI.

'Relative household deprivation' dimension	
Relative household deprivation	IMD 2015: Income domain IMD 2015: Employment domain IMD 2015: Education domain IMD 2015: Health and disability domain
'Locality related deprivation' dimension	Average time to travel to eight essential services IMD 2015: Housing in poor condition
'Population characteristics' dimension	ONS 2015 mid-year population estimates 75 +
'Spatial scale' dimension	Variability index

theoretical framework were driven principally on the basis that data were relevant to the domain of interest, were publicly available, and had been through quality assurance processes (Nardo et al., 2005). For this reason, data from the English IMD was extensively used, along with other official UK government statistics. Consultation was carried out with Directors of Public Health for rural areas through a group organised by Public Health England and local data sources were also considered to explore whether these may offer additional measures to provide local context. For example, the uptake of adult social care by LSOA and the number of Citizens Advice Bureau (CAB) enquiries by LSOA were considered but neither were finally included in the framework (although uptake of adult social care was used as a comparison variable for sensitivity testing). While such data offers the potential to capture facets of deprivation not currently reflected in the IMD, a problem is that it is gathered primarily for administrative purposes, not surveillance, and may not be readily available in a suitable format. Further, unless service provision is universally available, data on service usage (such as CAB enquiries) may reflect barriers to access, or unequal provision, rather than provide a measure of need. In total eight variables were selected for inclusion in the index (Table 3).

There is currently no official statistic for transport poverty that could be used to populate the 'Locality' dimension. The organisation Sustrans, (2012) have produced a transport poverty metric, and Mattioli et al. (2017) the 'Index of vulnerability to motor fuel price increases'. While potentially useful, both indicators currently have missing data for 19 LSOAs in Norfolk due to a change in LSOA boundaries between 2001 and 2011, and for this reason neither was used. The UK Department for Transport produce average travel times by all modes (car, public transport/walking and cycling) to eight essential services (DfT, 2015), and this dataset was used rather than the IMD Geographic Barriers indicator which measures distance to four services. This is because distance may not be a good predictor to access to services, particularly in rural areas (Niggebrugge et al., 2005). In addition, 'Housing in poor condition' from the IMD was included in the 'Locality' dimension. This is because, when analysed by RUC11 classifications, rural areas were found to be more disadvantaged on this indicator, and because the measure includes data on thermal efficiency and heating costs are a factor linked to increased costs of rural living (DEFRA, 2011). A limitation is that this statistic is modelled from a relatively small dataset (Deas et al., 2003), but it was deemed to be the best available.

The approach to selecting indicators for the 'Relative household deprivation' dimension was to identify those domains within the IMD that were not highly polarised to either rural or urban areas (see Fig. 1). These characteristics may make a household more vulnerable to the effects of the environment. For example, they may exacerbate the difficulties of longer travel times (Lucas, 2012), or reduce resilience to obesogenic environments (Burgoine et al., 2016).

Four possible indicators were explored for the 'Population' dimension: the percentage of single householders aged 65+ (2011 Census data), the percentage of individuals aged 75+ (ONS 2015 estimates), the percentage whose self-reported health is bad or very bad (2011 Census data), and a local indicator, the percentage receiving non-residential adult social care. While the latter is potentially useful as is it based on both income and assessed support need, it may be affected by several issues, including access to services in rural areas. Because ONS mid-year population estimates are updated annually, this data source was used rather than either of the two census indicators.

A variability statistic was developed for inclusion in the Spatial scale dimension; this makes use of census data that is available at a much lower level of geography than most other publicly available data. A census 'Output Area' (OA) contains on average 129 households, there are therefore between four and six OAs within an LSOA. The variability statistic shows the range of OA scores within an LSOA for the proportion of adults whose self-reported health was 'bad' or 'very bad' in the 2011 Census. The range is the difference between the OA with the lowest proportion and highest proportion of adults reporting bad or very bad health (standard deviations were also considered, but we were interested in extremes of the 4–6 OAs within an LSOA, rather than average deviation from the mean). To weight the index towards deprivation and to account for amplitude (i.e. to differentiate between LSOAs with the same range but different starting points), the maximum figure was added to the range. The statistic is represented by Equation (1), where x is the variable of interest (the percentage of residents with bad or very bad health), where V is the variability statistic for an LSOA, and where max [x] and min [x] identify the maximum and minimum levels of x observed within a given OA.

$$V[x] = (\max[x] - \min[x]) + \max[x] \quad (1)$$

The variability statistic was calculated for each LSOA in Norfolk, creating a variability index. Sparsely populated LSOAs in 'Rural town and fringe' show the greatest variability; 40% of these LSOAs fell in the most variable quintile of the index. For non-sparse 'Rural town and fringe' the figure was 25%, for 'Urban city and town' 20%, for 'Rural village and dispersed' 13%, and for 'Rural village and dispersed in sparse settings' 0% (note however that the numbers of LSOAs in sparse settings are low).

2.4. Exploring the structure of the indicators using multivariate analysis

In order to understand how the indicators within the theoretical framework were related and test the manner in which they had been aggregated into domains (Nardo et al., 2005), a Principal Component Analysis (PCA) was undertaken. PCA is a statistical technique that enables patterns in data to be explored by identifying the relationships between variables. It enables variables to be grouped together depending on the strength of their correlations.

The PCA resulted in the RDI indicators falling into three principal components; these are shown in columns 1, 2 and 3 in Table 4. The values in the table are known as loadings; these range from −1 to +1 and represent how strongly each variable is explained by each component. Groups of variables with high positive or negative scores on a component are therefore more strongly related to each other. Except for the variability indicator, all other indicators fall into the components theorised within the theoretical framework. The variability indicator, however, was almost equally distributed between the first and third components with loadings of −0.51 and 0.65 respectively. This led to a lack of clarity as to whether the spatial scale dimension is a distinct element of rural deprivation as theorised, and the decision was made to remove this dimension from the model. Indicators within the remaining three dimensions in the model are thus more highly correlated to each other than to the indicators in the other dimensions, and theoretically represent different facets of rural deprivation. This provides greater confidence when manipulating the weightings of the dimensions as a whole.

Table 4
Principal component loadings for factors associated with rural deprivation.

Variables (ranked and normalised)	Component 1	Component 2	Component 3
Employment scores	0.92	−0.03	−0.10
Health scores	0.89	−0.12	0.02
Education scores	0.84	0.00	0.08
Income scores	0.66	0.10	0.05
Housing in poor condition	0.22	0.88	0.07
Travel time to eight essential services	−0.28	0.79	−0.11
Aged 75+	−0.19	0.02	−0.91
Health variability statistic	−0.51	0.03	0.65

Rotation method used: Oblimin with Kaiser Normalisation. Rotation converged in 7 iterations. The number of factors extracted was based on the visual inspection of a scree plot.

2.5. Creating and testing the Rural Deprivation Index (RDI)

To create an index, indicator scores were first ranked so that they were on the same scale. Dimensions were then weighted and combined to form a composite index.

As a first step in the weighting process, three possible weightings (10%, 15% and 20%) were arrived at for the 'Locality' dimension. The Welsh, Scottish and Northern Irish IMDs all weight 'Distance from services' at around 10%, and this was used as a starting point to weight this dimension. The English IMD was found, effectively, to weight rural indicators higher than this due to the way it is calculated and therefore two further increments were used; 15% and 20%.

The Irish Pobal Index (Haase and Pratschke, 2012) has indicators for 'Demographic Profile'. Within this, two indicators are solely concerned with population structure rather than social class and together account of 20% of the total weighting. The population dimension was weighted at two different levels that resulted in it being close to this (18%) at its maximum; this was to take either 10% or 20% of what remained after weighting for the 'Locality' dimension. What remained (out of a total possible 100) was allocated to the 'Deprivation' dimension. Finally, weightings were applied to domains scores in two ways, exponentially transformed (using the same process as described in the IMD (Smith et al., 2015)), or not.

The weighting combinations resulted in the creation of eighteen 'Test Indices (TIs) for sensitivity testing; these are referred to as TI1, to TI18. For each of these, the number of LSOAs in the most deprived quintile for each rural-urban classification were calculated ('sparse' categories have been combined with their non-sparse equivalent). The results are shown in Table 5, along with results of the IMD for comparison; TIs 1–9 are those for which domain scores have been transformed.

For all versions of the TIs, the classification 'Rural town and fringe' has more LSOAs in the most deprived quintile when compared to the IMD. A higher weighing for 'Locality' results in more LSOAs in 'Rural Village and dispersed' in quintile 1 (and more in 'Rural town and fringe' when no exponential transformation is applied); a higher weighting for 'Population' resulted in more LSOAs in both 'Rural town and fringe' and in 'Rural village and dispersed'. Removing exponential transformations results in more LSOAs in both 'Rural town and fringe' and in 'Rural

Table 5
Number of LSOAs within quintile (most deprived) for TIs 1–22 and IMD.

Description of RDI	Weighting (%)				Number of LSOAs in quintile 1		
	TI	Deprivation	Population	Locality	Urban	Rural town and fringe	Rural village and dispersed
Test Indices where domains have been exponentially transformed							
Two dimensions only – Deprivation and Locality (three weightings for Locality)	1	90	–	10	83	15	9
	2	85	–	15	82	15	10
	3	80	–	20	80	13	14
Three dimensions – Deprivation, Locality and Population (at the higher weighting)	4	72	18	10	78	19	10
	5	68	17	15	75	19	13
	6	64	16	20	71	18	18
Three dimensions – Deprivation, Locality and Population (at the lower weighting)	7	81	9	10	83	16	8
	8	77	9	15	80	17	10
	9	72	8	20	75	14	18
Test Indices where domains have not been exponentially transformed							
Two dimensions only – Deprivation and Locality (three weightings for Locality)	10	90	–	10	82	14	11
	11	85	–	15	79	16	12
	12	80	–	20	75	19	13
Three dimensions – Deprivation, Locality and Population (at the higher weighting)	13	72	18	10	70	25	12
	14	68	17	15	65	26	16
	15	64	16	20	56	28	23
Three dimensions – Deprivation, Locality and Population (at the lower weighting)	16	81	9	10	78	19	10
	17	77	9	15	75	20	12
	18	72	8	20	70	20	17
IMD (for comparison)					86	9	12

village and dispersed' in quintile 1.

2.6. Testing the weightings against comparison variables

As a validity test of the TIs, each was correlated against the six comparison variables (CV) listed in Table 6 that were selected on the basis that they were relevant to rural deprivation but not used within either the TIs or the IMD 2015. While primarily focused on health, there is also one variable for education, one for employment, and one for the receipt of health-related benefits; two of the comparison variables are age-standardised. These latter variables were selected as they had been identified as being indicative of problems in measuring rural health by Norfolk County Council, the administrative authority for Norfolk.

All correlations between the TIs and each CV were statistically significant (Supplementary Table S1) except for the uptake of adult social care in 'Rural village and dispersed' (the IMD was not significantly correlated with this variable for 'Rural village and dispersed' either). This may reflect issues with access to services in rural areas.

The difference between the correlation coefficient for a TI and a CV, and the IMD and the same CV was calculated. Table 7 shows the results by Rural-Urban classification (with sparse classifications combined with non-sparse). A downward arrow indicates that the TI is less well strongly correlated than the IMD, an oblique arrow that it is equally or more strongly correlated but the difference is less than 0.1, and an upward arrow that it is more strongly correlated by 0.1 or more. Apart from the comparison variable for people with four or more long-term conditions (where the differences are minimal), the TIs were almost always better correlated for 'Rural village and dispersed' classifications. They were also almost always better correlated for 'Rural town and dispersed' and for 'Urban' classifications, although there were fewer instances where the difference was 0.1 or more.

Table 6
Comparison variables used for validity testing.

Comparison variables
Usual residents whose self-reported health is bad or very bad, 2011 Census.
Usual residents aged 16 and over who are unemployed or have a long-term health problem or disability, 2011 Census
Usual residents aged 16 and over who have no qualification, or whose highest level of education is level 1, 2011 Census
Adults receiving non-residential social care in Norfolk in December 2015, Norfolk County Council
Employment Support Allowance and Incapacity Benefit, May 2016, DWP (indirectly age standardised)
People with four or more Long Term Conditions (LTC), (indirectly age standardised)[a]

[a] Provided by Norfolk County council.

3. RDI selection

The sensitivity testing provided information on how well correlated each TI was to a number of comparison variables and revealed how weighting affected the number of LSOAs in the most deprived quintile by rural-urban classification. The criteria for which TI to select for the RDI were arrived at through considering the aim of this project, which was to identify rural deprivation. The selection criterion used was the TI with the highest differences in correlation coefficients with comparison variables when compared to the IMD for 'Rural village and dispersed' (using a ranking method) that also resulted in at least one additional LSOA classified as 'Rural village and dispersed' in the most deprived quintile. TIs 13, 14, and 15 scored equally high on the ranking, but TI13 did not result in any additional LSOAs in 'Rural village and dispersed'. To select between the remaining two, the TI with the highest variability in deprivation scores for LSOAs classified as 'Rural village and dispersed' was selected; this was TI14. TI14, which we will now refer to as the RDI, results in four additional LSOAs in 'Rural village and dispersed' settings falling into the top quintile for deprivation compared to the IMD, and 17 further LSOAs in 'Rural town and fringe'.

The RDI was plotted against the English IMD 2015 (Fig. 3) using LSOA ranks, where rank 1 is the most deprived; deprived LSOAs are therefore shown near the origin. The most deprived urban LSOAs using the IMD are generally less deprived using the RDI as they sit above the line of equality. LSOA in the 'Rural town and fringe' classifications are mostly more deprived when using the RDI. For the 'Rural village and dispersed' classification, deprivation is increased for those LSOA that are most deprived using the IMD (a number of 'Rural village and dispersed' LSOAs sitting below the line of equality near the origin).

The RDI was mapped to Norfolk LSOAS using quintiles (Fig. 4). Quintile 1, indicated by darker shading, is the most deprived. Fig. 4 also shows quintiles of deprivation using IMD 2105 scores. When using IMD scores, the majority of the most deprived LSOAs are in urban areas such

Table 7
Difference between correlation coefficients for IMD and TIs (when correlated with comparison variables). Downward arrow indicates that the RDI is less strongly correlated than IMD, oblique arrow that the RDI is equally or more strongly correlated with correlation coefficient up to o.1, upward arrow that it is more strongly correlated by over 0.1.

TI	Rural village and dispersed						Rural town and fringe						Urban					
	Receipt of ESA or IB*	4+ LTC	Receipt adult social care	Health bad or very bad	Qualifications: Level 1 or none	Unemployed or long-term sick	Receipt of ESA or IB*	4+ LTC	Receipt adult social care	Health bad or very bad	Qualifications: Level 1 or none	Unemployed or long-term sick	Receipt of ESA or IB*	4+ LTC	Receipt adult social care	Health bad or very bad	Qualifications: Level 1 or none	Unemployed or long-term sick
1	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↓	↗	↗	↗	↗	↗	↓
2	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↓	↗	↗	↗	↗	↗	↓
3	↗	↓	↗	↗	↗	↗	↗	↗	↗	↗	↗	↓	↗	↗	↗	↗	↗	↓
4	↗	↓	↑	↑	↗	↗	↓	↗	↑	↑	↗	↗	↓	↓	↑	↗	↗	↓
5	↗	↓	↑	↑	↗	↗	↓	↗	↗	↑	↗	↗	↓	↓	↗	↗	↗	↓
6	↗	↓	↑	↗	↗	↗	↓	↗	↗	↑	↗	↗	↓	↓	↗	↗	↗	↓
7	↗	↗	↑	↑	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↓
8	↗	↓	↗	↑	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↓
9	↗	↓	↗	↗	↗	↗	↓	↗	↗	↗	↗	↗	↗	↗	↗	↗	↗	↓
10	↑	↗	↑	↑	↗	↗	↗	↗	↗	↗	↗	↗	↗	↓	↗	↗	↗	↓
11	↑	↓	↗	↑	↗	↗	↗	↗	↗	↗	↗	↗	↗	↓	↗	↗	↗	↓
12	↑	↓	↗	↑	↗	↗	↓	↗	↗	↗	↗	↗	↗	↓	↗	↗	↗	↓
13	↑	↓	↑	↑	↗	↗	↓	↗	↑	↗	↗	↗	↗	↓	↑	↗	↗	↓
14	↑	↓	↑	↑	↗	↗	↓	↗	↗	↗	↗	↗	↗	↓	↑	↗	↗	↓
15	↑	↓	↑	↑	↗	↗	↓	↗	↗	↗	↗	↗	↗	↓	↑	↗	↗	↓
16	↑	↓	↑	↑	↗	↗	↗	↗	↗	↗	↗	↗	↗	↓	↑	↗	↗	↓
17	↑	↓	↑	↑	↗	↗	↗	↗	↗	↗	↗	↗	↗	↓	↑	↗	↗	↓
18	↑	↓	↑	↑	↗	↗	↓	↗	↗	↗	↗	↗	↗	↓	↑	↗	↗	↓

**Comparison variable transformed using natural log in order to create linear relationship*

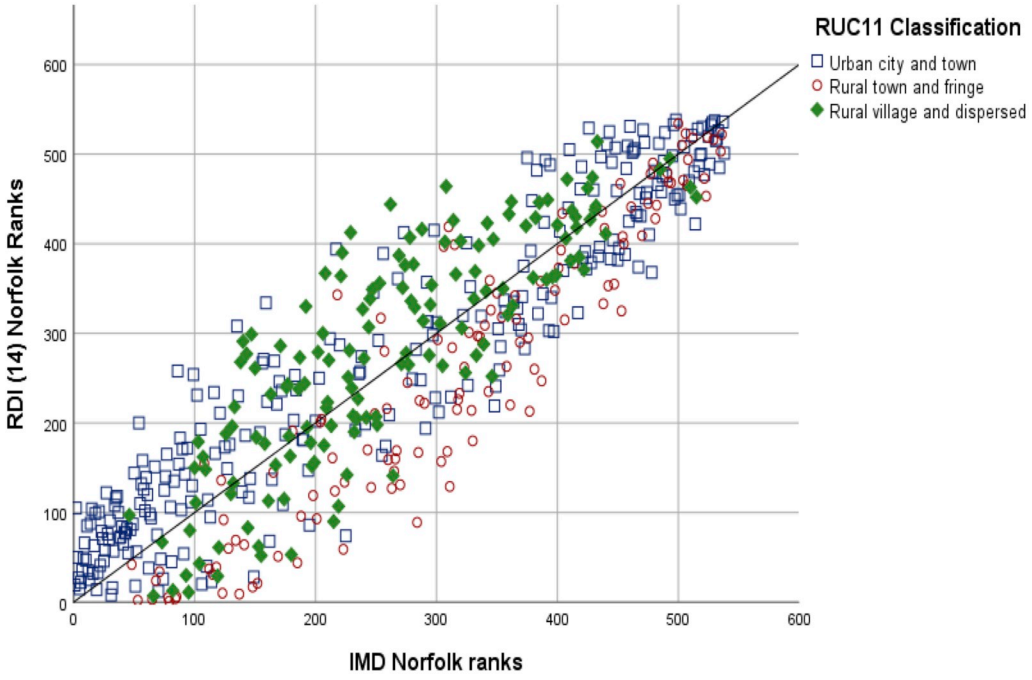

Fig. 3. Scatterplot of IMD scores and the RDI with line of equality.

as Great Yarmouth, Norwich and Kings Lynn (urban LSOAs occupy a smaller area due to higher population densities and are more difficult to see). Using the RDI scores, more rural areas are evident in quintile 1, including a number of rural towns, an area to the west of Norfolk around the Fenlands, and sparsely populated rural areas in North Norfolk.

4. Discussion

The English IMD is widely used to target resources and funding. However, it has been developed for the whole population and can be inflexible to adaptation for specific geographies. To address this problem, this research took a novel approach, focusing on how the index was structured and bundled. Highly correlated aspects of household deprivation are bought together in one domain, and indicators relevant to the local environment in another. These two domains, we suggest, represent distant components of deprivation. What is important is not so much the relative weights of the highly correlated items within the domains, but the relationship of the domains to each other. This is because deprived households may have less resilience when dealing with the challenges posed by their environment such as distance to services (Lucas, 2012).

The approach adopted differs from that taken for the IMD, where indicators are arranged into domains by theme. We would argue, for example, that the relative weights of income and employment within the IMD are not critically important as they are highly correlated. Indeed, Dibben et al. (2007) found that swapping the weights of the Health and Disability domain and Employment domain (which have 9% difference in weighting between them) had little effect on deprivation rankings for this reason. When populating the Locality dimension of the RDI we used indicators relevant to rural areas only, whereas the IMD combines indicators relevant to urban and rural localities within two of its domains. While this may have justification where an index is used for the whole population, this makes it difficult to assess deprivation in a particular geographic context.

The RDI structure proposed includes a domain to allow for an adjustment for population structure if required. This may be useful where an index contains age-standardised variables that describe relative deprivation, or inequality, rather than prevalence. This is relevant for rural populations in England that are older and may therefore experience higher prevalence of ill health. Exponential transformations applied to domains in the IMD were not used. This was because they were not found to improve correlations with comparison variables, and because they make it difficult to intuitively grasp the actual weighting of a domain. Deas et al. (2003) also point out that the implications of using the transformations have not been adequately specified.

A variability index to identify heterogeneity of deprivation within LSOAs that was developed as part of this research shows that, using levels of self-reported poor health, most variability occurred within LSOAs classified as ‘Rural town and fringe’ particularly the ‘sparse’ subcategory. This gives some support to the theory that larger rural LSOAs are less homogenous and therefore are more likely to hide pockets of deprivation (OCSI, 2012; Haase and Walsh, 2007; Woods, 2005). The variability index was not included in the final model because multivariate analysis indicated that it did not form a distinct and separate dimension of rural deprivation. However, it may be a useful tool to indicate LSOAs with a high degree of heterogeneity when service planning, with the caveat that OAs, while small, may not be small enough to identify the pockets of deprivation that have been hypothesised to occur in rural areas.

Rural areas, for this research, were defined as any area categorised as rural using the UK government's RUC11 classifications (Bibby and Brindley, 2015) with priority given to ‘Rural village and dispersed’ settings. Decisions taken when developing the RDI, for example, the selection of indicators, were dictated by this. Despite this, for all the different weightings of the RDI tested, LSOAs classified as ‘Rural town and fringe’ showed a greater increase in deprivation than those in ‘Rural village and dispersed’ (Table 5). This is interesting, as the narrative of rural deprivation may conjure up images of farms, isolated housing and villages rather than small rural towns and their outskirts. Indeed, there is a tendency when discussing rural deprivation to refer to a rural-urban dichotomy, neglecting the fact that there are different types of rural settings, with different characteristics and issues.

The RDI may be improved with the addition of other metrics. For example, metrics for fuel poverty and transport poverty could be useful if they become available and robust to LSOA level. Whilst analysis of the IMD indicator on housing affordability indicated that, for Norfolk as a whole, ‘Rural village and dispersed’ LSOAs were not disadvantaged, it

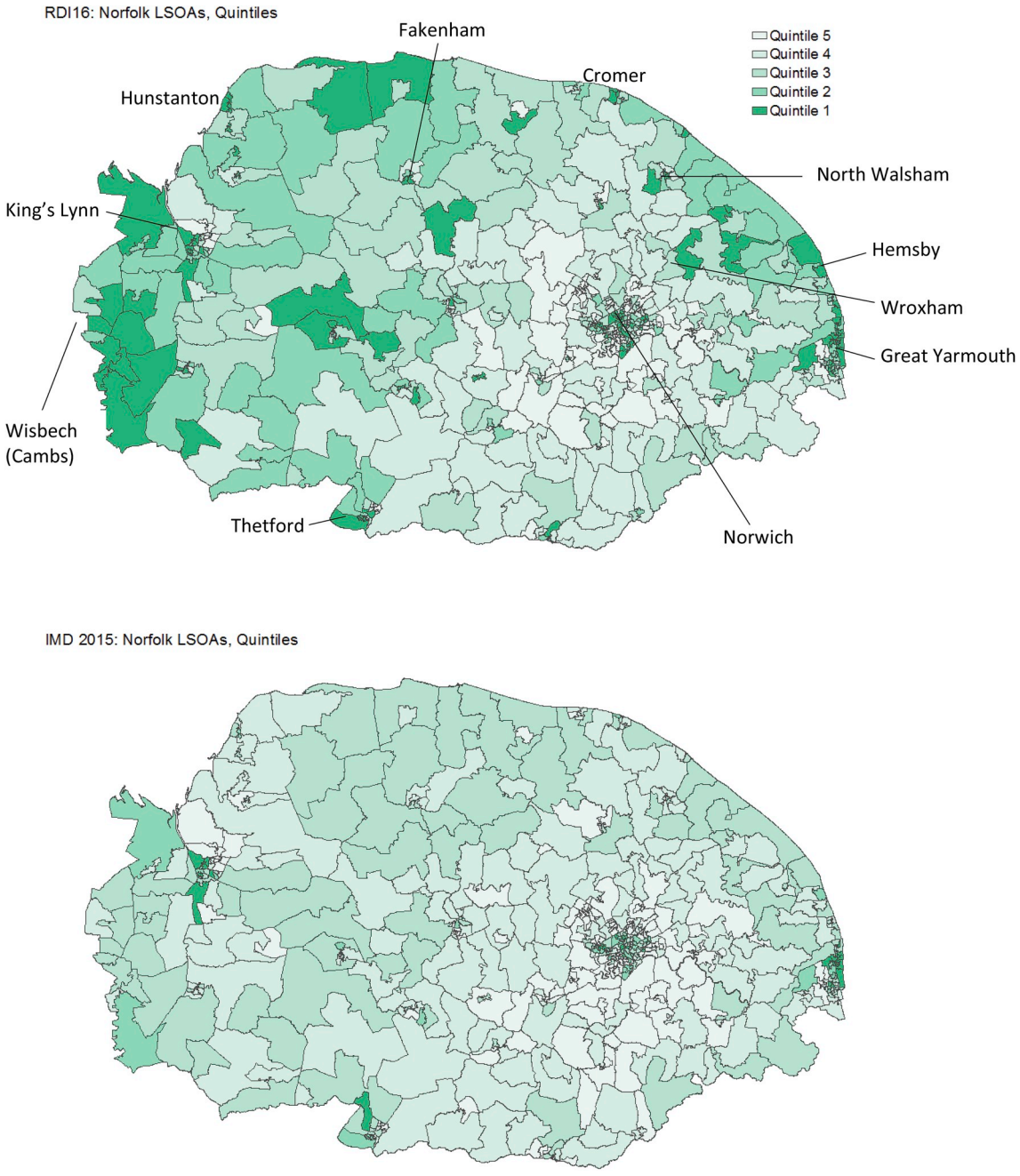

Fig. 4. Deciles of deprivation using the RDI (upper map) and IMD (lower map) for Norfolk (Quintile 1 = most deprived LSOAs).

may be worth inclusion in other circumstances, for example, where the interest is in areas with high levels of second home ownership. Finally, other characteristics may be explored to account for other spatial issues that may influence deprivation, such as distance to major urban conurbations, or even proximity to the coast (Area Based Analysis Unit, Office for National Statistics, 2009). The RDI could also be used to explore deprivation for other geographic contexts, for example urban areas. It is possible, for example, that the IMD Geographic barriers subdomain attenuates deprivation scores in city centres, while elevating scores in suburban areas where residents may be further from services, but less affected by factors such as air pollution and overcrowding.

The approach adopted in developing the RDI recognises that some of the sequalae of disadvantage, such as poor health, are observed across the urban-rural spectrum rather than being unique to either setting (Barnett et al., 2002; Gilthorpe and Wilson, 2003). Within the RDI, these more generalised characteristics of deprivation are set apart from those that have been identified in the literature to be relevant to rural deprivation. While the strong association between the RDI and IMD highlights the general similarity of disadvantage, indices such as the IMD may mask the subtle variation in rural areas in a manner that limits health service planning (Haynes and Gale, 2000). Discussions with the local Director of Public Health suggested that the RDI depicts deprivation in the west of Norfolk that was not apparent in the IMD but was manifest in patterns of service use.

5. Conclusion

Deprivation indices are used to provide a useful indication of which areas are more, or less, disadvantaged. They are also used by national and local governments, and by various grant funders in the allocation of resources. The ONS (2009) in an analysis of the spatial patterns of deprivation state that ' … in carrying out any type of analysis the user

needs to be very aware of the complexity and summary nature of the IMD measure' (p.113). They also highlight the need to look further than the IMD summary results, and to carefully consider the purpose for which the IMD is being used. Yet it can be difficult to know where to start when considering factors such as rurality as the IMD is not easily adaptable for such purposes. The model described here has the potential to provide a starting point for those who wish to create a summary deprivation measure, taking into account rurality or other local geographic factors, particularly as part of a range of approaches that can be used to allocate or apply for resources.

Declarations of interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.socscimed.2018.09.019.

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