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Investigating spatial variations in access to childcare provision using network-based GIS models

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Abstract

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1. Introduction

Accessibility to early childcare provision needs to be considered alongside the types of 'micro-' and 'macro-level' contextual factors that influence the choice of childcare in order to fully assess the impact of Government policies aimed, for example, at increasing female workforce participation (Davis and Connelly, 2005; Van Ham and Mulder, 2005). A recent cross-national qualitative study of childcare provision has drawn attention to the relative importance of geographical factors that may impact on childcare choices for families needing facilities at locations accessible to both home and workplace (McLean et al., 2017). These factors include geographical proximity, the availability of different modes of transport, and temporal considerations such as the opening times of childcare services in relation to the time budgets of parents and their current employment patterns. Other factors such as the number of places available, and the cost and quality of provision of the childcare, may also have a geographical component if there is a need to travel further in order to access suitable or more appropriate facilities. Despite the recognised importance of such factors, few studies to date have been concerned with mapping and analysing spatial variations in provision amongst the complex packages of childcare options available to parents, which include various formats of formal early childhood education (ECEC[1]) and informal, non-parental care.

The context for the approach reported in this study arises from a Welsh Government commitment to provide 30 hours of free early education and childcare per week to the working parents of three and four-year-olds for 48 weeks per year. This is claimed to be "the most generous childcare offer in the UK" (Welsh Government, 2016; p. 5), but is nevertheless similar to separate schemes operating in England, Scotland, and Northern Ireland. For example, in England the parents of all children aged 3 to 4 can receive 570 hours of funded childcare, typically consisting of 15 hours a week for 38 weeks per year. This increases to 1,140 hours (30 hours a week for 38 weeks) in households where the parent (and their partner, if they have one) work at least 16 hours a week earning at least the National Minimum Wage. The childcare offer in Wales includes 10 hours of 'Foundation Phase' education that is based in a school or a funded nursery, and it notably extends provision to 9 weeks of the year outside of school term time.

The Welsh offer has been guided by on-going research with parents of children in these age groups regarding current arrangements and those planned following the implementation of the childcare offer for Wales (Coates and Prosser, 2017). It is set to be fully implemented by 2020 and will be guided by the lessons learnt from pilot studies running in seven local authorities. The pilot areas began operating in September 2017 and encompass a range of urban and rural settings and a mixed economy delivery, with public, private and third sector involvement. In order to begin to understand the availability and accessibility of existing childcare capacity in Wales the authors were commissioned to map detailed patterns of access and provision to help inform the selection of the pilot areas. Whilst it was acknowledged there is currently a national shortage of childcare in Wales, much more spatially detailed information was needed that considered existing supply in relation to potential demand for local childcare services.

The focus here therefore is on the respective merits of approaches used to gather evidence regarding spatial patterns of formal childcare provision across all of Wales. Whilst the quality of provision, workforce characteristics, the availability of Welsh-medium care, informal forms of childcare provided by family members and neighbours, and the provision of care for children with additional learning needs are all important considerations for the overall implementation of the policy, none of these were included in this initial data collection and analysis stages. Nor do we consider in this paper: (i) the relative merits of the policy or the extent of the net benefits in terms of, for example, potential additional employment; (ii) the social and educational opportunities delivered by this policy initiative; or (iii) the projected take-up of the offer (but see Paull and Xu (2015) for a wider study of the impacts of different policy options in Wales). Rather the strength of the approach taken here is that, for the first time, we have been able to provide a highly detailed picture of geographical variations in local access to existing levels of childcare provision. This picture can then act as a benchmark with which to examine the future impacts of one of the flagship policies of the current Welsh Government. In so-doing it is possible to draw attention to both the limitations of existing approaches used to examine such patterns, as well as to the problems facing researchers charged with analysing existing sources of data to establish such an evidence base. As we demonstrate, the factors involved are far from trivial and point to a consideration of a more integrated and consistent approach to collating data that enables both spatial and temporal patterns in provision to be elucidated. The types of network-based GIS models described herein have huge potential in providing finely detailed maps of provision that account for both supply-side factors (e.g. the total hours of opening of centres, and number of placements offered) and potential service demand (using the distribution of working families with children in the appropriate age groups), all moderated by the impacts of distance. We conclude the paper by re-iterating the policy significance of this research in the light of the lessons learnt in order to provide a fuller picture of the current levels of childcare capacity available to meet policy commitments made in Wales.

2. Importance of measuring geographical accessibility to childcare

A number of previous studies have used mapping techniques to provide a picture of the (changing) provision of childcare services. Gallagher (2017) for example highlighted changes in provision in New Zealand since 2006, and in particular the increasing impact of the private sector on levels of provision. Where there is a lack of formal childcare services, parents without access to other means of provision (e.g. informal care) often have little or no choice about whether to work. McLean et al. (2017; p. 1369) identify the type of research that has used aggregate measures such as the number of places per child population, largely based on the formal provision of childcare, but they argue that "such aggregate data gives us little information about the challenges parents face in accessing available child care places". To date few if any attempts have been made to map detailed patterns of childcare provision to enable the wider implications of spatial variations in access for families lacking formal

childcare provision to be analysed. In such circumstances, low-income families may have limited childcare options which can result in poor choices for both them and their children. This in turn may impact disproportionately on women trying to participate in the workforce and who may have restricted options due to the nature of their caring responsibilities. Some studies have used geographical techniques to explore these issues at both localised and national scales (Blau and Robbins, 1991; Webster and White, 1997; Chiuri, 2000; Kreyenfeld and Hank, 2000; Gallagher, 2013; Compton and Pollak, 2014). More recently it has been demonstrated that problems often arise when the opening hours of facilities do not correspond to the time-space budgets of parents faced with arranging provision around their employment patterns (McLean et al., 2017).

Whilst it will always be difficult, if not impossible, to map the detailed nature of the 'logistical challenges' facing individual parents when choosing childcare providers, we demonstrate in this study that Geographical Information Systems (GIS) can provide a more nuanced picture of current levels of provision in relation to the distribution of potential demand, and can achieve this at very detailed spatial scales. In particular, by incorporating supply-side factors such as the placement capacity and opening hours of facilities within the types of network-based models introduced in this study, tempered by the impact of distance from the home or workplace on the use of such services, it is posited that a more accurate picture of childcare capacity can be gauged than that previously achieved using relatively coarse reporting units based on administrative boundaries. These spatially detailed insights into the accessibility of childcare facilities go some way towards addressing the concerns of McLean at el. (2017) that time components should be simultaneously considered alongside spatial patterns of provision when considering the availability of childcare to working parents. Van Ham and Mulder (2005) for example used network analysis to derive an access measure (rates of child places for those aged 0 to 4 within 10 minutes travel times of home residences) to formalised childcare opportunities in the Netherlands as part of a wider study of the influence of access to childcare on female participation in the labour market. Subsequent research on the use of detailed time-space approaches could provide a more complete picture of accessibility based on detailed time budgets of parents. However, these often require the use of resource-intensive methods based on travel diaries and thus, despite their promise, have not been widely adopted (Neutens, 2015). The approach used in this study demonstrates how patterns of provision can be analysed at very fine spatial scales whilst still achieving the aim of an all-Wales coverage. Furthermore, whilst our initial approach is predicated on the assumption of availability of private transport to reach childcare facilities, on-going work has demonstrated how existing and planned public transport opportunities can also be embedded within such models (Fransen et al., 2015).

Wales presents a suitable test-bed to examine the use of network-based analysis tools because, despite some encouraging developments such as appointing the first Commissioner for Children in the UK and introducing innovations such as the Flying Start programme and Foundation Phase early years curriculum that offer opportunities to some of the most vulnerable children, there remains significant gaps in early childhood services. Often services

are not available to all families in all areas of Wales, and some services, while providing young children with high quality experiences, do not meet the broader needs of the family and in particular working parents at a time when the economy and the welfare system is making it more of an imperative for them to seek work (Dallimore, 2016). This situation has directly led to the policy outlined in the Welsh Government's Programme for Government which ultimately aims to increase childcare provision in Wales. Wales is a small nation where decision makers are close to those who plan and implement policies on the ground; it should therefore be well placed to organise early childhood education and care to children and families in ways that make the most difference. It can also been argued that Wales has particular cultural and social strengths in areas such as the Welsh language, community cohesion and civil society that can be utilised to develop innovative and responsive ways of delivering early childhood services. However, before such policies are developed and implemented there is an urgent need to understand current levels of provision at detailed geographical scales so as to provide an accurate picture of early childhood education and care across Wales.

3. Methodology

3.1 Traditional approaches and problems in measuring childcare provision

This section summarises how the provision of childcare services has been estimated through a comparison of the spatial distribution of providers with that of potential demand arising from those population groups targeted in the childcare offer. A common way to assess the provision of any service is via a supply-to-demand ratio; in essence an estimate of how much of 'something' of interest (in this case childcare supply) is present in comparison to how much of the same 'something' is estimated to be needed or wanted (i.e. potential childcare demand). Data on the capacity of formal childcare provision across Wales is well known via information routinely collated by the Welsh Government, and this provides a good estimate of the overall supply of childcare services in Wales. Estimates of the number of children aged 0 to 4 years who would be potentially eligible for free childcare can be gauged from the UK Census of Population, to provide a good measure of potential demand. It should be emphasised that whilst service supply for formal childcare is relatively easily and accurately measured, the determination of potential demand remains closer to an 'educated guess'. Nevertheless, together these two data sets allow for the computation of a global supply-to-demand ratio indicative of the current level of childcare provision across Wales as a whole.

Using information supplied by Welsh Government this was computed to be about 0.6 placements per eligible child. Establishing this global figure has merit in that it sets a benchmark in time, whereby if subsequent policy interventions or marketplace forces lead to an increase or decrease in overall childcare capacity, or if the number of children potentially wishing to use such services rises or falls in the future, this score will reflect and document any such changes. However, it is also clearly a very crude measure that fails to reveal any

detail concerning variations in service availability that inevitably arise at local level. This is despite the fact that the locations and capacities of formal childcare services, and the total number of eligible children residing in population demand centres are known at quite detailed geographical scale. In the case of the former, recorded childcare provider information typically includes a UK Postcode attribute which can map its location to a local neighbourhood, a street, or in some cases an individual building. The UK Census provides demographic information for units called Output Areas that represent an average population cluster of about 300 persons and which are spatially located by means of a population weighted centroid. Such data are highly amenable to being stored, mapped, and more closely analysed in customised Geographical Information Systems (GIS).

An obvious approach to improving our understanding of spatial variability in service provision across Wales is to subdivide the area of interest into smaller frames of reference. The ability of GIS to perform point-in-polygon analyses makes it possible to compute a supply-to-demand ratio for any selected sub-region of Wales. This is the 'traditional' approach adopted by most childcare provision studies to date. So, for instance, we could compute a ratio within the confines of each Local Authority District (currently 22 in Wales) and compare scores between them. Given the availability of other administrative units offering increasingly detailed frames of reference (the UK census hierarchy consists of 'Middle Layer Super Output Areas', 'Lower Layer Super Output Areas', and finally the aforementioned 'Output Areas' at the finest level of spatial detail) this approach can appear to offer a straightforward solution to the task of revealing spatial variations in provision.

There are, however, well-documented problems in using supply-to-demand ratios computed from administrative boundaries. Firstly, it remains the case that whatever frame of reference is adopted the ratio still reveals nothing about internal variations of service availability, as schematics (a) and (b) in Figure 1 illustrate. Both examples have an identical supply-to-demand ratio, but in one case the population centres appear to have equal access to services whilst in the other they clearly do not. This is because distance (or time, as an alternative proximity measure) is also an important factor. Rational people tend to use near-by facilities rather than travel to distant alternatives; so residents in the demand centres shown in (b) will most likely feel that they have disparate access to the supplied service.

To minimise issues of unrevealed internal variance and to maximise spatial detail analysts may be drawn towards using the smallest available administrative areas, but this leads to further complications. In particular, in this form of analysis, no matter the frame of reference used, no account is taken of actual proximities between, nor the relative magnitudes of, those supply and demand sites that fall within its boundaries. Furthermore, arbitrary administrative boundaries bear no relationship to the true behaviour of people seeking access to services. As stated before, people prefer nearby services and in seeking access do not restrict themselves to consider only those childcare centres that fall inside the administrative zone where they live. As schematic (c) in Figure 1 suggests, parents living in the highlighted demand centres will most likely use a supply centre from an adjacent administrative zone because it is

nearest. A supply-to-demand ratio computed on the assumption of full 'containment' within an administrative boundary is clearly likely to be erroneous. Furthermore, as analysts make use of smaller administrative zones this cross-border issue is progressively magnified, and so the validity of computed supply-to-demand ratios become increasingly questionable.

Another problem relates to the arbitrary subdivision of space created by administrative boundaries, which nevertheless still impact upon results obtained. As suggested in schematics (d) and (e) in Figure 1, the precise locations of boundaries can influence the ratios produced. Finally, it must be recognised that accessibility is determined not just by where supply and demand points are located relative to each other, but also by their respective capacities and volumes. Referring back to Figure 1 (a), if the capacity of the upper-left supply point was 6 'units' and that for the lower-right 2 'units', this would clearly influence service availability amongst demand centres as compared to having equal capacities of 4 'units' at both sites. This argument applies equally to the situation of varying volume amongst demand centres.

Data concerning childcare provision may in the past have been made available only at relatively coarse geographical scale, such as for Local Authority Districts in Wales for example. There may then be little choice as to how this information can be presented, and a map such as that shown in Figure 2 may have to suffice. However, where data can be obtained with precise geographical tags, as is now becoming the norm, the use of the previously described 'container' approach based on administrative zones is increasingly unnecessary and undesirable. Not only should we seek to store and manage such information in a GIS, but we can also expect to leverage its capabilities to facilitate advanced spatial statistical modelling techniques such as the two-step floating catchment area algorithm described below. By embracing more sophisticated techniques detailed geographical analysis of the varying levels of childcare provision can be accomplished whilst avoiding many of the issues and difficulties raised above.

3.2 'Floating Catchment Area' methods

The "two-step floating catchment area" technique (hereafter "2SFCA") computes a familiar supply-to-demand ratio, but circumvents many of the problems identified above concerning the use of arbitrary administrative areas as frames of reference. As its name implies, this algorithm consists of two distinct sequential stages of calculation. For the sake of explanation it is clearer to start with the second step, and then consider the actions and purpose of the first. The key concept in 2SFCA is the 'floating catchment' which in turn is based upon reasonable assumptions that people seek access to services located in close geographical proximity to where they live. More specifically it relies on the following two modelling assumptions:

(i) that a closer service point is more likely it be used than one further away
(ii) that there is a limit to how far people will travel to reach a desired service

The algorithm is illustrated in Figure 3 using an extract of our data on childcare provision in Wales. The black squares represent demand centres where the number of eligible children

aged 0 to 4 are known. These locations are defined by Office for National Statistics (ONS) Output Area population weighted centroids. They represent the spatial distribution of the population at the finest geographical level at which UK census counts are provided by using a single summary reference point on the ground. The white circles represent childcare facilities, each having a capacity recorded in terms of the number of placements available and the opening hours. In Step 2 of the 2SFCA algorithm for every demand centre in turn the GIS is used to construct a unique catchment area. Examples are illustrated in Figure 3(a) for three labelled Output Areas, 'A', 'B', and 'C', with their catchments depicted as simple circles. Each individual catchment represents the area over which people living at the respective demand centre are prepared to travel in order to access childcare. Circular catchments are drawn in this diagram to aid visual clarity but in reality the road infrastructure, which is also shown, is used by the GIS to compute a detailed and complex shaped travel catchment area. This computation assumes travel takes place along roads at speeds predicated on road classifications, and that the catchment area limits are defined by a threshold value specified as a maximum travel time or maximum travel distance from the demand centre origin.

Each catchment creates a unique frame of reference for evaluating service accessibility for that particular demand centre. All childcare facilities that fall inside a catchment are considered reachable by the population, and the service capacity of these facilities (e.g. number of places or number of placement-hours) are added up to provide a measure of service supply for that specific demand centre. Crucially, floating catchments (so-called because they 'float' from one demand centre to another) reflect human behaviour (i.e. the use of nearby services within distance or time constrained limits) and are defined completely independently of administrative boundaries. In the example shown, demand centre 'A' can access the combine capacities of two childcare centres, demand Centre 'B' can reach only one, and demand centre 'C' has access to a total of three childcare providers.

Such catchments, uniquely defined for each demand centre, will often overlap. This implies that any given supply site can fall into more than one catchment. This occurs in Figure 3(a) for instance, where one childcare provision site is "shared" by both demand centres 'A' and 'B'. In reality, the situation is often highly complex with service provision points potentially falling inside many demand centre catchments, as suggested by Figure 3(b). This raises a problem in that we cannot assume a demand centre has access to the full capacity of each supply site falling inside its floating catchment, as implied earlier, because very often this capacity must be shared amongst many local demand centres.

Step 1 of 2SFCA directly addresses this issue. Floating catchments are first constructed around each service supply site. Essentially the same actions are performed by the GIS to compute the total demand volume inside each supply site catchment. The availability of service at a given supply site is then determined by its capacity divided by the total demand volume – essentially a supply-to-demand ratio computed using the supply site's floating catchment as the frame of reference, as illustrated in Figure 3(c). It is these ratio scores that are then added up in Step 2 rather than the supply sites' total capacity. Supply capacity is thus

proportionately distributed amongst all in-reach demand centres, rather than having its full capacity counted multiple times amongst all near-by demand centres.

One final issue remains to be addressed, namely to account for the internal distribution of supply and demand inside the floating catchments and to address the observation that closer services are more likely to be used than those further way. To achieve this distance-decay effect, all points in each floating catchment calculation are weighted according to geographical proximity (Figure 4) – giving rise to the enhanced two-step floating catchment area methodology (E2SFCA hereafter). Within each floating catchment a weight is assigned to each contained point, ranging from 1.0 at the catchment's centre of origin and declining linearly to 0.0 at its defined threshold distance. Thus in Step 1 each demand volume is moderated by its distance to a supply site, and in Step 2 the availability of each supply site capacity is moderated by its distance to the demand centre. If desired, more complex distance-decay functions are easily incorporated into the model to acknowledge that decay effects can be non-linear in nature.

Together, the use of a two-stage floating catchment algorithm and a geographical distance-weighting effect addresses the major weaknesses described earlier when computing supply-to-demand ratios in arbitrary administrative boundaries. For each population demand centre, all reachable service sites are identified, and weighted according to both their geographical distance and their supply capacity expressed relative to the expected local demand. In Figure 5 a number of typical scenarios are illustrated, assuming that supply capacities and demand volumes are fixed in all cases: in example (1) a supply site lies close to a demand centre so receives a high accessibility score, both points fall inside a common administrative boundary; in example (2) a supply point is more distant resulting in a lower accessibility score, but the fact that it is also outside the demand point's administrative boundary is irrelevant; in example (3) the demand centre receives a higher score due to it having two supply centres inside its floating catchment, again the fact that one lies outside its own administrative boundary is irrelevant; and in example (4) the demand centre receives an access score of zero because no supply sites are considered to be reachable, even though one supply site does exist inside its own administrative boundary.

E2SFCA scores reflect proximity of services (how near they are), accumulative opportunity (how many supply sites can be reached locally), and supply capacity (e.g. the number of childcare placements at each site). They also reflect local demand level so, for instance, having exclusive access to a single supply site with a small capacity may score more highly than having access to multiple supply sites with large capacities but which must be shared amongst numerous neighbours. E2SFCA scores still express a simple to understand supply-to-demand ratio analogous to that computed for an administrative zone, but without the conceptual weaknesses associated with that approach. In particular they overcome the limitations of ratios derived for arbitrary administrative boundaries that bear little or no relation to the 'activity space' of those individuals who seek to use such services, and they

allow accessibility to be mapped at much finer spatial scales is achievable using the traditional administrative container methodology.

3.3. Educational Applications of FCA approaches

Floating catchment area techniques have recently been used to study spatial accessibility to primary healthcare (Langford et al., 2016; Bauer et al., 2017), food stores (Chen, 2017), libraries (Guo et al., 2017), green spaces (Xing et al., 2018) and sporting infrastructure (Higgs et al., 2015). However very few studies to date have applied E2SFCA to examine the spatial implications of variations in access to childcare or wider educational opportunities. Williams and Wang (2014) used FCA to measure spatial accessibility to public high schools in Louisiana at three cross sections in order to compare changes in access scores over time, and demonstrated poorer access scores in urban areas and those with higher proportions of African-American students. They also found schools with lower scores were associated with poorer academic performance. To date, the study by Fransen et al. (2015) remains one of the few to have used FCA tools to explore accessibility to day care facilities, specifically in a province of Belgium. Their approach has advanced the use of static cross-sectional FCA approaches to incorporate measures of trip-chaining behaviour which accounts for daily mobility patterns of the working population who are potential users of day care centres. In the next section, we describe how such tools can be used to provide a baseline assessment of current levels of childcare accessibility in Wales, and which have been used to guide the selection of pilot areas for the Welsh Government's Childcare Offer.

4. Investigating childcare capacity in Wales

In Wales early childhood education and care is provided formally through childcare settings such as day nurseries, registered childminders, pre-school playgroups, cylch meithrin (a Welsh-medium playgroup) and schools that provide non-compulsory early education in nursery classes (Graham, 2014). 'Childcare' for pre-school children in Wales is regulated by Care Inspectorate Wales and categorised as either childminder care, full day care, sessional day care, or crèche care. There are significant differences in provision between local authorities in Wales but these overall figures need to be considered in the light of the total number of places in relation to the population of children in any given area. A further consideration in any analysis of childcare is that not all services are available at all times. In general, childminders and full day care settings (usually day nurseries) offer childcare that closely matches the working hours of parents (on average 8am to 6pm, 5 days per week, for 50 weeks per year). Sessional care settings (most pre-school playgroups and cylch meithrin) only offer childcare for short periods – usually 2½ or 3 hour sessions – and most only operate during term times.

4.1 Data sources and data preparation

Data on the current provision of childcare across Wales were supplied by Care Inspectorate Wales. It consisted of a series of CSV format flat files that included a capacity measure (specifically, placements available), a location marker (specifically, a full UK postcode), and a service type indicator (drawn from an enumerated list consisting of: 'childminder', 'full-day care', 'sessional day care', 'out-of-school care', 'open access play centres' and 'crèche'). Files associated with each service type were formatted differently and often carried additional attribute fields unnecessary for this analysis. Data preparation consisted firstly of importing all data into a relational database (Postgres with PostGIS spatial extension) where redundant attributes were removed and validity checks performed, before combining information on all service types into a common table. Geocoding was undertaken in Postgres by matching the unit postcode of each provider with a lookup table of all current and past Welsh postcodes imported from the 'Doogal' website (Bell. C, https://www.doogal.co.uk/).

A small number of records were rejected during data preparation due to various issues. Some service provider postcodes were located in England rather than Wales, some recorded postcodes were invalid and could not be matched, and some records had missing capacity information. Data associated with 'out-of-school care', 'open access play centres' and 'crèche' provision was, after further consultation with the Welsh Government, dropped from the analysis due to difficulties in determining their capacity and availability; the total numbers of providers in these categories was anyway very small. Hours of availability were not known accurately for each individual provider, so a decision was taken to work on an assumption of 8 hours per day for full day care sites and childminders, and 4 hours per day for sessional care sites. The final dataset consisted of the locations, available placements and total placement hours of approximately 650 full day care centres, 780 sessional care centres, and 2,130 child minders. These were transferred to the ArcMap™ GIS where E2SFCA modelling was conducted. Estimates of childcare demand were also provided by Care Inspectorate Wales, based upon the 2011 UK Census but incorporating 2015 mid-year updates. A count of 'eligible children' was created for each Output Area population weighted centroid using the aged 0 to 4 total population count modified by the reported proportion of working parent households. Children are deemed eligible only if they are from households where both parents, or where the lone parent, are working as per the '30 hours' policy.

4.2 Accessibility modelling results

E2SFCA scores were computed in ArcMap using the Network Analyst Extension and a bespoke Add-In tool developed by the authors and made freely available online (reference to be supplied after review). The decision was taken to base all analyses on supply capacity reported as 'hours of availability' rather than 'placements' because this allowed modelled outputs to more closely match information conveyed through media coverage of the Welsh Government childcare offer. For the same reason E2SFCA scores were scaled to represent

"the number of hours of available childcare provision per week per child eligible to receive free childcare provision". All results presented here used floating catchments based on a 10 minute network travel time. It should be noted that speed along network road segments was predicated on road class to match national speed limits, but no account was taken of any delays caused by traffic congestion, negotiation of junctions, flow control measures such as traffic lights, or the time taken to accelerate to the nominal road speed. This travel time limit should not be taken too literally since the actual travel time to reach a service will always vary according to individual circumstances, geographical location (e.g. urban/rural), ambient weather conditions, the time of day, and so on. Rather it is a modelling parameter that is used to control the balance of the E2SFCA analysis between providing a more localised focus (at smaller values) and a more regional assessment (at larger values). Other travel time settings were modelled, with results passed on to the Welsh Government, but are not reported here as they produced very similar outcomes. Accessibility scores were computed separately for each childcare provision type, but are shown combined in this study to provide an analysis of total service level. Scores obtained for Output Areas were also re-expressed for higher UK census geographies (e.g. Lower Super output Areas) and passed on to the Welsh Government, but again these outputs are not presented here.

Firstly, the global provision rate, reported earlier as 0.6 placements per child, equates to 15½ hours of provision using our preferred measurement units. The E2SFC scores obtained for individual Output Areas (10,035 in total across Wales) showed a considerable range, as depicted in Figure 6. Scores are relatively normally distributed with a mean of 20.6 hours and a median of 19.7 hours. Eleven Output Areas scored zero – these populations were estimated to not be in reach of any childcare provision site within the specified travel time limit. The maximum recorded score was 88 hours of childcare provision per week. The quintile boundaries for the scores are Quintile 1: 0 – 14 hours, Quintile 2: 14 – 17¾ hours, Quintile 3: 17¾ – 22 hours, Quintile 4: 22 – 27½ hours, Quintile 5: 27½ – 88 hours. These imply that, at the time of analysis, only about one fifth of all Output Areas currently experience a level of childcare provision that would meet the Welsh Government's Childcare Offer.

Mapping the E2SFCA scores (Figure 7) highlights how considerable geographical variations exists in the current level of provision. As might be expected, in general higher levels of childcare services are found in urban centres and lower levels in remote rural communities, but the ability of the FCA algorithm to equate local supply with local demand means that this relationship is not universal. Notably high levels of provision arise in north-east Wales (e.g. around Conwy) regardless of urban-rural distinctions, and the strong contrasts between adjacent councils in south-east Wales, as shown previously in Figure 2, are replicated but with substantially more internal variation now made visible. In particular the contrast in the level of spatial detail between Figure 2 and Figure 7 is stark, particularly perhaps in the large and predominantly rural councils of central and western Wales. Even within these rural areas localised 'hot-spots' are often evident where childcare centres located in small market towns create service levels comparable to those in inner city areas, but only for residents located close to the town centres.

Mapping the Output Areas scores for individual service provision types (maps not shown here) also emphasised how day care centres make up a high proportion of the total service availability in major employment centres (such as Cardiff, Newport, Swansea and Wrexham), while small-scale child minders are responsible for delivering a much larger share of the sector in rural and peri-urban settings. It is difficult in a map such as Figure 7 which covers a large geographical area, to demonstrate clearly the precision and nuanced level of detail obtained from E2SFCA mapping. It is only by zooming in to smaller areas (e.g. Figure 8) that settlement-by-settlement, and even street-by-street, variations in service provision are clearly seen. Such detailed information may be critical in assisting in the planning of future provision and local policy, and for encouraging the development of capacity in those areas where there is the most urgent need or greatest current shortfall.

4.3 Limitations and plans for further developments

Whilst the potential benefits of FCA modelling over traditional mapping and analyses based on administrative zones have been discussed and promoted through the example given above, there remain many limitations to the current study that should be noted. Firstly, these models have relied upon estimates of potential demand arising from recorded census counts which represent only a best guess of the actual or realised demand in any particular area. Where possible other sources of information, such as the length of current waiting list for local providers, should be used by local planners and those tasked with targeting policy development, although this information is often difficult to acquire or is absent altogether in which case potential estimates remain the best available solution. Similarly, the key FCA modelling parameter – the maximum acceptable distance/time of travel – is based only on a pragmatic estimate in this study. However, the models are easily re-executed if sources become available to offer a more informed estimate of its value. For example, a survey of actual travel times experienced by those dropping children off at the start of a day, or an exploration of the distances of registered home addresses of parents using specific childcare provision sites might be considered.

We must also acknowledge that many other subtleties arise in childcare provision which can often make a significant difference to the real-world choices available to parents and to the true suitability and availability of a service. For example, the precise opening hours of a facility, or whether part-time provision is available in the morning or the afternoon. All formal childcare facilities, both public and non-maintained (private and voluntary sector), have been included in our models. It is possible for non-maintained facilities to impose rules and restrictions on eligibility that would then result in an effective overestimation of supply. If there are parents who currently do not work only because they have no access to childcare, this implies that the demand may be underestimated because non-working parents are not included in the current calculation. Furthermore, we have assumed that all facilities cater for the full 0-4 age range, whilst it is possible that some facilities may specialise in providing childcare only for younger or older children within this range. Using the maximum capacity

of each service delivery point also ignores the fact that regulations dictate different child-staff ratios are needed for differing age groups. For a fixed level of staffing, a facility has a smaller capacity for babies and very young children than for older children. Data were simply unavailable to elucidate or model many of these fine distinctions. Another limitation arises from modelling part-time provision by assigning a reduced set of hours to a site without any knowledge of its precise period of delivery. It is accepted that morning-only or afternoon-only delivery could significantly impact the true availability of a service in relation to an individual's specific working practices. We have also assumed that the hours provided by two part-time places are directly equivalent to those supplied by one full-time place. In reality they are unlikely to be so: two part-time morning-only placements clearly would not satisfy the needs of a parent requiring one full-day placement for example.

Whilst our E2SFCA scores are computed independently of administrative boundaries, it remains the case that the study area as a whole still acts a form of container. The scores presented here assume the border between Wales and England is an impenetrable barrier. In truth it is highly likely that some parents living close to the border will use nearby services in England, and that similar leakages may take place in the opposite direction. With the small travel time threshold used in these analyses, such border effects are likely to be minor relative to the overall picture, and could be eliminated altogether if additional data for England were to be included within an appropriate buffer zone. The modelling currently undertaken and reported above is also based on an assumption that parents are seeking childcare services in the vicinity of their homes. In reality there is undoubtedly a highly complex set of reasons behind why any particular parent selects any particular childcare provider including, for example, word-of-mouth reputation, maintain continuity amongst siblings, the quality of facilities and perceived standards of service, and so on, most of which are unamenable to incorporating into such generalised models. However, one factor known to be significant is the choice made between selecting provision close to home versus that close to place of work (or possibly en-route to a place of work).

Future efforts will attempt to incorporate UK census information on *workday* estimates which record the population of Output Areas during a typical working day based on those working in the area and those residing in the area but not currently working. As stated at the outset, the focus in this paper has been on highlighting the advantages of the FCA modelling approach over those utilised in previous childcare provision studies. Further work will include a detailed interpretation of the spatial patterns that have been revealed by this analysis, presenting an investigation into the potential causes behind such patterns, and evaluating their implications for future childcare policy development in Wales and beyond.

5. Conclusions

The Childcare Act (Wales) 2006 requires local authorities – as far as is practicable – to ensure that there is enough childcare for working parents and those undertaking job-related training in their area. A review of Childcare Sufficiency Assessments in Wales found in 2015

that 82% of local authorities in Wales had insufficient childcare for working parents (Butler and Rutter, 2014). Particular gaps in provision were highlighted in a number of areas including part-time day care for three and four year olds, childcare in school holidays, sessional childcare and Welsh-medium childcare. Gaps in sufficiency were found in deprived areas where fewer parents are in work and where those that do work are less able to afford to pay for services. The Welsh Government Free Childcare Offer therefore aims to redress this situation by providing 30 hours of free early education and childcare per week to the working parents of three and four-year-olds with a primary aim of increasing the number of women entering the workforce. However the evidence base to draw upon to help implement this policy is currently limited to aggregate (local authority) level provision of childcare. The approach adopted in this study can be used to describe the current level of each type of care (including the number of places and hours of opening) for each type of provision as part of wider studies concerned with, for example, identifying localised under-supply or inappropriate pattern and types of childcare and early years education provision with regard to local labour market opportunities.

At coarse geographical scales it is relatively straightforward to calculate provision in relation to potential demand. However, the resultant ratio can tell us nothing about any local variations in supply-to-demand within the chosen frame of reference (i.e. local authority administration areas). Almost inevitably such variations will arise as a result of the exact locations of the enclosed supply relative to demand centres as well as their relative capacities and volumes and these can be incorporated into floating catchment area methodologies to provide a more useful measure of accessibility to childcare. However, whilst the tools developed here have a real advantage in providing a more realistic information of the availability of places that incorporates both distance constraints and facility opening hours, as McLean et al. (2017) argue the issues surrounding the choice of childcare are in reality likely to be even more complex as a result of the logistical challenges facing parents. In particular their study as well as those of others suggests that the take-up of childcare offers such as this will largely be dependent on the time constraints impacting on parents arising from their working patterns and the actual timing of availability of childcare. The development of space-time accessibility measures is an active area of GIS research; including their application in ethnographic studies of access to day care centres that take into account employment and caregiving responsibilities of parents (Schwanen and de Jong, 2008). In our future endeavours we will investigate how such constraints can be further incorporated into the types of tools developed here.

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Figure 1: Issues associated with a 'container' based approach to childcare provision

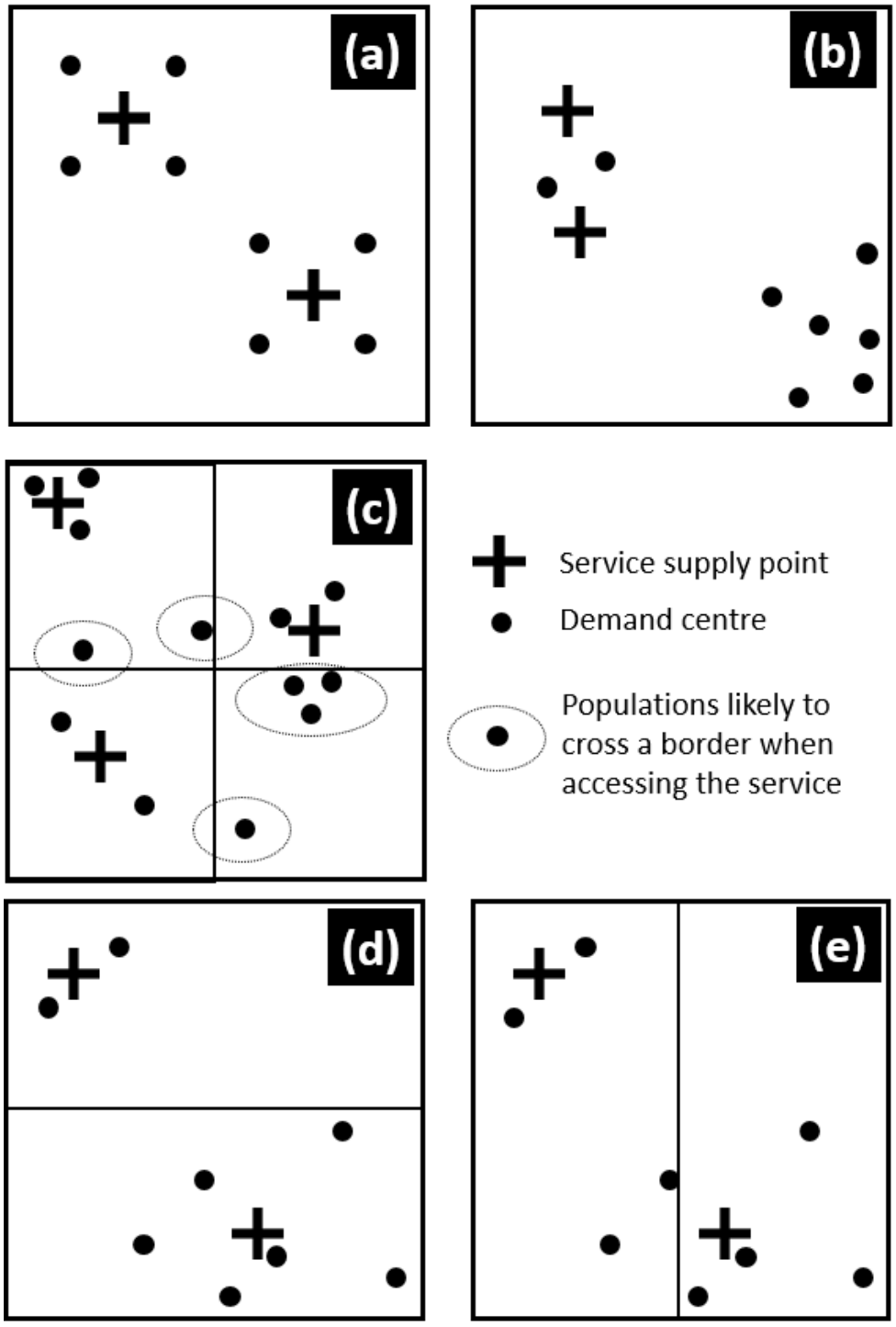


Figure 2: Childcare provision in Wales, mapped using Local Authority Districts

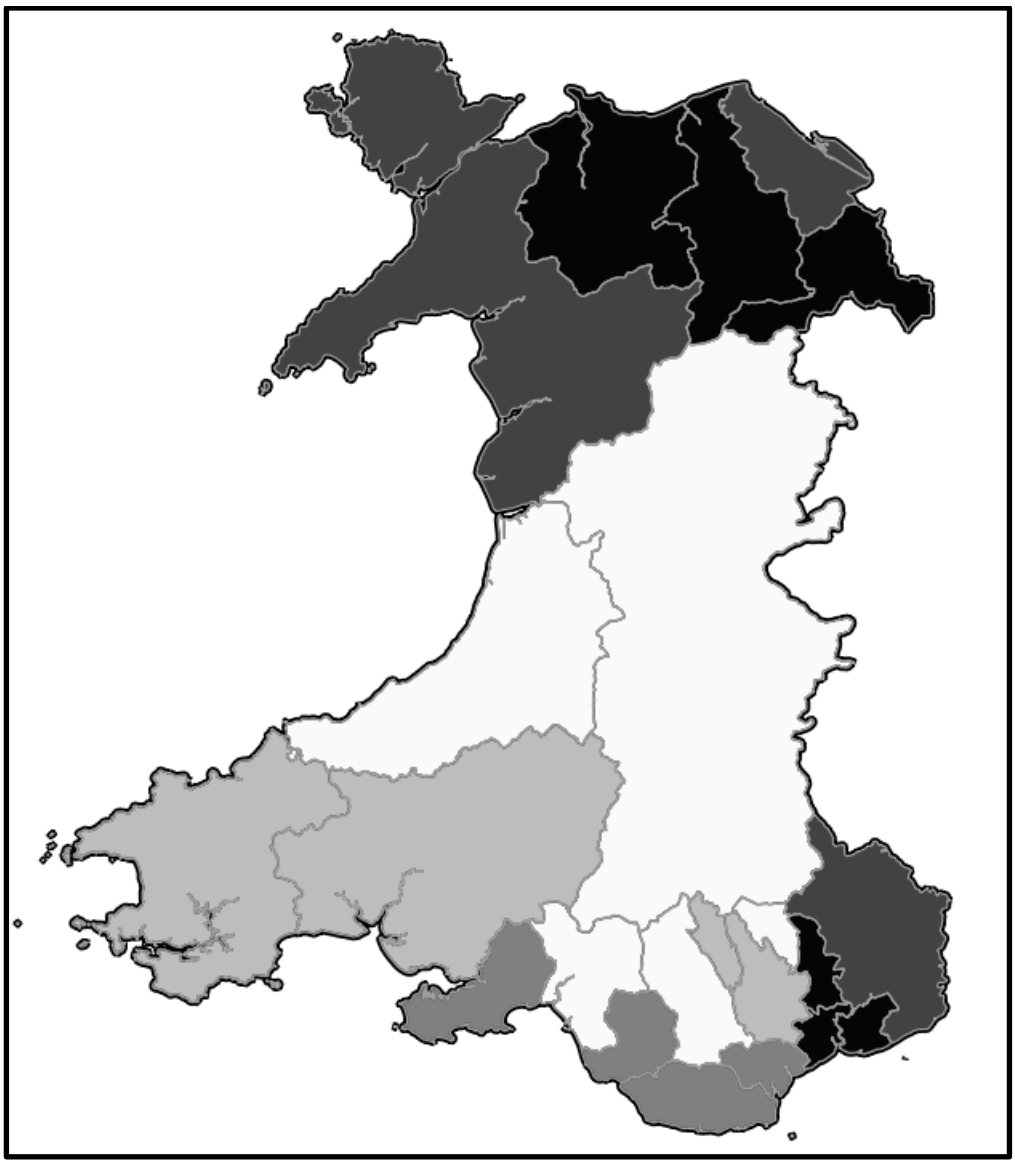
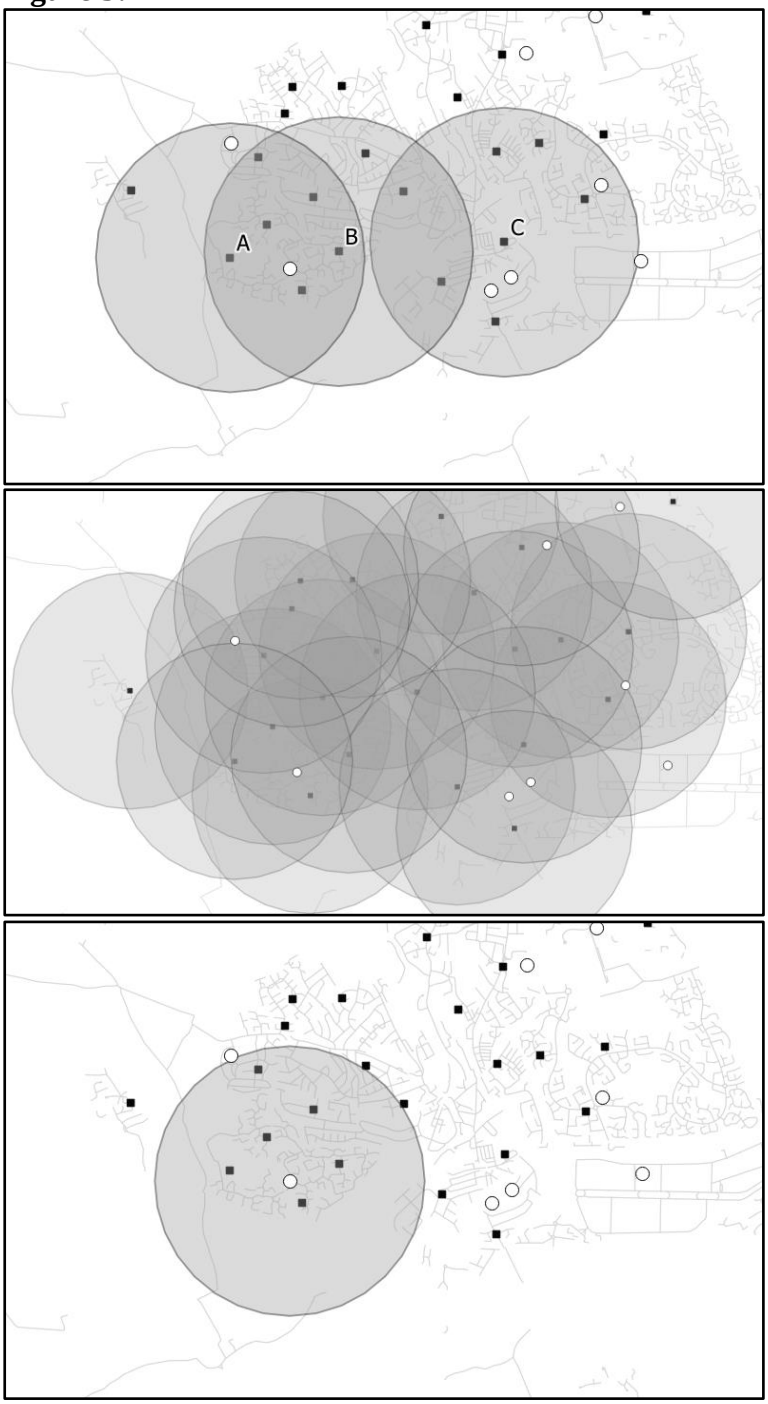


Figure 3:



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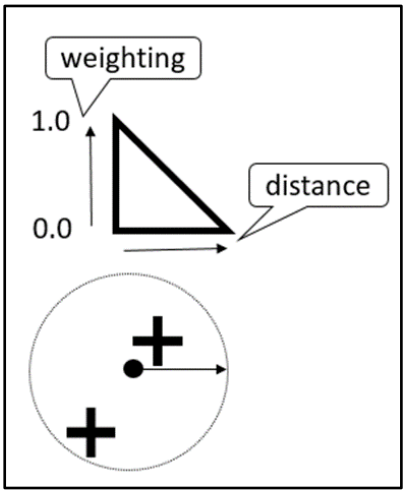

Figure 5:

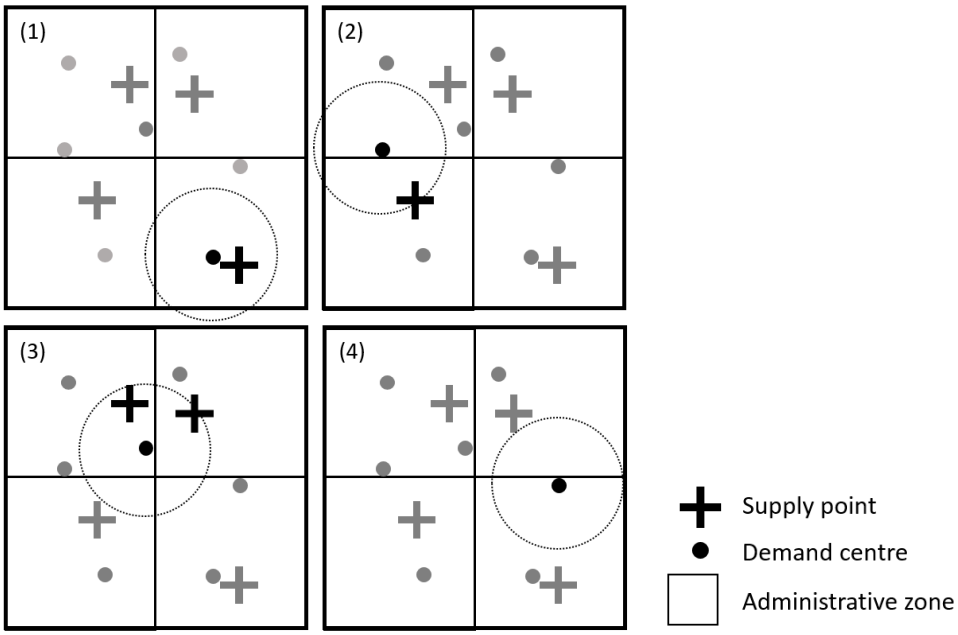

Figure 6

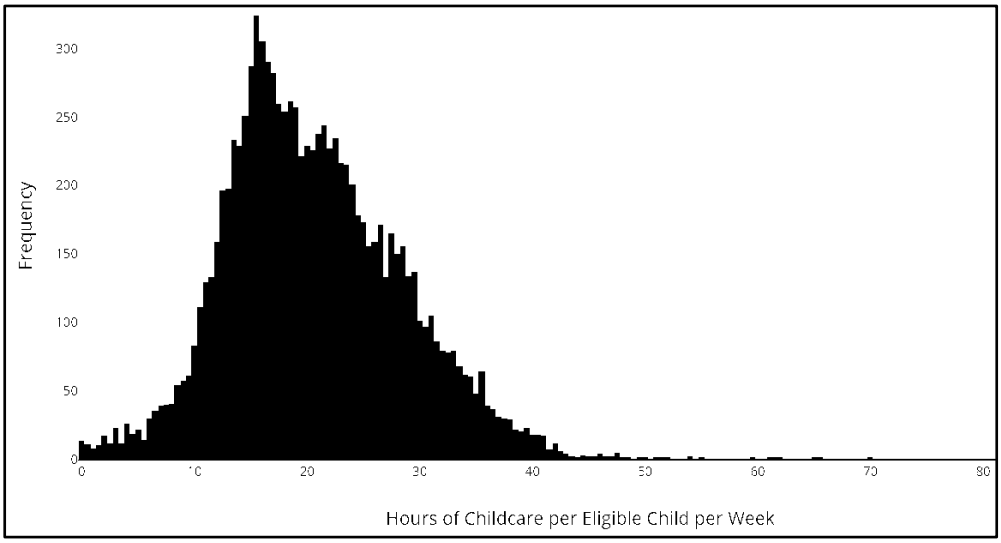
Frequency
300
250
200
150
100
50
0
0
10
20
30
40
50
60
70
80
Hours of Childcare per Eligible Child per Week

Figure 7

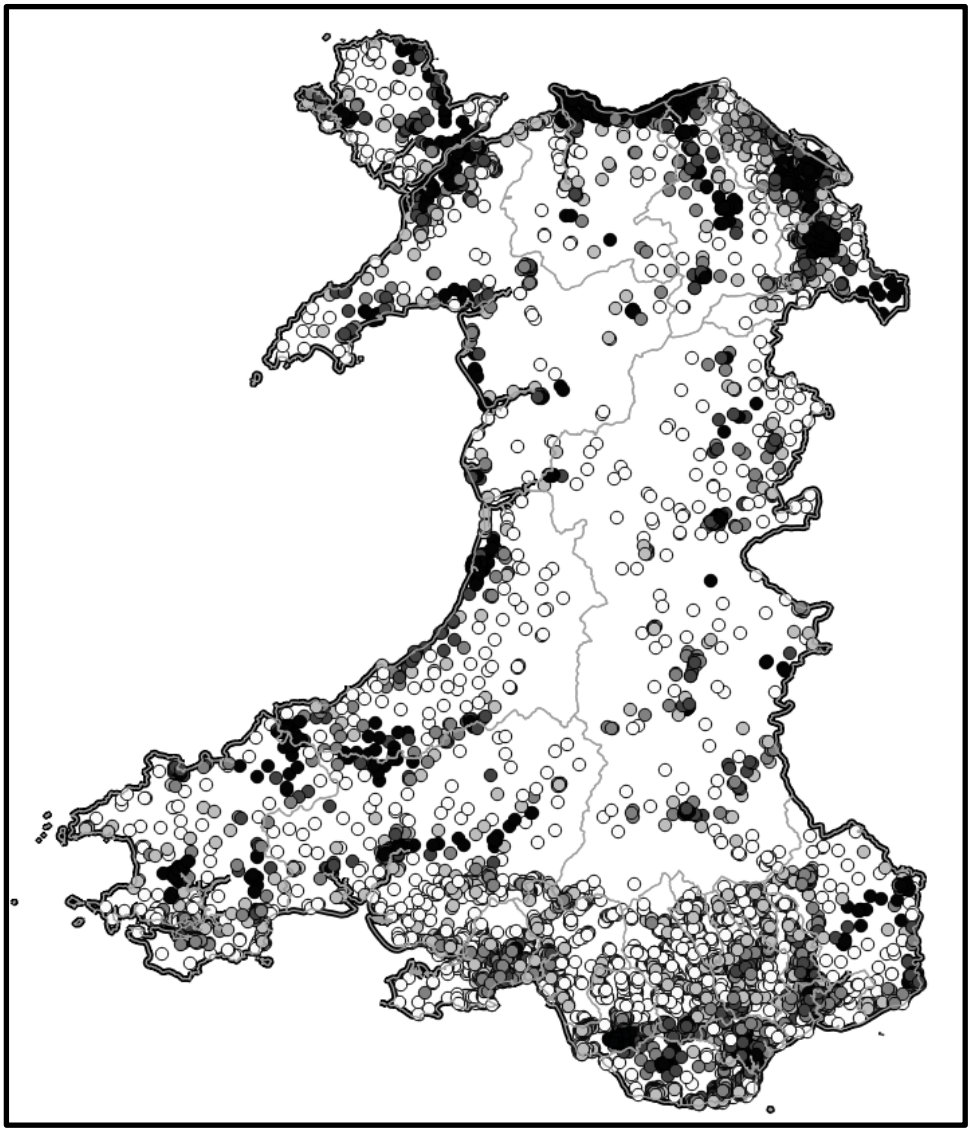

Figure 8