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Testing the Self-Sufficiency of Radiotherapy Catchment Areas

Paper for *Applied Spatial Analysis and Policy*

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Testing the Self-Sufficiency of Radiotherapy Catchment Areas

Abstract

“Natural” catchment areas are important for supporting planning and marketing for a range of different public services, to enable improvements in access, quality and productivity. However, established methodologies used in their construction can mask varying patterns of cross-boundary movements. This issue was investigated in relation to radiotherapy services in England, using the *Nomogramma di Gandy* to test the degree of self-sufficiency of the 50 cancer centres’ “natural” catchment areas for 2011/12. The analyses demonstrated differential patterns across the country, and highlighted that an understanding or appreciation of the volatility of patient flows relating to different catchment areas is key to risk analysis when considering future trends in radiotherapy services and referral patterns. The *Nomogramma di Gandy* represents a high-level filter, which complements catchment area and population methodologies, and uses simple, available data to monitor trends over time. It readily enables the interpretation of self-sufficiency and patient flow dynamics across a large number of centres. In principle, the approach should be transferable to other public services that utilise catchment areas and populations.

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All diagrams were created using Microsoft Excel. They were then copied with the “Bitmap” option from “Paste Special” used to place them into the respective Word files. Excel versions can be provided upon request.

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Testing the Self-Sufficiency of Radiotherapy Catchment Areas

Paper for Applied Spatial Analysis and Policy

1. Introduction

1.1 Utilisation of Catchment Areas

The concepts of catchment areas and catchment populations are used in many public services such as hospitals (Gilmore 2010; Shafrin 2010), primary health care (NHS Choices 2013), mental health services (Kinane and Gupta 2001), schools (Bedford Borough Council 2013; Noreisch 2007), prisons (Youth Justice Board 2013) and airports (Civil Aviation Authority 2011). They are used to define or reflect the area and population served by a given institution or service, and they are particularly relevant to radiotherapy treatment services where catchment population sizes support planning and marketing, and enable comparisons of the relative resources available to centres (Department of Health 1999; Department of Health 2012). The need for improvements in access, quality and productivity in health services is great given the projected increases in demand and the financial climate for public services (NHS Improvement 2013a).

Internationally, the International Atomic Energy Agency (IAEA) (2007) undertakes comprehensive audits of radiotherapy practices, for the purposes of quality improvement across its 160 member states (as at November 2013) (IAEA 2014), and one of its key required patient demographic data is the “fraction of cancer patients (of the total number in the catchment area) who come for radiotherapy, where the statistical data are available” (IAEA 2007).

There are two means of calculating the size of a catchment population: one involves statistical formulae, which use data on populations and the geographic relationships between services and service users, to calculate a single population figure (Gandy 1979a); the other involves establishing the resident population of defined geographical areas (National Cancer Services Analysis Team 2010), which may be set by agreement or to reflect actual geographic relationships between services and service users. Logically, there should be a consistent approach to the definition of catchment areas and populations, at least within any one given country/ member state.

1.2 Radiotherapy Catchment Areas in relation to English Cancer Centres

The Calman-Hine Report (NHS Executive 1995) set out three fundamental principles for the delivery of cancer services. These were that patients, wherever they live, should have equality of: -

- Access to Cancer Services
- Quality of Cancer Services
- Clinical Outcomes.

The report recommended that cancer centres, which provide radiotherapy services, should serve a population of more than one million people. However, it was considered acceptable for some cancer units, with a smaller catchment population, to provide radiotherapy services, if the travel time to a more remote cancer centre would be unduly onerous for patients (NHS Executive 1995). This limit was generally accepted as greater than sixty minutes by road (Association Of Cancer Physicians 1994). In this situation a cancer unit could provide radiotherapy services but its staff should have close professional and functional links with a parent cancer centre.

A Royal College of Radiologists survey (1998) included each cancer centre's local estimation of the size of its own catchment population. Inevitably these estimates were based on the location of the furthest towns from which patients will normally travel for treatment, which generally resulted in an overestimate of the population served. Thus the aggregate total of the estimated catchment populations was determined to be significantly more than the total population of the United Kingdom (UK) (approx. 69 million as compared with 54 million for the 1996 mid-year estimate of total UK population) (Department of Health 1999). This served to illustrate the need for centrally calculated catchment areas and populations.

To help achieve the Calman-Hine Report objectives (NHS Executive 1995) the Department of Health (1999) commissioned a detailed analysis of radiotherapy services in the UK, which subsequently acted as the basis for future planning. The resultant report included algorithms designed to enable Trusts, Primary Care Groups, Health Authorities and Regional Health Authorities to plan services by modelling the effects of investment, disinvestment and reconfiguration of radiotherapy services and to identify the scope for increased efficiency in the usage of existing resources. Given the above problems of relying on cancer centres' local estimates, the Department of Health (1999) commissioned the National Cancer Services Analysis Team (NatCanSAT) to carry out an analysis which more accurately calculated the catchment populations, and ensured that they aggregated to the national population.

1.3 National Clinical Analysis and Specialised Applications Team

The NatCanSAT was established in 1996 and was funded originally through the National Cancer Action Team to provide in-house medical informatics services to the NHS, which included: software application and website development to geographical data analysis, including involvement in cancer clinical audits (United Kingdom Association of Cancer Registries 2013). NatCanSAT has since changed its name to the National Clinical Analysis and Specialised Applications Team to reflect an expanding remit, whilst still retaining its existing abbreviation. It is hosted by The Clatterbridge Cancer Centre NHS Foundation Trust (NatCanSAT 2013a).

NatCanSAT has been responsible for the determination of catchment areas and the calculation of catchment populations for cancer centres across England since 1999, thereby enabling levels of staff, beds and equipment in each radiotherapy centre to be normalised against the centre's catchment population and underlying cancer registration rate (excluding non-melanomatous skin cancers) (Department of Health 1999; Department of Health 2012). To support this work NatCanSAT uses the Esri geographical information system (Esri 2013).

The primary methodology used by NatCanSAT (referred to as Method A) involves the number of patient episodes occurring in each census ward being summated and grouped by the centre in which each of the patients was treated. The whole population of the census ward is then allocated to the cancer centre, which had the greatest number of episodes within the ward during the time period in question. Accordingly the whole population of each census ward is allocated to an individual cancer centre. If the activity within a ward is divided equally between two or more cancer centres, then the resident population is divided equally between the centres. The population allocated to each centre is then summated to arrive at a total catchment population for each centre. Each census ward can then be colour coded by its dominant cancer centre and plotted on a map to demonstrate the extent of an individual cancer centre's main catchment area. This hereafter is referred to as the cancer centre's "natural" catchment area. Repetition of this approach enables the creation of a map of the whole of a geographical area, broken down into provider-dominant catchment areas, which can overlay statutory boundaries (NatCanSAT 2010). Examples of this have been published (Ball et al. 2013; Department of Health 2012).

In addition, NatCanSAT has determined catchment areas on a tumour-specific basis, using relevant patient activity data, to allow for the fact that an individual cancer centre's catchment population for

Breast cancer may be significantly different than its catchment area for Lung or Urological cancers (Department of Health 1999).

It should be noted that NatCanSAT also uses a complementary methodology for calculating single catchment population figures (referred to as Method B). This involves the number of patient episodes occurring in each census ward being summated and grouped by the centre in which each of the patients was treated. The population of each census ward is then allocated, pro rata, to each of the centres, which had patient episodes within the ward during the time period in question. Thus, in Method B, the population of each census ward is allocated to one or more centres. The population allocated to each centre is then summated to arrive at a total catchment population for each centre. Method B addresses the fact that the catchment populations for certain regional and national specialist referral centres were considered to be understated using Method A. Such centres treat small numbers of patients from a large number of widespread wards for certain diagnoses or treatments, and in aggregate these can represent a significant workload. Unfortunately, because the numbers involved for each individual ward are small, and the majority of patients are treated by the main local cancer centre, the specialist centre gets none of the wards involved credited to its catchment population (NatCanSAT 2010).

Both Methods A and B are used by NatCanSAT (2010), and the centres themselves, according to context; Method A utilises and maintains established geographical areas, and provides both a catchment population estimate and a catchment area map, whilst Method B generates a (more accurate) catchment population calculation. Because it does not involve a catchment area map Method B was outside the research.

1.4 Cancer Networks

It should be noted that all cancer centres will relate to cancer networks across England. A cancer network involves all the organisations and agencies, such as hospitals, GP practices, hospices, community hospitals and voluntary services, which are responsible for providing care to cancer patients and their families within a defined geographical area. The main aim of a cancer network is to plan and develop services for patients and their families, so that they are provided with the highest quality of care across their whole cancer journey pathway i.e. from the first suspicion of cancer, through treatment and ongoing after care. There were 28 cancer networks covering England in 2013 (NHS Improvement 2013b).

Clearly, given that there are 50 cancer centres providing radiotherapy across England, there are varying relationships between individual cancer centres and cancer networks. The geographical areas covered by the English cancer networks are quite distinct from the cancer centres' "natural" catchment areas for radiotherapy, and are therefore outside the research.

1.5 Aims and objectives of research

Gandy et al (2011) explored how access to public services could be demonstrated diagrammatically using the *Nomogramma di Gandy (NdiG)*, which is a long-established analytical tool and diagrammatical method, which provides a practical means of analysing service user mobility to establish the degree to which services provided in an area or region are self-sufficient. The *NdiG* can present a complex situation in a way that enables inferences to be readily made. Its design focuses on percentages, but percentages by definition mask relative size and therefore it is always desirable for *NdiG* presentations to be set alongside tables showing the actual data and percentages. Gandy et al (2011) made comparisons between the *NdiG* and other graphical methods of illustrating geographical access, which included the NatCanSAT methodology (Method A). It was concluded that the *NdiG* and Method A use very similar data, and that Method A, by assigning each location to one service provider or another, can mask where there are locations with many patients going to different providers. The *NdiG* is different in that it aims at highlighting where there is variable mobility. However, it was important to recognise that NatCanSAT's objectives were observably different in that they construct catchment area maps and determine the populations of the catchment areas (Gandy et al. 2011).

From liaison with NatCanSAT at the time it was evident that there was potential for cancer centre catchment areas to evolve over time for radiotherapy, given a number of factors that could impact on patient flows: the devolution of radiotherapy services (Institute of Physics and Engineering in Medicine, Society and College of Radiographers, Royal College of Radiologists 2013) potentially making newly devolved services more accessible to patients living in areas outside the services' catchment area, compared to the centres these patients have traditionally used; legislation that increases patient choice (Department of Health 2003; Department of Health 2010); and trends in the incidence of those cancers that require radiotherapy treatment. In addition, the advent of new radiotherapy-related treatments such as proton beam therapy (previously only available outside the UK) could influence patient flows (NHS Specialised Services 2013).

Pulling all factors together suggests that there will be increasing volatility in patient flows over time, which could have consequences for established catchment areas, and the evaluation of services in terms of access, clinical outcomes, performance, quality, workforce and workload. Therefore it is important to establish the degree to which cancer centres' "natural" catchment areas are self-sufficient, and continue to be self-sufficient. Therefore, the author sought data with a view to undertaking analytical research to evaluate whether the application of the *NdiG* could usefully be used to evaluate and monitor the degree of self-sufficiency in the established cancer centre catchment areas for radiotherapy services. The *NdiG* had traditionally been utilised in respect of formal statutory geographical boundaries, e.g. regions and health authorities, and this research would be the first time that it would be applied to areas whose boundaries had been constructed by an analytical methodology.

The aims of the research were to:

- Assess whether *NdiG* analyses were readily interpretable in the context of catchment areas and radiotherapy, and adequately reflected "self-sufficiency"

Supporting objectives were to:

- Analyse and display differentials between different cancer centres;
- Highlight/ determine cancer centres where more detailed analyses of their patient flows and catchment areas may be necessary;
- Measure and demonstrate changes in patterns over time;
- Test that the data used was appropriate, valid and available.

This paper presents the outcomes from this research.

1.6 Application of the *Nomogramma di Gandy*

The *NdiG* is a high-level tool which measures the degree to which an area or region is self-sufficient in the delivery of a specified (public) service (Gandy et al. 2011). "Self-sufficiency" in the context of the research would be the degree to which the cancer centres operated independently of one another for radiotherapy; complete independence would be if a centre treated 100 percent of the patients from within its "natural" catchment area, and 100 percent of the patients from within the "natural" catchment area were treated by the centre (Gandy et al. 2011). Given NatCanSAT's process for creating "natural" catchment areas, each cancer centre's "natural" catchment area would ideally be self-sufficient in respect of the treatments delivered.

The *NdiG* is a two-dimensional diagram that involves simple data and which has two main axes, as follows:

X axis = Percentage of Patients Treated in Local Area that were Local Patients

$$= (R \times 100) / (R + I)$$

Y axis = Percentage of Local Patients Treated in Local Area

$$= (R \times 100) / (R + E)$$

Where in the context of the research:

R = Number of patients treated at centre who were from that centre's catchment area

I = Number of patients treated at centre who were from outside that centre's catchment area

E = Number of patients from a centre's catchment area who were treated elsewhere

"I" is sometimes referred to as the number of patients "imported" into an area, whereas "E" is sometimes referred to as the number of patients "exported" from an area (Gandy et al. 2011).

As described above, the interpretation of the *NdiG* is that the nearer to the co-ordinates (100,100) a centre's catchment area is, the more independent it is of other centres' catchment areas, i.e. they are more self-sufficient or self-contained. If the value of Y/X is greater than 1 then the cancer centre's catchment area is a net "importer" of patients, i.e. more patients come in from outside than the number of local patients that are treated outside the area. Similarly, if Y/X is less than 1 then the cancer centre's catchment area is a net "exporter" (Gandy et al. 2011). Figures 1, 2 & 3 below adopt the optional convention of having the letters "A" and "B" above and below the 45° diagonal to make it easier for references. Centres that are positioned in "A" are net importers of patients, whilst those in "B" are net exporters (Gandy et al. 2011).

2. Data

The Radiotherapy dataset (RTDS) was a new dataset established in April 2009 to collect data centrally on every patient treated with radiotherapy in, or funded by, the NHS in England. Prior to the inception of the RTDS, very limited radiotherapy data were collected, and there were a wide variety of definitions of each of the currencies in use. The RTDS was aimed at standardising currencies, and introducing new currencies which were aligned with other activities in the NHS (Department of Health/ National Cancer Action Team 2011). Data in the RTDS are based upon downloads of activity from

every linear accelerator in England through its oncology management system linked to the local patient administration system to give a full overview of each patient episode (Hoskin et al. 2013). RTDS have been collected by NatCanSAT since April 2009, and allow for the routine collection of clinically and managerially relevant activity data from radiotherapy facilities with good quality reporting, in order to commission or monitor radiotherapy services in an evidence-based manner (NatCanSAT 2012).

The required research data was obtained through a Freedom of Information (FOI) Act 2000 request, and included no identifiable patient data, and therefore no ethical approval was required. These data accorded with the above data requirements for the *NdiG*, viz. the number of patients treated who were residents of each centre's catchment area, separating out how many were treated at that centre and how many were treated at a different centre, plus how many patients were treated at each centre who were from outside the centre's catchment area. Therefore the design of the research followed the standard application of the *NdiG* (Gandy et al. 2011). The response to the FOI request (NatCanSAT 2013b) was received in October 2013, and the research utilised the data and cancer centre catchment areas for the latest year for which they were both available at the time of the FOI request, viz. 2011/12.

It was noted that if a patient moved house between two courses of radiotherapy they would have been counted twice, but it was considered that the numbers involved would be very small. The author assigned each centre to its local standard English region (Office for National Statistics 2012), in order to ascertain whether there were any regional geographical patterns in play.

In essence, all of the requested data is presented in Table 1, and this was used to create Figures 1, 2 & 3. It is considered that the outcomes from the research are important and can benefit others involved with similar catchment area issues, whether in radiotherapy or other services.

3. Results

There were 50 cancer centres in England that delivered radiotherapy in 2011/12, including the centre at the Peterborough and Stamford Hospitals NHS Foundation Trust, which opened in May 2011. The values for the three main *NdiG* statistics (R, I & E) and derived indicators for the *NdiG*'s X and Y axes are provided in Table 1. It will be seen that the number of centres in each of the nine standard English

regions was as follows: East Midlands - 5; East of England - 6; London - 9; North East - 2; North West - 4; South East - 7; South West - 9; West Midlands - 5; Yorkshire & Humber – 3.

There was a total of 122,552 patients treated across all centres during 2011/12, an average of nearly 2,450 patients per centre per annum. The minimum was 697 (Royal Free, London), the median was 2,160 and the maximum was 7,545 (Christie Hospital, Manchester, North West). It should be highlighted that the figure for Christie Hospital was 37 percent higher than the next largest volume of 5,521 (Clatterbridge Cancer Centre, North West). Nine centres (18 percent) had annual equivalent volumes of less than 1,200 patients (approximately 100 per month).

It will be noted there is a difference of 1,132 between the total number of patients treated by centres that came from outside their catchment area and the total number of patients who were treated outside their local centre's catchment area (0.9 percent of all patients treated). In its response to the FOI request NatCanSAT (2013b) advised that this is because there are some areas where no one centre was dominant, and hence the patients involved were not attributed any of the centres' catchment areas (although they were attributed to the centre where they were treated).

For presentational purposes, a single *NdiG* showing all of the 50 centres would be very "busy" in black and white (given that each centre would require its own unique symbol) and difficult for the reader to interpret because of the number of overlapping symbols. Therefore three *NdiGs* are presented, each focusing on a major geographical subdivision of England. These are: North East, North West & Yorkshire & Humber (Figure 1); East Midlands, South West & West Midlands (Figure 2); and East of England, London & South East (Figure 3).

Given that the minimum value of X was 28 percent (and that for Y was 58 percent) the *NdiG* axes were truncated to 25 percent for presentational purposes. This was repeated for all three figures, so that there would be consistency of presentation, which helps when making visual comparisons.

Figure 1 shows that the catchment areas in the Northern regions are very self-sufficient, with the lowest value of X being 95 percent and the lowest value of Y being 93 percent for the nine centres.

Figure 2 shows that there is also a great deal of self-sufficiency in the East and West Midlands, with all values of X & Y higher than 83 percent. Four out of the five centres in the East Midlands had both values higher than 90 percent, whilst there were none in the West Midlands. This arguably reflects the fact that the East Midlands involves cities that are geographically separate, whereas several centres in the West Midlands are within the West Midlands conurbation itself, which means that travel for

related patients is easier. A similar pattern was found in the South West region, where all values of X & Y were higher than 83 percent, and four of the nine centres had both values higher than 90 percent. Figure 3 shows that four of the six centres in the East of England region had their values of X & Y higher than 90 percent. The exceptions were Cambridge University Hospitals and the new Peterborough and Stamford Hospitals' centre; this is not surprising given the geographical proximity of the two centres to one another, and the fact that the latter was in its first year of operation and it will take time for referral patterns to settle down. There was also a great degree of self-sufficiency in the South East region with all values of X & Y higher than 83 percent, although only three of the seven centres had both values of X & Y higher than 90 percent.

Not surprisingly, London is where the cancer centres' patient flows are the most volatile, with none of them having both values of X & Y greater than 90 percent. Five of the nine centres had X values of less than 80 percent, and five had Y values of less than 80 percent. University College London (2.08), Royal Free (1.50) and Royal Marsden (1.19) had the three highest Y/X ratios of all cancer centres in the country, reflecting their specialist roles. This is in part reflected by University College London (28,59) and Royal Free (39,58) being the two clear outliers on the diagram, not only for London but for the whole country.

[INSERT Table 1]

[INSERT Figure 1]

[INSERT Figure 2]

[INSERT Figure 3]

4. Discussion

4.1 Commentary on Results

The results clearly and readily demonstrate that there is a great deal of self-sufficiency in many regions. Indeed, across the whole of England 91 percent of patients were treated in their local "natural" catchment area. From an access perspective, it is arguably desirable for as many patients as possible to be treated locally. In this regard it is the Y value that is of most interest. Given that the number of patients from areas where no one centre was dominant was less than one percent of the total, it is reasonable to assume that their impact on the Y values for each of the 50 individual centres is marginal, and can be ignored for the purposes of discussion.

Examination of Table 1 shows that eleven centres (22 percent) had values of Y greater than 95 percent. Twenty-nine centres (58 percent) had values of Y greater than 90 percent, with forty-four centres (88 percent) having values of Y greater than 80 percent.

The value of X reflects the degree to which a centre attracts patients from outside its “natural” catchment area, and hence specialist centres would show lower values because of the patients referred to them from other areas. The corollary is that a high value of X effectively illustrates a focus on mainstream treatments for local patients. Seventeen centres (34 percent) had values of X greater than 95 percent. Thirty-one centres (62 percent) had values of X greater than 90 percent, with forty-five centres (90 percent) having values of X greater than 80 percent.

A key issue from the results was that the main specialist centres, which are based in London, treated such low percentages of their local populations. Over 40 percent of patients from the catchment areas of both the Royal Free and University College London went elsewhere for treatment. It is inevitable that the question is asked about why such patterns are witnessed. From its ongoing contacts with the London radiotherapy community NatCanSAT infers that the main reasons are that:

- Within London there is a great deal of specialisation, which links to specialist cancer surgery, and therefore referrals are made to centres according to cancer site or treatment type;
- Patient choice is a factor: working patients may elect to be treated in the area that they commute to, rather than where they live; having many small centres in close proximity enables greater choice; and public transport links may make a geographically more distant centre more accessible than a local centre;
- Long-established clinical networks transcend geography, with certain suburban areas having flows into specific city-centre hospitals for historical reasons.

(H. Forbes, personal communication October 15, 2012)

4.2 Interpreting “Self-sufficiency”

In principle the author anticipated that there should be a high level of self-sufficiency in the established “natural” catchment areas because they had been created using data about actual patient flows, allocating census wards to the cancer centre where (most) patients were treated. It is reasonable to assume that most cancer centres will be interested in having a high value of Y from a marketing perspective, because they will each want to treat as many of the patients from within their own catchment area as possible. By comparison, the lower the value of X the more a centre is

attracting patients from outside its catchment area. However, as the concept of “self-sufficiency” is integral to the *NdiG*, the question posed is what percentage figure might represent “self-sufficiency” in the context of catchment areas relating to radiotherapy? For instance, it could be argued that a centre with a high value of Y alone is “self-sufficient”, irrespective of its value of X, because it treats nearly all patients from its own catchment area with few going elsewhere.

The results show that the aggregate X figure for England was 90 percent, with an aggregate Y figure of 91 percent (Y being slightly higher than X because of the patients from areas where no one centre was dominant). Therefore, for the purposes of discussion it is suggested that a centre having values of both X and Y of 90 percent, or greater, represents a practical definition for “self-sufficiency” for radiotherapy using the *NdiG* and its associated indicators; certainly, centres with such high values of X and Y operate largely independently of other centres. Twenty-five centres (50 percent) had values of X and Y both greater than 90 percent. Clearly, this is a topic that is open to interpretation and therefore this suggestion is made to promote debate.

There were seventeen centres (34 percent) that had values of X and Y both greater than 80 percent, but not both greater than 90 percent. Seven of the remaining eight centres were all in London; the other was the Peterborough and Stamford Hospitals’ centre which only opened in 2011/12. Each of the other two London centres had values of X and Y both greater than 80 percent, but not both greater than 90 percent. That none of the London centre’s catchment areas individually met the author’s 90 percent yardstick for self-sufficiency poses the question as to whether centre-specific catchment areas make sense within such a metropolitan context. It might be more appropriate for the patient flows of certain centres, which complement one another’s services, to be combined so that they relate to a collective catchment area. This would be a subject for further research.

4.3 Usefulness of the *NdiG*

It is important that the “natural” catchment areas for cancer centres are as robust as possible, given that they dictate the calculation of the catchment populations served (using Method A), which in turn influence service planning and modelling (Department of Health 1999; Department of Health 2012). What the analyses covered in this paper demonstrate is that the *NdiG* diagrammatically sets out the self-sufficiency situation of each centre’s catchment area in a way that can be readily interpreted visually, leading to the identification of those centres where there are marked patient flows across

boundaries. Having the table with the actual data and indicator values alongside the diagram(s) enables the provision of the associated detail.

The *NdiG* also serves to highlight the dynamics of patient flow relating to individual catchment areas, which was the original purpose for its development (Gandy 1979b). For example, two centres could be serving similar sized catchment populations, but one is very self-sufficient (i.e. few cross-boundary patients) and the other has significant but counterbalancing patient flows crossing its boundaries. The former centre is not as potentially susceptible to changes in market forces and patient flows as the latter, which is very important from a planning and marketing perspective. Such dynamics need to be appreciated when local services are being reviewed (e.g. by external parties such as the IAEA), particularly as the aforementioned factors of devolved radiotherapy services (Institute of Physics and Engineering in Medicine, Society and College of Radiographers, Royal College of Radiologists 2013), increased patient choice (Department of Health 2003; Department of Health 2010), and trends in the incidence of cancers requiring radiotherapy treatment come into play over time.

There is an implicit assumption that once “natural” catchment areas have been defined, using Method A, then they should be maintained for a given period. This is reasonable given that cancer centres need to know, or have a degree of certainty about, the area and population that they serve in order to develop robust business plans for several years ahead, encompassing data on the demography, cancer epidemiology and patient flows for their areas and populations. Similarly, consistency is important to underpin the aforementioned IAEA (2007) patient demographic data requirements. Trends in the *NdiG* patterns could point to where there might be significant changes in patient flows which justify consideration of whether the “natural” catchment areas of the centres affected need to be recalculated and redefined. Such action might be appropriate where there are changes in patient flows which are concentrated in certain locales, as opposed to being spread across the whole area.

Consequently the *NdiG* can act as a primary filter to monitor and evaluate the self-sufficiency of cancer centres which also highlights the dynamics relating to patient flows, thereby complementing NatCanSAT’s Method A (or Method B). The data required for the *NdiG* is basic, straightforward and easy to acquire, and the statistical indicators can be understood without difficulty in the context of radiotherapy.

The research represented an initial analysis of RTDS data using the *NdiG*. Repeat analyses for monitoring and trend purposes are for the future at the time of writing. However, it is known that the

NdiG can be used to show trends in a variety of ways: the first, and simplest, is to create the *NdiG* for each of however many time periods are being considered, place them consecutively alongside each other, and then look for any trends in the patterns; the second is to use one *NdiG* and show the patterns for (preferably) two periods using two sets of symbols; the third option is to use arrows, sequentially linking the relevant points on the *NdiG* (Gandy et al. 2011). Once *NdiG* analyses are programmed, the amount of cost and effort required to re-run them is considered minimal.

4.4 Transferability

This paper describes how the *NdiG* has been used to evaluate the self-sufficiency of “natural” catchment areas for radiotherapy in England, and can be used to monitor patient flow patterns over time. The methodologies applied by NatCanSAT (2010) in relation to “natural” catchment areas can be applied for any appropriate services that are delivered on a regional basis, in countries where relevant data is available, including postcode systems to help establish localised patient flows. Postcode systems, and their related precision, vary between countries (Da Cruz 2012; Wroblewski 2008), and the base area covered for censuses will also vary (Social and Spatial Inequalities Research Group 2004; United States Census Bureau 2013), with consequent implications for what might be the size of the smallest population unit that would be being attributed to each service provider in any given country. It would be inferred that the smaller the census area and population then the greater the resultant precision of the aggregate “natural” catchment area population calculated using NatCanSAT’s methodologies.

It follows that wherever such “natural” catchment areas are constructed and maintained for the purposes of service delivery and planning, then their ongoing self-sufficiency should be periodically monitored using the *NdiG*, in part to see if there are any trends in patient flows that need attention. The author considers that in principle the findings from the research are transferable for other public services which use catchment areas and populations, such as primary health care (NHS Choices, 2013), mental health services (Kinane and Gupta 2001), schools (Bedford Borough Council 2013; Noreisch 2007), prisons (Youth Justice Board 2013) and airports (Civil Aviation Authority 2011), subject to the availability of appropriate data. This will be the subject of further research.

5. Conclusions

The primary aim of the research has been established: that the *NdiG* analyses were readily interpretable in the context of radiotherapy catchment areas, and adequately reflected “self-sufficiency”. They appropriately display differentials between cancer centres, and have established and proven ways of demonstrating changes over time (Gandy et al. 2011). They highlight the dynamics in patient flows for individual “natural” catchment areas, and can be used to monitor trends, potentially pointing to centres where “natural” catchment areas need to be recalculated and redefined. The data used was appropriate, valid and available.

The catchment areas and population sizes of cancer centres are important for supporting planning and marketing, and enabling comparisons of the relative resources available to centres (Department of Health 1999; Department of Health 2012). Such planning and marketing needs to enable improvements in access, quality and productivity (NHS Improvement 2013a), and an understanding or appreciation of the volatility of patient flows relating to different catchment areas is key to risk analysis when considering future trends in radiotherapy services and referral patterns. The *NdiG* represents a high-level filter, which complements NatCanSAT’s existing methodologies, and uses simple, readily available data, to monitor and readily interpret self-sufficiency and patient flow dynamics across a large number of centres. In principle, the approach should be transferable for other public services which use catchment areas and populations.

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