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# Identifying Functional Regions in Australia Using Hierarchical Aggregation Techniques

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**Abstract**
This paper continues our work focused on developing a new socio-economic geography for Australia such that the chosen spatial aggregation of data is based on an analysis of economic behaviour. The underlying hypothesis is that the development of a geographical classification based on underlying economic behaviour will provide new insights into critical issues of regional performance, including unemployment differentials, the impact of industry, infrastructure and changes in local public expenditure on local labour markets. As a precursor to detailed work on the 2006 Census of Population and Housing data, we establish the proof of concept in this paper of the Intramax methodology using 2001 Journey-to-Work data from the Australian Bureau of Statistics (ABS) for the state of New South Wales. The functional regionalisation generated by the Intramax method is then tested using ABS labour force data. We compare 2001 ABS Census of Population and Housing data aggregated by the ABS labour force regions to the same data aggregated using our functional regions. The results demonstrate the potential value of this technique for the development of a new geography.

KEY WORDS *spatial aggregation; functional economic areas; intramax algorithm; spatial clustering*

## Introduction

This paper continues our work focused on developing a new socio-economic geography for Australia such that the chosen spatial aggregation of data is based on an analysis of economic behaviour (see Watts *et al.* 2006). The underlying hypothesis that has motivated this work is that the development of a geographical classification based on an analysis of labour market behaviour will provide new insights into critical issues of regional performance, including unemployment differentials, the impact of industry, infrastructure and changes in local public expenditure on local labour markets. A systematic understanding of levels of interaction between neighbouring areas, will facilitate an assessment of the adequacy of the administrative geographical demarcations currently used by the Australian Bureau of Statistics (ABS) to collect and disseminate their labour force data.

Recent Australian studies have analysed spatial patterns of unemployment, housing and related socio-economic phenomena using administratively-defined Australian Standard Geographical Classification (ASGC) spatial aggregations typically at the Statistical Local Area (SLA) and/or Statistical Region (SR) level (for example, O'Connor and Healy, 2002; Lawson and Dwyer, 2002; Baum *et al.*, 2005; Mitchell and Carlson, 2005; Yates, 2005; Yates *et al.*, 2006a; 2006b; Mitchell and Bill, 2006; Gregory and Hunter, 1995). Most Australian researchers are reluctant to acknowledge that the interpretation of these spatial data can be


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compromised by the Modifiable Areal Unit Problem (MAUP), although this problem has long been recognised by geographers. Openshaw (1984, 3) says that 'the areal units (zonal objects) used in many geographical studies are arbitrary, modifiable, and subject to the whims and fancies of whoever is doing, or did, the aggregating' and resulting analyses are fraught. In short, the spatial groupings must be justified so these aggregations should be based on informed choice. However the principles for grouping areas are not clearly defined. Indeed the 'optimal' grouping does not maximise an objective function, otherwise formal mathematical methods might be appropriate. Rather the problem is somewhat idiosyncratic and, ignoring any distance constraints, there are a very large number of possible solutions, given that none of the following are specified a priori: (a) the number of regions; (b) the number of SLAs in each region; and (c) the allocation of areas between the regions. This means that some form of algorithm is required, which is inevitably somewhat arbitrary in its specification.

Just as geographical regions may be defined by physical features, we hypothesise that a meaningful socio-economic geography should be defined by socio-economic features of space. It is most unlikely that that these 'regions' will correspond exactly to a demarcation based on administrative/political criteria. Significant issues arise when erroneous geography is used. First, a poorly delineated geography invokes measurement error. Thus, a local measure such as SLA unemployment, may be unrelated to socio-demographic and policy variables at a similar scale, and lead to spurious causality being detected and misguided policy conclusions being drawn. Second, analysing erroneously aggregated spatial data with standard statistical tools will yield results that may not only lack economic meaning but also suffer bias due to spatial correlation. Based on an earlier pilot study (Watts *et al.*, 2006) we hypothesise that studies relying on ABS administratively-based Census of Population and Housing areas or the Labour Force Survey regions produce misleading inferences when applied to socio-economic analysis or policy. Watts *et al.* (2006) found significant spatial correlation in key labour market variables and sensitivity to spatial aggregation, when they compared 2001 AGSC geography with experimental commuting areas generated using the 2001 Census of Population and Housing data.

Unfortunately, only limited attempts have been made in Australia to create such a 'space' (see Watts *et al.*, 2006). Journey-to-work (JTW) data provides information about the interaction between a large number of spatial units and is a useful basis for defining a functional regionalisation. The theoretical basis for demarcating regions based on commuting behaviour is outlined in Watts *et al.* (2006). It is applicable to any of the possible aggregation methodologies that are available. A region is conceived as a geographical area within which there is a high degree of interactivity (commuting by residents) and is thus the appropriate spatial scale to capture the interplay between labour supply and demand in a particular localised setting. These spatial markets result from both costs of mobility between jobs and the limitations of information networks (Hasluck, 1983). Employers and workers who interact within a functional region are assumed to be well informed and able to respond quickly to changes in market conditions relative to those outside any particular region. While Hasluck (1983) is critical of such an attempt to create regionalisations; on balance, we support Green (1997) who sees commuting clusters as revealing the boundaries of local labour demand and supply and hence as a sound basis for an 'an alternative geography' for labour market analysis.

Different terminology has been employed to identify these areas including *Commuting Areas*, *Local Labour Market Areas*, *Functional Labour Market Areas* and *Commuting Zones*. Early on, Berry (1968) referred to these aggregations as functional regions. In this paper and consistent with the *extant* literature (on intramax techniques) we use the term functional region to describe our regional aggregations based on JTW data. In this paper, and consistent with our conjecture above, we seek alternative aggregations of the JTW data which reflects economic behaviour (commuting interaction) rather than administrative structures.

Previous work by Watts (2004) and Watts *et al.* (2006) used a non-hierarchical, rules-based demarcation method first developed by Coombes *et al.* (1986) to determine a new 'behavioural-based' geography (for a detailed description of the method see Coombes *et al.*, 1986, 948–52 and Papps and Newell, 2002, 9–14). In summary, the Coombs *et al.* algorithm is based on: (a) the *a priori* specification of the magnitudes of a number of parameter values; and (b) a complex sequence of stages in which areas are identified as foci according to particular criteria, which are then combined according to a weighted interaction function and then further combined into temporary or proto groups of areas, again by reference to the interaction function and other criteria. These proto-groups are then entirely dismembered if the associated value of an objective (spline) function does not exceed a critical value.

There are two obvious shortcomings of the algorithm. First, the choice of foci and proto-groups as the sequence of steps is implemented is dependent on the set of arbitrarily specified parameter values. The sensitivity of the solution to these values is hard to gauge without extensive experimentation. Second, the dismemberment process would appear to generate a final set of groupings with numerous singleton groups, but also some very large groups, at least using Australian SLAs. A simplified version of the 1986 algorithm was first used on the 2001 UK Census data (Bond and Coombes, 2007), but these deficiencies appear to remain (Watts, 2009).

Figure 1 presents the mapping for New South Wales derived from Watts (2004). Spatial autocorrelation measures were calculated using unemployment rates at the postal area level in 2001, to examine the regions generated by Watts (2004), termed 'commuting areas' or local labour markets (LLMs). Global spatial autocorrelation indices are formal measures of the extent to which near and distant observation items are related. Global statistics can be decomposed to provide local measures of spatial association (LISAs), which reveal statistically significant clusters of above average values (*hotspots*) and statistically significant below average concentrations (*coldspots*) for the phenomena under investigation. LISA maps at the postal area level revealed considerable spatial heterogeneity in labour force outcomes, and highlighted a key motivation for the development of the new geography. They revealed that Statistical Region (SR) boundaries which roughly approximate ABS labour force geography conflate areas with statistically significant heterogeneity (that is both hotspots and coldspots), while finer commuting areas generally did not. However, as the Sydney 'commuting area' comprised the entire Sydney Metropolitan Area (see Figure 2) the 'commuting area' geography seems to miss much of the

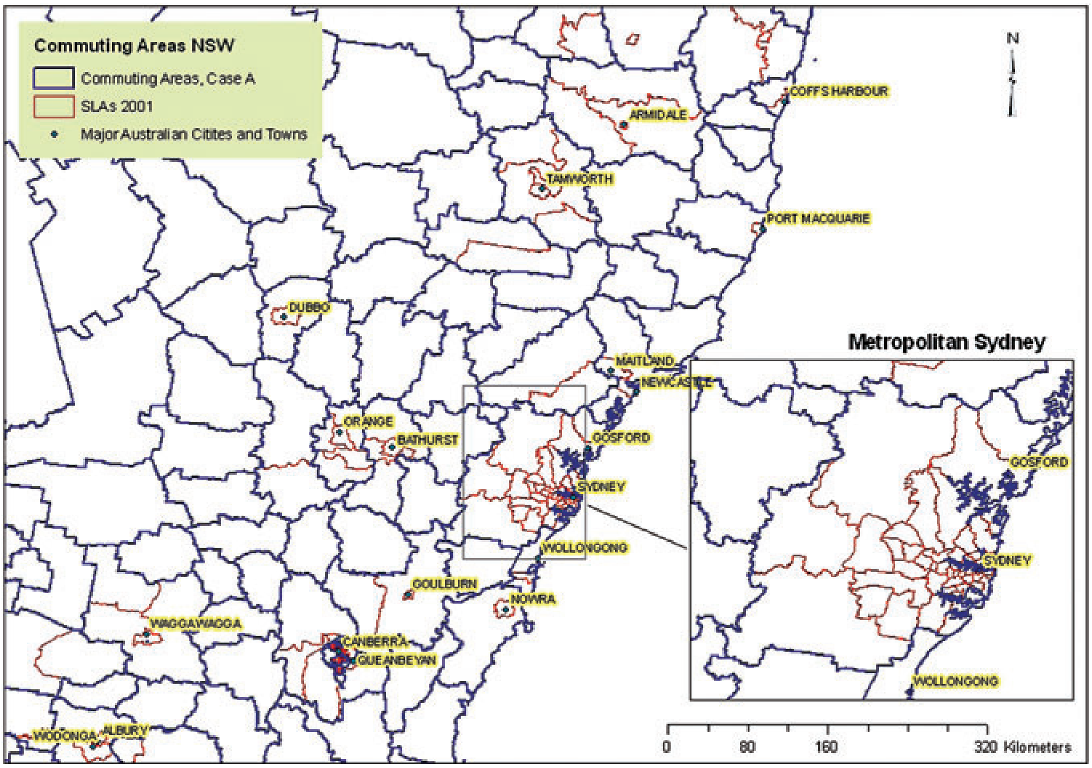


Figure 1 Functional regions for NSW derived using the rules-based Coombes approach.

significant (non-random) heterogeneity in labour market outcomes within Sydney. Notably it created a geography which conflated unusually low and statistically significant clustering of unemployment rates in the eastern and northern suburbs and clusters of unusually high unemployment rates in Sydney's inner and outer west.[1]

In this paper we take an alternative approach to functional regionalisation and deploy the Intramax method. JTW flows between areas can be depicted as a square matrix with each row denoting an origin (residential location) and each column representing a destination (workplace location) (see Table 1). The Intramax method is a hierarchical clustering algorithm (Masser and Brown, 1975) that maximises 'the proportion of the total interaction which takes place within the aggregation of basic data units that form the diagonal elements of the matrix, and thereby to minimise the proportion of cross-boundary movements in the system as a whole' (Masser and Brown, 1975, 510). Masser and Scheurwater (1980, 1361) say that the 'intramax procedure is concerned with the relative strength of interactions once the effect of variations in the size of the row and column totals is removed . . . relative strength is expressed in terms of the difference between the observed values and the values that would be expected on the basis of the multiplication of the row and column totals alone.'

The Intramax method is concerned with how the aggregation impacts on interaction flows (journeys) across the regional boundaries. The main diagonal elements of the JTW matrix represented in Table 1 (at any stage of aggregation), capture the journeys that begin and end in the same region, whereas the off-diagonal elements show journeys that cross regional borders. Masser and Brown (1975, 509) say that 'the most important distinction that must be made in the grouping procedure is between the proportion of interaction in the *diagonal* as against the *non-diagonal* elements of the basic flows matrix' (emphasis in original).

Barros *et al.* (1971, 140) refer to the 'strength of interaction' as the proportion of total journeys that cross regional boundaries. Clearly, as we aggregate smaller regions into larger (functional) regions, the proportion of interactions that cross boundaries should decline and a rising proportion of interactions thus would be considered intra-regional.

As a way forward, we seek to define our functional economic regions (based on labour market commuting behaviour), by maximising 'the proportion of the total interaction which takes place' between the individual regions and thus minimising 'the proportion of cross-boundary movements in the system as a whole' (Masser and Brown, 1975, 510).

The results reveal the Intramax technique to be a very useful for understanding the operation of the Sydney labour market and demarcating functional regions. At each stage of the clustering process fusion occurs between regions in such a way as to maximise commuting flows or interaction – providing valuable insight into those SLAs whose labour markets are most 'linked' in metropolitan and non-metropolitan New South Wales. Overall the technique collapses many of the standard labour force regions (used by the ABS in the dissemination of its statistics) in metropolitan Sydney (but preserves established distinctions between east and west) and splits many non-metropolitan labour force regions, particularly around major regional centres. An applica-

Table 1 JTW flow matrix with *j* regions.

| Destination<br>Origin | Region 1 | Region 2 | . . . | Region *j* | Total |
|---|---|---|---|---|---|
| Region 1 | 1 to 1 | 1 to 2 | . . . | 1 to *j* | $\sum_j a_{1j}$<br>Sum of flows out of Region 1 |
| Region 2 | 2 to 1 | 2 to 2 | . . . | 2 to *j* | $\sum_j a_{2j}$ |
| . . . | . . . | . . . | . . . | . . . | . . . |
| Region *j* | *j* to 1 | *j* to 2 | . . . | *j* to *j* | $\sum_j a_{jj}$ |
| Total | $\sum_i a_{i1}$<br>Sum of flows into Region 1 | $\sum_i a_{i2}$ | . . . | $\sum_i a_{ij}$ | $n = \sum_i \sum_j a_{ij}$<br>**Total Interaction** |

tion to 2001 Census of Population and Housing data reveals that, on average, regional unemployment rates are higher and labour force participation rates are lower when applying this new geography. The enhanced behavioural homogeneity of the functional regions also reduces the intra-region dispersion (measured by the standard deviation in unemployment rates). This suggests that the strength of commuting flows between contiguous areas is capturing the economic interaction between them.

The paper is organised as follows. The next section describes the data used in this study. We then outline the Intramax method of functional region demarcation. The following section presents the regionalisation based on the application of the Intramax method and analyses some of the implications of the resulting geography. Concluding remarks follow.

## Data

Australian Bureau of Statistics Journey to Work data from the 2001 Census of Population and Housing was used at the Statistical Local Area level for New South Wales and its cross border interactions (the area chosen to allow a direct comparison with Watts, 2004, which used the Coombes approach).[2] Using the 2001 JTW data cube from the ABS Census of Population and Housing, we deleted the following destination locations (columns): Sydney (undefined); no fixed address; migratory and off-shore; undefined New South Wales; not stated and not applicable. Lord Howe Island was also deleted. In addition, the corresponding residential (origin) locations were deleted (rows). The remaining JTW matrix thus had 197 SLAs. To protect confidentiality small flows are randomised by the ABS. Consequently all entries of less than 6 were set to zero.

To help in the explication of the Intramax technique, Table 1 provides a schematic representation of the square JTW flow matrix where the rows are designated as origins and the columns are destinations.

The summary details of the 197 × 197 matrix for NSW journey-to-work flows between SLAs are detailed in Table 2. Zero elements constitute 88 per cent of the JTW matrix (no commuting between pairs of places) which means that the 'network depicting the commuting patterns is relatively unconnected' (Brown and Holmes, 1971, 61), with many SLAs not being linked by commuting flows.[3]

## The Intramax method

The Intramax method considers the size of the interaction (JTW flows) to be 'of fundamental importance' (Masser and Brown, 1975, 510). To express this concern the method considers the 'interaction matrix', that is, the JTW matrix, to be a 'form of contingency table' and then formulates the 'objective function in terms of the differences between the observed and the expected probabilities that are associated with these marginal totals' (Masser and Brown, 1975, 510).

If we view Table 1 as a contingency table then the expected values of each element are derived as the product of the relevant column sum (Equation 3) multiplied by the ratio of the row sum (Equation 2) to total interaction (Equation 4). For example, the expected flow out of Region 2 into Region 1, $a_{21}$ in Table 1, where $a_{ij}$ is the element in row $i$ and column $j$ of the contingency table (JTW matrix), is given as

$$a_{21}^{*} = \sum_i a_{i1} \frac{\sum_j a_{2j}}{\sum_i \sum_j a_{ij}} = \sum_i a_{i1} \left( \sum_j a_{2j} / n \right) \quad (1)$$

This is the 'flow that would have been expected simply on the basis of the size of the row and column marginal totals' (Masser and Brown, 1975, 512).

The row sum of the JTW matrix is

$$a_{i*} = \sum_j a_{ij} \quad (2)$$

The column sum of the JTW matrix is

$$a_{j*} = \sum_i a_{ij} \quad (3)$$

The total interaction $n$ is the sum of the row sums

$$n = \sum_i \sum_j a_{ij} \quad (4)$$

Table 2 Summary JTW matrix characteristics and interactions

| | |
|---|---|
| Number of regions | 197 |
| Percentage of zero elements in JTW matrix (%) | 88 |
| Total interaction (trips) | 2,449,385 |
| Intra-regional interaction (trips) – Trace of matrix | 1,099,613 |
| Percentage of intra-regional trips (%) | 44.9 |

The null hypothesis for independence between the row and column marginal totals of a contingency table is defined as:

$$H_o : a_{ij}^{*} = \frac{\sum_j a_{ij} \sum_i a_{ij}}{n} = \frac{a_{i*}a_{j*}}{n} \quad (5)$$

If the grand total of the flows is normalised such that $n = 1$ and $a_{ij}^{*} = a_{i*}a_{*j}$ then Masser and Brown (1975, 512) note that 'the difference between observed and expected values $(a_{ij} - a_{ij}^{*})$ for the flow between zone *i* and zone *j* may be taken as a measure of the extent to which the observed flow exceeds (or falls below) the flow that would have been expected simply on the basis of the size of the row and column marginal totals.'

The objective function of the hierarchical clustering algorithm using a non-symmetrical JTW matrix, is defined as

$$\max I = (a_{ij} - a_{ij}^{*}) + (a_{ji} - a_{ji}^{*}), \quad i \neq j \quad (6)$$

In the Flowmap software[4], which was used to perform the Intramax, Equation (6) is modified as follows:

$$\max I = T_{ij} / (O_i D_j) + T_{ji} / (D_j O_i), \quad i \neq j \quad (7)$$

Where $T_{ij}$ is the interaction between the origin SLA *i* and destination SLA *j*; $O_i$ is the sum of all flows from origin *i* to *j*; and $D_j$ is the sum of all flows from destination *j* to origin *i*.

In relation to Equation (7), Goetgeluk and de Jong (2005, 9) say that 'the proportional amount of within group interaction is maximised in each step of the procedure . . . two areas are fused that have the strongest relative relations' in terms of commuting flows.

At each stage of the clustering process, fusion occurs between the regions that have the strongest commuting ties (interaction), as represented by Equation (7). The stepwise procedure then combines the clustered interaction and the matrix is reduced by a column and a row. The remaining actual and expected commuting flows are re-calculated and the *i*,*j* combination of regions maximising (7) is again calculated, and so on. With *N* regions (197 in our study) after *N*-1 (196) steps, all regions would be clustered into a single area (the state of New South Wales) and by construction, all interaction would be intra-zonal with one matrix element remaining. In contrast to the Coombes algorithm, there is no dismemberment of groups of regions during the operation of the algorithm.

Masser and Brown (1975) place a contiguity constraint on the maximisation process to eliminate the possibility that clusters between non-contiguous regions would form. There is very little chance that contiguity would not be satisfied in the Intramax clustering process. So as intra-zonal flow increases (at higher levels of the dissolution process) the newly forming clusters are almost certain to be contiguous. However, with respect to commuting, there is no logical reason why two non-contiguous regions could not belong to the same local labour market. The Intramax algorithm as well as other algorithms, would not identify that, in these circumstances, commuting entailed crossing a boundary out of the region and then re-entering the region, since only the identity of the origins and destinations would be recorded. Peculiarities of the housing, occupational and transport patterns overlaying employability could generate such a result. In our data, the contiguity constraint is not enforced but the results deliver functional economic regions with the constituent SLAs being contiguous.

**Results**

Regions with large relative JTW flows (as compared to the expected flows) are fused in the first stages of the clustering process and those with smaller relative intra-region JTW flows are fused in the later stages. Figure 2 produces a dendrogram for the Sydney MSR (excluding the Hunter) and Figure 3 produces a dendrogram for the Gosford-Hunter region.

Recall from the previous work of Watts *et al.* (2006) that the Coombes methodology, while yielding significant aggregations of SLAs, did not generate fine spatial demarcations of functional economic regions within the Sydney MSR. In this context, Figures 2 and 3 reveal some very interesting patterns. In the first stages of the aggregation process, the SLAs of Burwood and Strathfield fuse to form the basis of an inner-west Sydney cluster with the SLAs of Ashfield, Concord and Drummoyne (all of which are in the Inner Western Sydney Statistical Subdivision in the 2001 ASGC) and then collect the Leichardt SLA soon after. Around 58 per cent of all the JTW flows in and out of these clusters are intra-zonal for this new aggregation. The SLAs of Canterbury and Marrickville also fuse early and incorporate the Bankstown SLA soon after to form an inner south-west Sydney cluster. Around

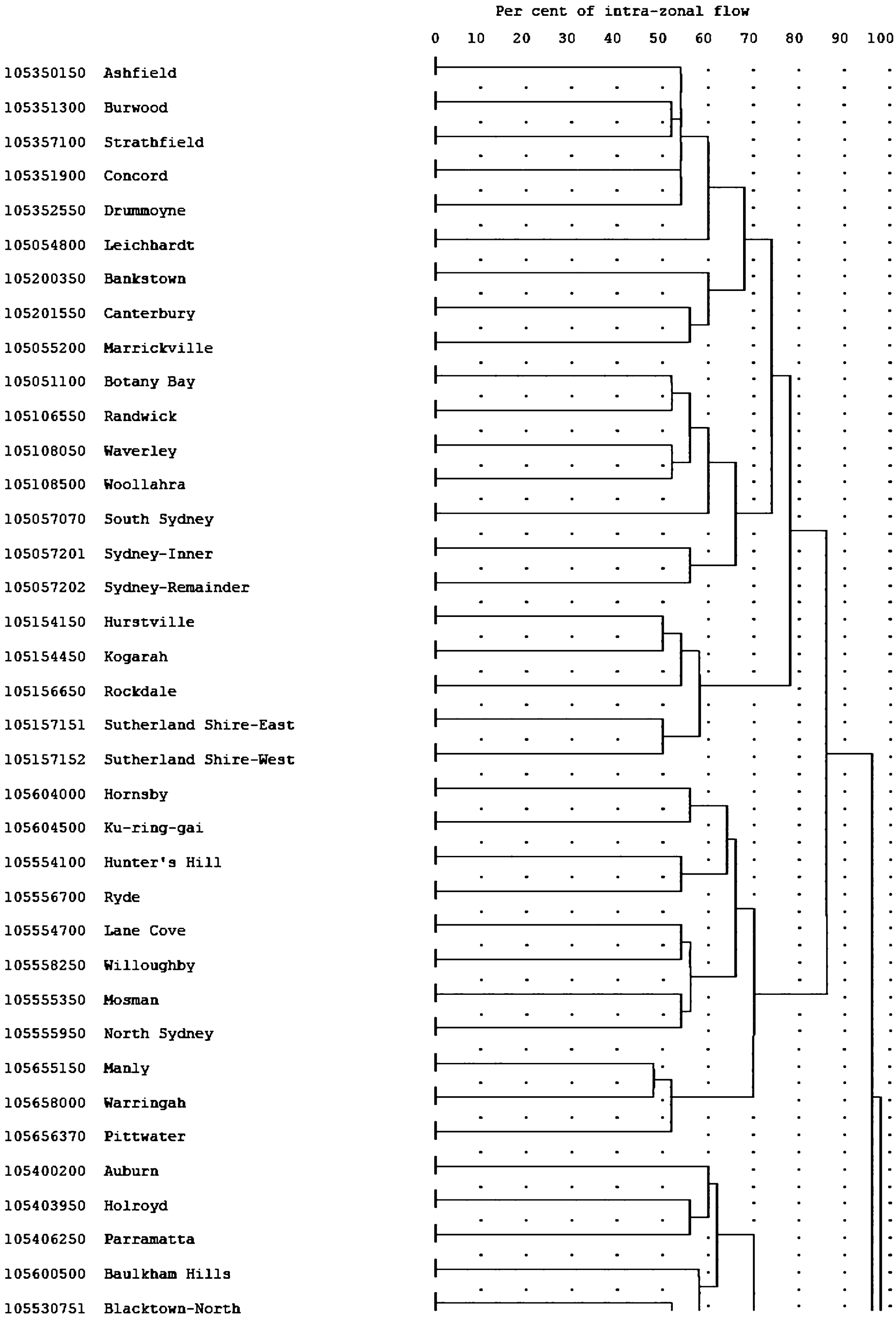


Figure 2 Dendrogram for Sydney-Illawarra.

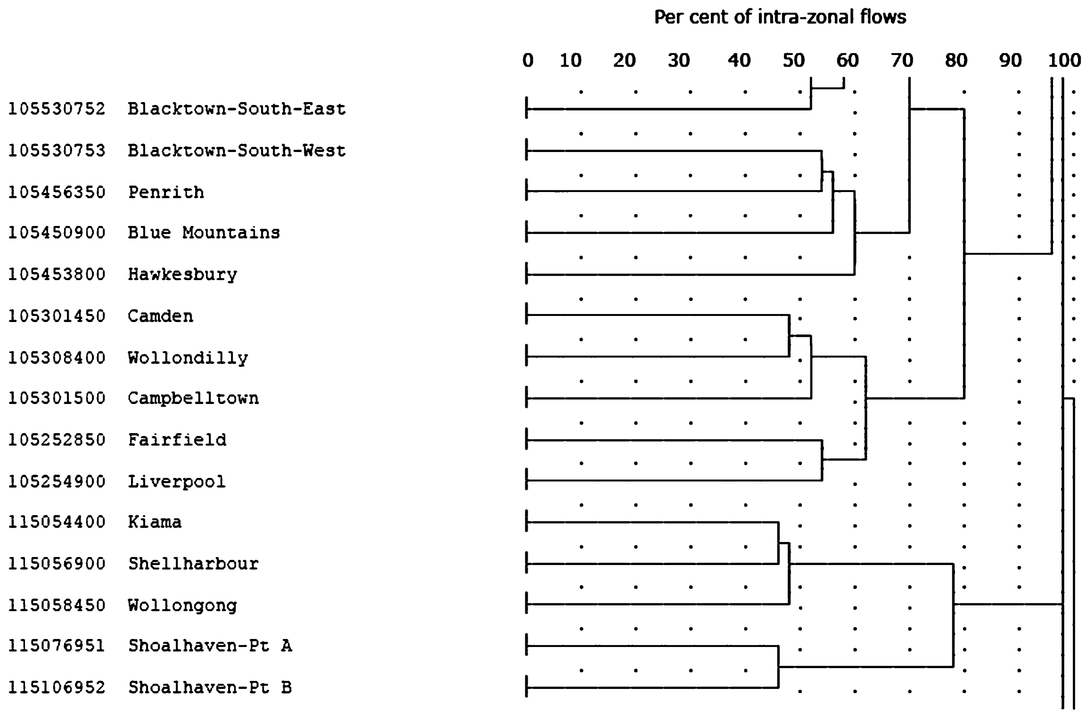


Figure 2 (*Continued*).

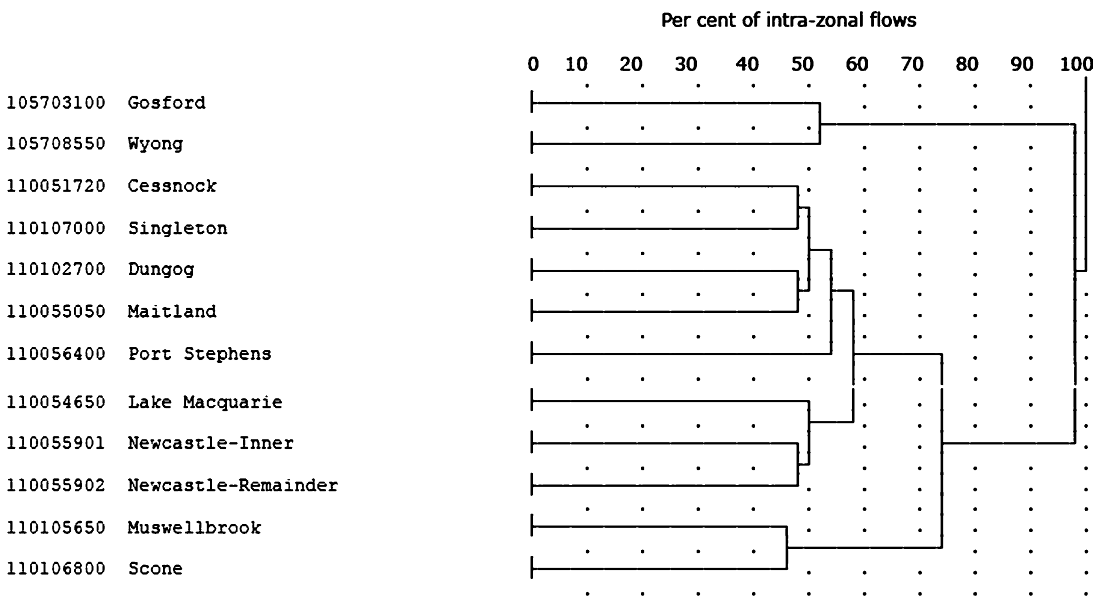


Figure 3 Dendrogram for Central Coast and Hunter functional regions.

55 per cent of the JTW flows in and out of these clusters are intra-zonal. Figures 4 to 7 map the subsequent clustering whereby the inner west and inner south-west fuse to form a new cluster and around 65 per cent of its total flows are intra-zonal.

To the south and east of the Sydney CBD, other clusters form. The Botany Bay SLA initially fuses with the SLAs of Randwick and Waverley with the Woollahara SLA. At this point intra-zonal flows in each constitute around 48 per cent of total flows. The two clusters fuse (52 per cent intra-zonal) then fuse again with the South Sydney SLA. In turn, this grouping fuses with Sydney CBD (the SLAs of Sydney-Inner and Sydney Remainder) and the new aggregation has around 65 per cent intra-zonal interaction. At a later stage of the grouping this entire block forms a new cluster and the proportion of intra-zonal JTW flows are around 78 per cent for this new group. There are still cross-boundary flows (22 per cent) but there is a strong sense of 'intra-action' in this grouping.

To the south-west, the SLAs of Kogarah and Hurstville fuse first as do the SLAs of Sutherland Shire-East and Sutherland Shire-West. The Rockdale SLA joins the first of these clusters and together they fuse with the Sutherland Shire cluster to form a 5 SLA cluster, quite distinct from the near inner south-west and inner-west and south and east clusters discussed above. This larger southern cluster has around 57 per cent of its total flows as intra-zonal. At a much later stage of the aggregation the southern cluster fuses with the previous cluster incorporating Sydney CBD, inner west and inner south-west and inner south and east to form a cluster where 80 per cent of the total flows are intra-zonal.

In the north, the SLA of Hornsby looks east to the Ku-ring-gai SLA and to the north-east the SLAs of Hunter's Hill and Ryde fuse (both clusters containing 50 per cent intra-zonal flows). These north and north-east clusters in turn fuse with about 60 per cent of their flows being intra-zonal. Closer to Sydney, on the north side, the SLAs of Lane Cove and Willoughby fuse as do the SLAs of Mosman and North Sydney (again with about 50 per cent of their total flows being intra-zonal). These clusters fuse and then fuse

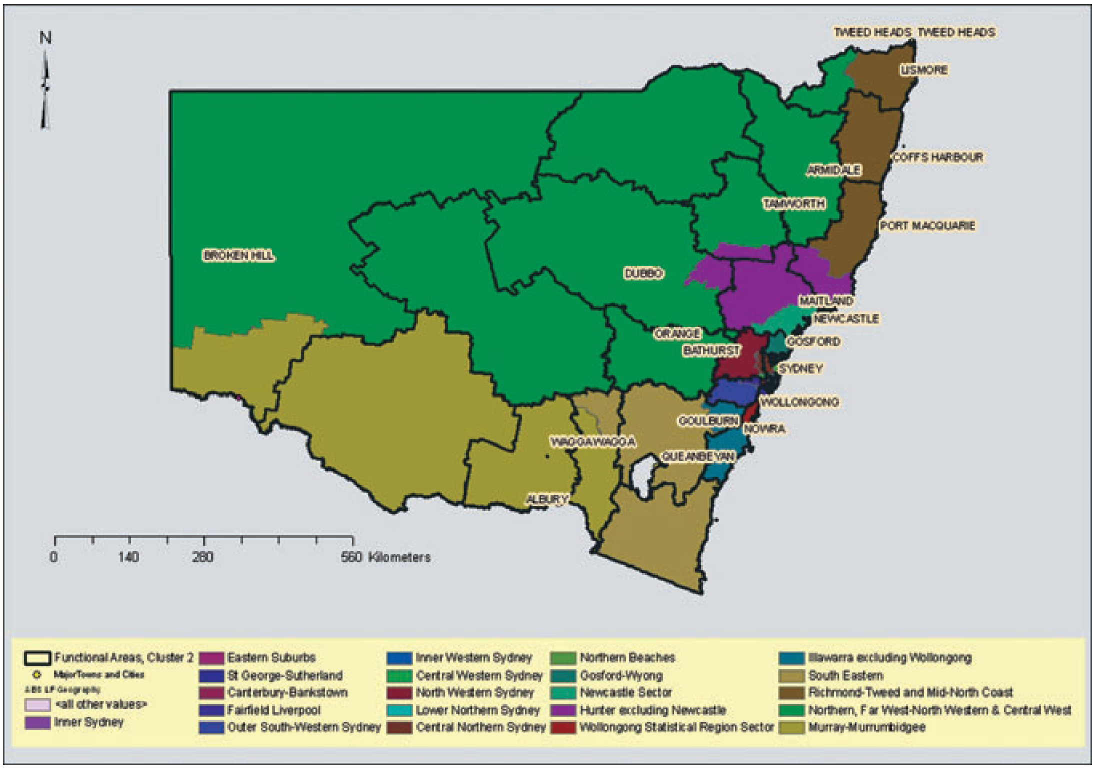


Figure 4 Comparison of ABS Labour Force Region geography and Functional Region Geography (Cluster 2), NSW (*Source*: ABS, JTW Custom matrix, 2001 and ABS, SLA to LF concordance 2004).

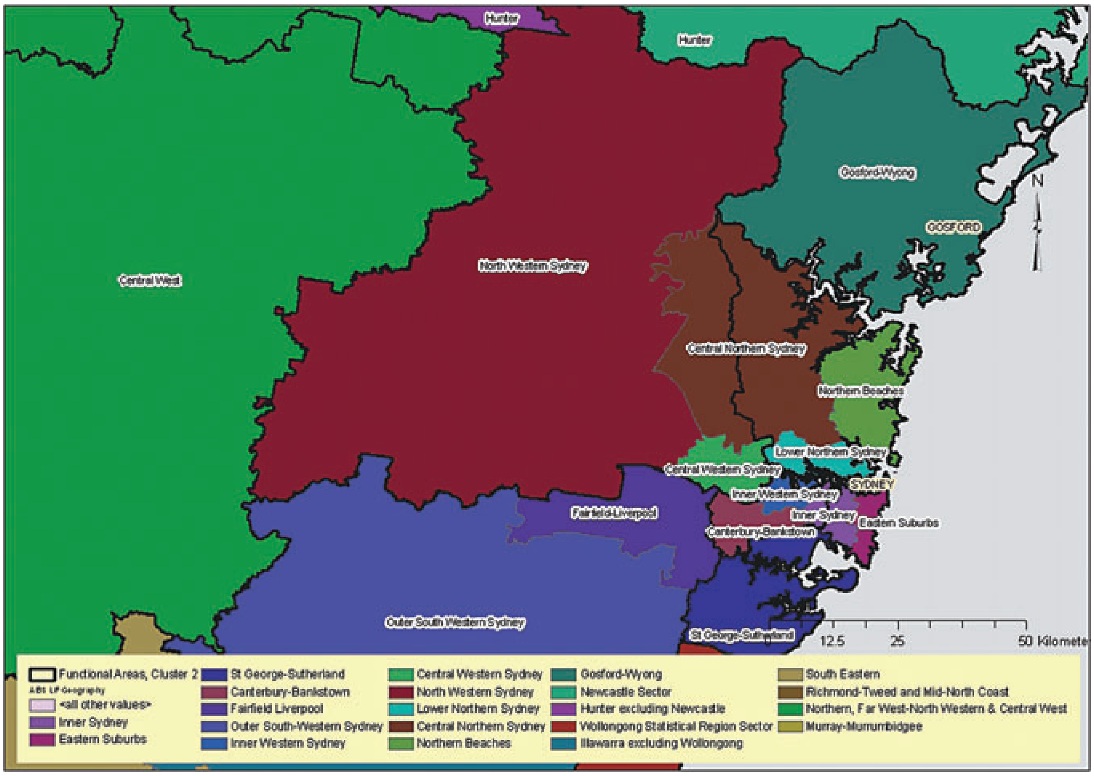


Figure 5 Comparison of ABS, Labour Force Region and Functional Region Geographies (Cluster 2), Sydney Metropolitan Region (*Source*: ABS, JTW Custom Matrix, 2001 and ABS, SLA to LF concordance 2004).

again with the north-east and northern cluster with about 60 per cent of their flows being intra-zonal.

Interestingly, nearby north-side SLAs, Manly and Warringah (east of the Pacific Highway) fuse early and then attract the Pittwater SLA which is further north along the coast. Together this new cluster of 3 northern coastal SLAs represents a definable cluster containing about 50 per cent of intra-zonal flows. They subsequently fuse with the other north/north-east cluster where about 60 per cent of total flows are intra-zonal.

At a later stage of the clustering process the north/north-west regions fuse with cluster south/south-west/east including the Sydney CBD to form a larger cluster where the proportion of intra-zonal flows exceeds 80 per cent. This is a strongly defined cluster.

A further interesting point is that the SLAs in the outer western parts of the Sydney Metropolitan Statistical Region – the SLAs of Holroyd and Parramatta fuse and then look south to fuse with the Auburn SLA. Similarly, the SLAs of Blacktown-North and Blacktown-South fuse first then look north-east and fuse with the Baulkham Hills SLA. These two larger clusters in turn aggregate and the percentage of intra-zonal flows to total flows for this new cluster exceeds 55 per cent.

Nearby, the SLA of Blacktown-South West looks further to the west and fuses with the Penrith SLA and this cluster fuses further to the west with the Blue Mountains SLA and to the north with the Hawkesbury SLA. About 55 per cent of the total flows of this new cluster are intra-zonal. This north-western/western cluster aggregates into the Holroyd/Parramatta/Blacktown-North and South and Baulkham Hills cluster with 65 per cent of intra-zonal flows.

Further to the south-west, the SLAs of Camden and Wollondilly fuse, then fuse with the Campbelltown SLA. The SLAs of Liverpool and Fairfield also fuse. These two south-western clusters aggregate to form a well-defined south-west cluster with about 55 per cent intra-zonal flows.

In turn, at the next significant grouping stage this south-west grouping aggregates with the

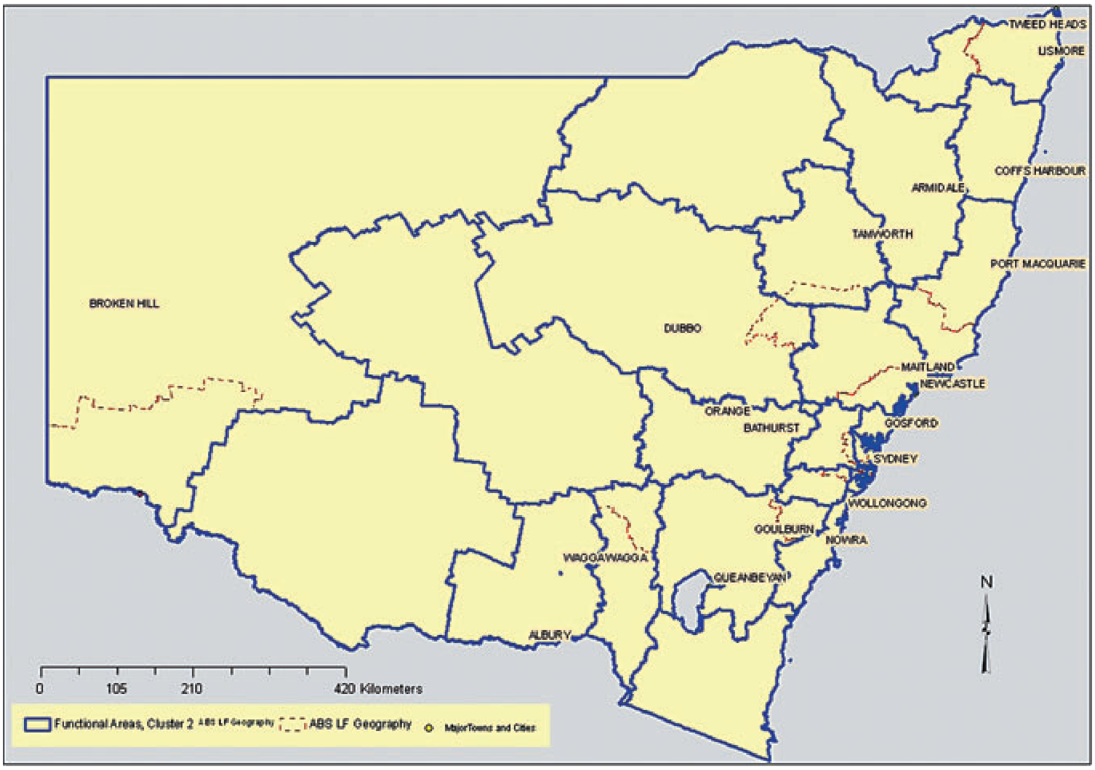


Figure 6 Comparison of ABS Labour Force Region geography and Functional Region Geography (Cluster 2). NSW (*Source*: ABS, JTW Custom Matrix, 2001 and ABS, SLA to LF concordance 2004).

north-west/outer-west cluster to form a strongly defined grouping in outer Sydney and about 70 percent of total flows are intra-zonal. When this south-west cluster eventually aggregates with the other large Sydney cluster some 90 per cent of total flows for this large region are intra-zonal.

The Illawarra SLAs are quite distinct. The SLAs of Kiama and Shellharbour fuse as do the SLAs of Shoalhaven-Part A and Shoalhaven-Part B. The Kiama/Shellharbour cluster fuses with the Wollongong SLA and then with the Shoalhaven pair. At this level of aggregation, intra-zonal flows constitute about 70 per cent of total flows for this Illawarra region. This region clusters with the large Sydney region at around 92 per cent intra-zonal, just after the big outer west/south-west cluster fuses with the larger Sydney cluster.

Of interest is the way in which the SLA of Wingecarribee (part of the Illawarra Statistical Division) stands separate with around 78 per cent of its total flows being intra-zonal and looks further south into the rural SLAs of Boorowa, Gunning, Yass, Queanbeyan, and the ACT to form a larger cluster.

Another interesting result is associated with the SLAs belonging to the Gosford and Hunter region (see Figure 3). The SLA of Gosford is typically considered to be part of the Sydney metropolitan area (Watts *et al.*, 2006) but these results challenge that assertion. The SLAs of Gosford and its northern neighbour, Wyong, initially fuse to make a cluster with 52 per cent of total flows intra-zonal. The SLAs of Cessnock and Singleton fuse as do the SLAs of Dungog and Maitland and these two clusters fuse to form a new grouping (with 50 per cent of its total flows intra-zonal). The SLA of Port Stephens looks west to this cluster first. The SLAs of Newcastle Inner and Newcastle Remainder fuse first then look south to fuse with the Lake Macquarie SLA. This aggregation then fuses with the lower Hunter cluster (including the SLA of Port Stephens). This new functional region has about 58 per cent of its total flows intra-zonal). The Upper Hunter SLAs – Muswellbrook and Scone – fuse (48 per cent intra-zonal) and fuse with the lower Hunter/Lake Macquarie cluster (74 per cent intra-zonal).

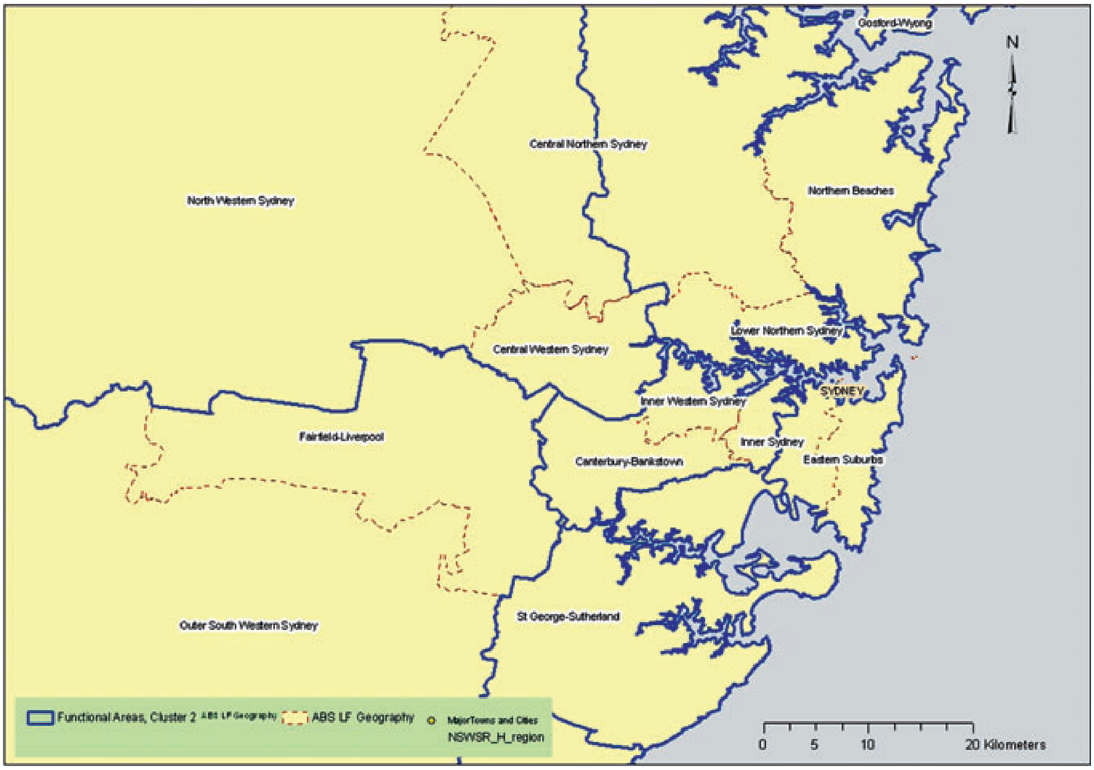


Figure 7 Comparison of ABS Labour Force Region geography and Functional Region Geography (Cluster 2), Sydney Metropolitan Region (*Source*: ABS, JTW Custom Matrix, 2001 and ABS, SLA to LF concordance 2004).

The Upper Hunter SLA of Gloucester looks north to the fusion between the SLAs of Taree and Great Lakes and these in turn form a mid-north coast/hinterland cluster with the SLAs of Hastings, Kempsey and Nambucca (88 per cent intra-zonal). They further aggregate north rather than south. These results clearly indicate that the SLA of Gosford looks northwards rather than southwards in terms of its dominant commuting interaction.

To render the concept of functional regions operational, some level of clustering (number of steps) has to be chosen and the resulting regionalisation defined. The exact point at which we stop the algorithm is a matter of judgement and cannot be determined in any rigid way.[5] A convention adopted in the literature is to define a 'stop criterion' as some level of clustering (number of steps) where homogeneity within a cluster is lost. Goetgeluk (2006, 11) states that a large increase in the intra-zonal flows during the fusion process does not generally indicate 'a merger of two rather homogenous zones.' The 'stop criterion' would thus use the regionalisation that was defined 'just before the high increase in intra-zonal flows'.

We can determine this point from an examination of the dendrogram and the fusion report (summarised in Table 3) provided by the Intramax process. Prior to the start of the fusion process, Table 2 tells us that the total number of intra-zonal flows is 1,099,613, representing marginally under 45 per cent of all the commuting flows (trips). Table 3 presents a truncated version of the fusion report for the Intramax process starting at Step 69 (which involved the fusion of the two Newcastle SLAs and was the first significant jump in the cumulative intra-zonal interaction). The large jumps or 'break points' in the fusion output occur when there are significant increases in the cumulative intra-zonal interaction as a result of a fusion. These start occurring from Step 168, then Steps 170, 174, 176 and 182. In terms of Steps 168 and 170 these involve the inner west clustering with the inner south (168) and then the Sutherland Shire clustering with the inner south (170). Further analysis is required to determine

Table 3 Fusion report for the Intramax aggregation process, NSW SLAs 2001.

| Step | Dissolved Area | | Enlarged Area | Percentage Intrazonal Interaction | Cumulative Intrazonal Interaction | No of Regions |
|---|---|---|---|---|---|---|
| 0 | | | | 44.89 | 44.89 | 197 |
| 69 | Newcastle-Inner | -> | Newcastle-Remainder | 0.3% | 47.4% | 128 |
| 87 | Shellharbour | -> | Wollongong | 0.7% | 48.5% | 110 |
| 92 | Lake Macquarie | -> | Newcastle-Remainder | 1.3% | 50.3% | 105 |
| 93 | Sutherland Shire-West | -> | Sutherland Shire-East | 0.4% | 50.8% | 104 |
| 101 | Wyong | -> | Gosford | 0.5% | 51.9% | 96 |
| 105 | Pittwater | -> | Warringah | 0.4% | 52.4% | 92 |
| 106 | Camden | -> | Campbelltown | 0.3% | 52.7% | 91 |
| 122 | Blacktown South-West | -> | Penrith | 0.3% | 53.9% | 75 |
| 127 | Liverpool | -> | Fairfield | 0.4% | 54.6% | 70 |
| 133 | Holroyd | -> | Parramatta | 0.4% | 55.2% | 64 |
| 134 | Blue Mountains | -> | Penrith | 0.3% | 55.5% | 63 |
| 136 | Willoughby | -> | North Sydney | 0.4% | 56.2% | 61 |
| 138 | Waverley | -> | Randwick | 0.4% | 56.7% | 59 |
| 140 | Cessnock | -> | Newcastle-Remainder | 0.9% | 57.8% | 57 |
| 141 | Hurstville | -> | Sutherland Shire-East | 0.6% | 58.4% | 56 |
| 142 | Baulkham Hills | -> | Blacktown South-East | 0.4% | 58.8% | 55 |
| 144 | South Sydney | -> | Randwick | 0.9% | 59.7% | 53 |
| 148 | Auburn | -> | Parramatta | 0.3% | 60.1% | 49 |
| 151 | Bankstown | -> | Canterbury | 0.3% | 60.7% | 46 |
| 152 | Campbelltown | -> | Fairfield | 0.7% | 61.4% | 45 |
| 154 | Blacktown South-East | -> | Parramatta | 1.5% | 62.9% | 43 |
| 157 | Ryde | -> | Hornsby | 0.4% | 63.3% | 40 |
| 158 | Sydney-Inner | -> | Randwick | 1.8% | 65.2% | 39 |
| 161 | North Sydney | -> | Hornsby | 1.2% | 66.5% | 36 |
| 163 | Penrith | -> | Parramatta | 2.0% | 69.2% | 34 |
| 165 | Warringah | -> | Hornsby | 1.1% | 70.4% | 32 |
| 168 | Canterbury | -> | Randwick | 3.7% | 74.0% | 29 |
| 170 | Sutherland Shire-East | -> | Randwick | 3.8% | 77.9% | 27 |
| **173** | **Shoalhaven-Pt A** | **->** | **Wollongong** | **0.1%** | **78.0%** | **24** |
| 174 | Fairfield | -> | Parramatta | 2.1% | 80.2% | 23 |
| 176 | Hornsby | -> | Randwick | 6.3% | 86.4% | 21 |
| 182 | Parramatta | -> | Randwick | 10.4% | 96.9% | 15 |
| 183 | Gosford | -> | Newcastle-Remainder | 0.4% | 97.2% | 14 |
| 190 | Wollongong | -> | Randwick | 0.9% | 98.2% | 7 |
| 191 | Newcastle-Remainder | -> | Randwick | 1.3% | 99.6% | 6 |
| 195 | Hastings-Pt A | -> | Randwick | 0.2% | 99.8% | 2 |
| 196 | Orange | -> | Randwick | 0.7% | 100.00% | 1 |

*Source*: ABS, JTW custom matrix, 2001. Percentages are rounded up so may not add up to 100%.

whether these pre-clustered regional aggregations are interactive enough to be classified as functional regions in their own right. We suspect not at this stage and, as a consequence, we considered Step 173 to be a reasonable stop point such that 78 per cent of flows were now considered intra-zonal by this regionalisation and 24 clusters emerge as distinct functional regions. In making this decision, we decided that the fusion determined by Step 174 (outer south-west with west) was creating an aggregation that probably blurred important labour market differences. This is pure conjecture at this stage and further analysis of occupation and industry data is required to test its veracity.

We identified 3 useful regionalisations that will provide the basis for further analysis and testing. Cluster 2 (24 regions and 78 per cent cumulative intra-zonal flows), which is our preferred stopping point in this paper, is the intermediate level. Cluster 1 defined 40 functional regions with cumulative intra-zonal flows marginally over 63 per cent, whereas Cluster 3 defined 15 regions with cumulative intra-zonal flows marginally under 97 per cent. The judgment as to whether one of these Clusters is useful would be based on whether the resulting between regional variance of labour market variables, such as unemployment and labour force participation, represented a significantly greater share of the total variance than those defined according to administrative boundaries. However these measures are aspatial.

The maps in Figures 4 to 7 compare the Functional Regions (Cluster 2) generated above with the standard ABS Labour Force areas (which roughly conform to Australian Standard Geographical Classification Statistical Regions), used to disseminate regional statistics from the Labour Force Survey (see ABS, 2004).[6] In aggregate for New South Wales approximately the same number of regions exists under both systems: 21 Labour Force regions and 24 Functional Regions. However the spatial distribution of these regions is significantly different between the two geographies.

Three general points can be made: (a) Many more regions are generated in non-metropolitan NSW when using the Functional Regions, particularly in the north and north-west, compared to the standard Labour Force areas; (b) Large regional towns (such as Wagga Wagga, Albany and Dubbo) emerge as epicentres of functional regions; and (c) Fewer functional regions emerge in Sydney than currently exist as the standard ABS Labour Force areas.

Other more specific comments include:

1. The Functional Region geography divides Inner Sydney in two and combines Eastern Suburbs and Inner Sydney to form one eastern Sydney suburban Functional Region (see Figures 3 and 5);
2. Canterbury Bankstown, Inner western Sydney and eastern Inner Sydney combine to form an inner-west functional region;
3. Fairfield Liverpool and outer South Western Sydney Statistical Regions (SRs) combine to form an outer South Western Sydney functional region;
4. Central Western Sydney SR, North Western Sydney SR and Central Northern Sydney SR (east side) combine to form one Western Sydney functional region;
5. Wollongong Statistical Region Sector and Nowra SR form one functional region along the south coast;
6. Part of Illawarra SR (excluding Wollongong) combines with Goulburn; Wingecarribee combines with the South Eastern SR to form one functional region;
7. Newcastle statistical region sector and Hunter combine to form one functional region;
8. The Hunter SR divides at Gloucester/Great Lakes to combine with Port Macquarie to form a mid-north coast functional region (extending to Nambucca);
9. A functional region emerges in Dubbo and surrounds (formerly part of the Northern, Far-West North Western SR), also incorporating Merriwa, formerly in the Hunter SR;
10. Orange and Bathurst and surrounds (part of the Central West SR) form one functional region;
11. Murray-Murrumbidgee SR splits into four separate functional regions: one situated in the far north west in Wentworth and surrounds; one encompassing Hay and the Murray Murumbidgee region; one situated in and around Albury and one in Wagga Wagga and surrounds;
12. The Far West North Western SR is broken into eight Functional Regions. Tenterfield combines with Richmond Tweed (Lismore) SR to form one functional region; a functional region emerges around Armidale and one around the Tamworth, as well as separate functional regions encompassing Dubbo and Broken Hill, and their surrounds. In the south east of the Central West SR a functional region emerges around Bathurst. Cobar (Far West North West) combines with Lachlan, Parkes, Bland, Forbes, and Weddin all regions formerly in the Central West SR to form one functional region. Finally part of the Northern SR forms one functional region encompassing the towns of Walgett, Narrabri, Moree Plains, Bingara and Yallaroi.
13. Murrurundi (formerly part of the Hunter SR), merges with part of the Northern Far-North Western (encompassing Manilla, Barraba and Gunnedah) to form a functional region;
14. The SR of Richmond Tweed and Mid North Coast separate to form three functional regions, one situated around Lismore and surrounds (combining with Tenterfield as mentioned), another encompassing Coffs Harbour and surrounds and a third centred on Port Macquarie (and combining with

Gloucester/Great Lakes in the south, formerly part of the Hunter SR).

## Comparison of labour force estimates

Table 4 uses 2001 Census of Population and Housing data to compare measures of unemployment, labour force participation and the ratio of part-time to full-time employment generated using the ABS labour force region geography and the Functional Region geography.[7] The results indicate that, on average, the design of the ABS labour force regions is such that these geographies tend to produce lower estimates of the unemployment rate and higher estimates of labour force participation when compared to those of the newly created functional regions. Measures of standard deviation in unemployment rates indicate that there is less dispersion between SLAs comprising a functional region a compared to that in those SLAs in a labour force region. The intra-regional deviation in rates is 1.8 for the functional regions compared to 2.1 for the labour force regions, which suggests that unemployment rates within this new geography are much more alike, or homogeneous. While it is difficult to assert the primacy of one geography over another, the particular groupings of SLAs devised by the ABS for the dissemination of its labour force statistics are not as internally homogeneous as are those of the Functional Regions devised using the Intramax technique. The pattern of the ABS labour force regions is principally based on the need to maintain statistical reliability and this requires equal distribution of population and labour force[8]. The outcome of this is the proliferation of LF regions in metropolitan Sydney versus non-metropolitan NSW. The important point to note is that the MAUP problem may be resulting in tangible differences in measures of regional labour force outcomes. Keeping in mind the need to ensure statistical reliability in regional estimates, the particular delineation of spatial boundaries deserves serious consideration in the dissemination of Australian labour force statistics.

## Conclusion

In exploring the best way to delineate regional labour markets such that the resulting geography has inherent 'economic meaning' we have developed spatial demarcations (termed functional regions) based on a hierarchical aggregation technique known as Intramax. This technique is applied to Journey to Work data which explicitly captures the economic interactions of firms and workers across space. The technique, in all three stages of clustering, delivers very interesting results. It establishes a new geography representing the space over which supply (workers) and demand (firms) are seeking to interact as shown by the maximisation of commuting flows. It also helps us to better understand the ways in which the regions are linked, as illustrated by the hierarchy visible in the dendrograms. The latter application is particularly useful within metropolitan areas where labour market flows have previously been represented by sizeable matrices of data, which are difficult to order and comprehend. The hierarchical aggregation technique clearly indicates which regions are connected by their labour market flows and the order in which they connect. This has obvious applications for planners and policy makers broadly interested in regional interactions (in terms of economic activity and housing), as well as those expressly interested in labour market problems.

The Intramax technique emphasises labour force flows and optimises SLA groupings based on higher than expected interactions between neighbouring areas (regions), and appears to provide a much closer approximation of a local labour market. Mapping the 24 functional regions (cluster 2) provides an informative critique of the current labour force area designations. These functional regions generally collapse metropolitan and split non-metropolitan labour force regions (with the splits often centred around major regional towns). This would suggest the need, perhaps, for the ABS to reassess its current labour force area designations (keeping in mind its requirements for statistical reliability in delivering regional estimates from a national survey). The functional region pattern outlined in this paper reduces intra-region dispersion in unemployment rates, which is to say that this technique tends to group areas that are more homogeneous. A simple application using 2001 Census of Population and Housing data reveals that, on average, the emerging unemployment rates are higher and labour force participation rates are lower than those of the standard labour force regions, an indication that the MAUP problem may be resulting in observable differences. Given that ABS regional labour force estimates are widely used by policy makers and practitioners it is important that these findings are given due consideration.

Further work remains to be done in applying this technique to the 2006 Census of Population and Housing data to develop an updated geogra-

Table 4 Comparison of ABS, Functional Region and Labour Force Region Geographies, 2001.

| Functional Region Geography | UR | LFP | PT/FT Emp. | Standard Deviation (UR rate) | Labour Force Region Geography | UR | LFP | PT/FT Emp. | Standard Deviation (UR rate) |
|---|---|---|---|---|---|---|---|---|---|
| | % | % | % | | | % | % | % | |
| Canterbury-Bankstown | 6.9 | 62.2 | 39.7 | 1.8 | Inner Sydney | 6.2 | 70.6 | 36.5 | 1.2 |
| South Sydney, Inner Sydney | 5.5 | 68.5 | 39.8 | 1.3 | Eastern Suburbs | 4.8 | 67.7 | 42.6 | 0.9 |
| Hurtsville, Kogarah and Sutherland Shire | 4.5 | 65.8 | 44.9 | 1.3 | St George Sutherland | 4.5 | 65.8 | 44.9 | 1.3 |
| Lower Northern Sydney, Eastern Central Northern Sydney and Northern Beaches | 3.7 | 68.0 | 46.7 | 0.5 | Canterbury-Bankstown | 8.4 | 56.8 | 40.7 | 0.7 |
| Hawkesbury, Blacktown, Blue Mountains and Baulkham Hills | 6.4 | 65.6 | 42.4 | 2.6 | Fairfield Liverpool | 10.6 | 59.1 | 37.1 | 3.1 |
| Fairfield-Liverpool and Outer South Western Sydney | 9.0 | 62.4 | 39.6 | 3.4 | Outer South Western Sydney | 7.0 | 67.4 | 43.0 | 2.3 |
| Wollongong and Shoalhaven | 9.4 | 56.6 | 57.4 | 2.1 | Inner Western Sydney | 5.4 | 63.4 | 40.8 | 1.6 |
| Yass and Yarrowlumla | 5.3 | 64.0 | 50.8 | 1.9 | Central Western Sydney | 8.1 | 60.0 | 39.5 | 2.6 |
| Goulburn | 8.4 | 58.0 | 64.7 | 3.8 | North Western Sydney | 6.5 | 66.7 | 43.0 | 2.1 |
| Gosford-Wyong | 8.5 | 56.8 | 58.4 | 1.9 | Lower Northern Sydney | 3.9 | 68.8 | 39.1 | 0.5 |
| Newcastle and Port Macquarie | 9.8 | 58.3 | 58.4 | 1.9 | Central Northern Sydney | 3.6 | 68.2 | 50.6 | 0.4 |
| Great Lakes and Hastings | 12.7 | 48.6 | 70.0 | 3.7 | Northern Beaches | 3.4 | 69.6 | 49.8 | 0.4 |
| Coffs Harbour and Grafton | 13.5 | 52.9 | 71.7 | 2.4 | Gosford-Wyong | 8.5 | 56.8 | 58.4 | 1.9 |
| Tamworth & Surrounds | 8.9 | 60.2 | 50.1 | 2.4 | Newcastle Sector | 10.2 | 57.6 | 60.3 | 0.9 |
| Armidale & Surrounds | 8.9 | 58.5 | 54.3 | 2.0 | Hunter excluding Newcastle | 8.2 | 56.3 | 52.5 | 1.8 |
| Narrabri, Moree Plains and Surrounds | 9.3 | 64.0 | 44.8 | 2.3 | Wollongong Statistical Region | 9.0 | 58.7 | 54.8 | 1.9 |
| Richmond-Tweed and Tenterfield | 12.4 | 53.3 | 69.8 | 1.7 | Illawarra excluding Wollongong | 8.8 | 53.0 | 65.7 | 3.5 |
| Dubbo and Surrounds | 7.6 | 61.0 | 47.3 | 1.5 | South Eastern | 6.8 | 61.7 | 54.1 | 2.9 |
| Lachlan, Forbes, Parkes and Colbar | 7.0 | 60.8 | 44.4 | 1.2 | Richmond-Tweed and Mid-North Coast | 12.9 | 52.0 | 70.5 | 2.3 |
| Orange, Lithgow and Surrounds | 7.7 | 61.3 | 49.7 | 2.1 | Northern, Far West-North Western and Central West | 8.3 | 60.5 | 49.0 | 2.3 |
| Wentworth and Central Dowling | 9.9 | 56.4 | 51.2 | 3.7 | Murray-Murrumbidgee | 6.3 | 63.7 | 46.6 | 1.7 |
| Tumut, Gundagai and Surrounds | 6.4 | 60.0 | 46.6 | 1.1 | | | | | |
| Albury, Hume and Surrounds | 7.2 | 63.5 | 49.5 | 1.6 | | | | | |
| Murray-Murrumbidgee and Surrounds | 4.9 | 64.9 | 42.4 | 1.6 | | | | | |
| **Standard Deviation** | ***2.5*** | ***4.8*** | ***9.6*** | | **Standard Deviation** | ***2.4*** | ***5.5*** | ***9.2*** | |
| **Average (of regions)** | ***8.1*** | ***60.5*** | ***51.4*** | 1.8 | **Average (of regions)** | ***7.2*** | ***62.1*** | ***48.5*** | 2.1 |
| **Average (in aggregate)** | **7.2** | **62.2** | **47.6** | **3.4** | **Average (in aggregate)** | **7.2** | **62.2** | **47.6** | **3.4** |

*Source*: ABS, Census of Population and Housing, 2001.

phy. Exploring the occupation dimensions of these local labour markets (see Bill, Mitchell and Watts, 2008) may also be a useful future application of the method demonstrated here.

NOTES

1. Subsequent analysis reveals that a different parameterisation of the rules-based Coombes algorithm can yield more spatially disaggregated commuting areas in the Sydney Metropolitan Area. The authors will publish a comparative analysis of these two techniques in due course.
2. Watts (2004) developed a regional demarcation for NSW based on the Coombes *et al*. algorithm (Coombes *et al.*, 1986), but cross-border commuting was ignored and the adjustment of small flows to zero was not undertaken. It is considered that these nuances in the dataset used do not explain the differences in the regionalisations produced.
3. Of course, in many of these instances, the SLAs are many kilometres apart, so that daily commuting would be unfeasible.
4. The Flowmap software is available from http://flowmap.geog.uu.nl. We also thank Tom de Jong who gave excellent software support.
5. All grouping algorithms entail the adoption of arbitrary judgments. Intramax is less vulnerable to this criticism.
6. The labour force geography illustrated in the above maps is based on an SLA to labour force region concordance provided by the ABS, for 2004 see: http://www.ausstats.abs.gov.au/ausstats/subscriber.nsf/0/AE3E261E3BA2506ECA257139007746CE/$File/61050_sla%20to%20lfs%20region%20concordance_jul2004.xls.
7. Labour force measures are drawn from the ABS 2001 Census of Population and Housing as it corresponds to the Journey-to-Work matrix used to construct the Functional Regions, and it is sufficiently spatially disaggregated.
8. The ABS (2004) notes that 'LFS regions were originally established after extensive consultation with major users of labour force data. Estimates for these LFS regions were first released in 1985. Factors in the design of the LFS regions included: the sample sizes required to yield reliable estimates; the need for consistency with the ASGC; and the need for comparability with other statistical collections. LFS regions are determined, in part, by the expected sample size for each region. If the regions are too small, then the accuracy of estimates will not be acceptable: relative standard errors on estimates will be very large, and the estimates will not be reliable or useful. The regions represent a compromise between user interest in small area data and the design limits of the sample'. See: http://www.abs.gov.au/AUSSTATS/abs@.nsf/94713ad445ff1425ca25682000192af2/44a9700b59346b98ca256f5600768aac!OpenDocument

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