Agglomeration externalities
– a missing piece of the project appraisal puzzle?

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1 Introduction

Appraisal of transport projects typically entails some form of economic cost benefit analysis. Various aspects of such appraisal are subject to criticism which ranges from the application of inappropriate values of unit resource costs, through to divergent views on discount rates, as well as exclusion of costs or benefits of the project that the critic feels are material to the result of the appraisal. One response to this perennial controversy has been for State Treasuries and constructing authorities to issue guidelines dealing with methods, valuations, discount rates and costs to be included. Whether these deal with the various parameters correctly is still subject to sporadic debate, but they do result in a degree of consistency, transparency and comparability between different projects' appraisals.

This paper examines a potential source of project benefits that is referenced in overseas guidance but is apparently absent from local guidance and practice, at least in NSW. These relate to agglomeration externalities. The concept is that the larger an urban agglomeration is within a certain geographic or travel time footprint, the higher that agglomeration's economic productivity will be, i.e., for a given set of inputs, output will be higher, if the degree of agglomeration is higher. If this is correct, then if a transport project were to result in travel time savings and thereby bring an existing agglomeration closer together, there would be a travel time saving (currently included in an appraisal) plus some additional value of output as a consequence of improved productivity.

This paper undertakes a brief review of the literature on agglomerations and how they might relate to transport in the next section. It also examines several project appraisal guidelines to see how this concept is treated. Subsequently, the methods applied and data sources used in this study are described. Results of the analysis are then presented, along with a discussion and a conclusion.

It must be stressed that this paper reports work that should be regarded as exploratory in nature: there are substantial limitations in the available data and aspects of the method. These are noted in the relevant sections. These limitations suggest a need for better disaggregate data and more research.

2 Literature overview

Agglomerations or clusters form an important theme in the study of competitive industries and processes of economic development, with Porter (1990) observing that:

> *'Clusters of competitive industries that achieve success are … vertically deep, involving many stages of the vertical chain...'* *(p. 164)*

and that:

> *'The mutual reinforcement within clusters also leads to surges in innovation (and international competitive position) in whole sectors of a national economy.* *(p. 164)*

This suggests that effective clusters are not necessarily characterised by a narrow and highly specialised base, but encompass a range of related activities.

The role of clusters in economic development is not a new phenomena, with Norwich (2003) describing the advantage of co-location of a broad range of specialised skills, permitting mass production to standardised designs, which emerged as a result of the modernisation programme for the Venetian Arsenal, which commenced around 1110 AD. At its ultimate peak, with a workforce of some 16,000, the Arsenal could '…turn out fully-equipped warships at the rate of one every few hours' (p. 84).

Glaeser *et al.* (1992) draw a distinction between the factors that explain city formation and the dynamics that explain city growth. They test data to establish how applicable different theories of the sources of city growth are, and find that, for the period of their data, intra-industry knowledge spillovers are less important for growth than spillovers across industries.

There is a substantial body of work that examines the relationship between the size of an agglomeration and productivity. Much of this work has entailed establishing some form of production function and generally uses data on manufacturing input and output. Lee (2003) provides a review of this work, including discussion of aspects of the theory of optimum city size prior to moving on to reviewing empirical studies. Dealing with productivity in services faces difficulties in defining output and measures of input (Bartelsman and Doms, 2000).

The theory of optimum city size relates to a balance of marginal increases in productivity with increasing city size and associated economies of scale, with competing increases in marginal diseconomies of higher costs, such as rents and congestion costs (Lee, 2003, p. 5). When reviewing the empirical studies, Lee (2003) identifies a number of controversies with the specification of the models (e.g., the effect of accounting for the initial capital stock); treatment of data (e.g., cross-sectional versus longitudinal); and, that a literature exists that describes diseconomies in terms of city size.

Sveikauskas (1975) found that observed wages were considerably higher in large cities, with the average industry's labour productivity being some 5.98% higher with each doubling in city size. Segal (1976) suggests that there was a step-change in productivity for metropolitan areas (US data was used) at around a population of 2 million, with productivity being some 8% higher for cities greater than 2 million, but that further increases were not related to city size.

Moomaw (1983) explored a range of variables that might influence productivity, finding that in five industries, population size is a significant and positive variable.

Of note is that a separate literature exists that deals with productivity in an aspatial manner and that this tends to identify factors such as '…ownership, quality of the workforce, technology, international exposure and the regulatory environment' (Bartelsman and Doms, 2000), rather than city size or agglomeration. This literature's concern with scale is in terms of plant size and potential economies of scale that might be achieved through exporting production, not with city size (Bartelsman and Doms, 2000). Similarly, Ahn (2001), in an extensive review of the literature on productivity and firm dynamics across OECD countries, does not mention agglomeration externalities or city size.

Lee (2003) goes further in his analysis, to attempt to quantify the effects of Schumpeterian dynamics (or 'creative destruction') on productivity. His production function includes metropolitan population, even though Lee is critical of population size as an explanatory variable for productivity at the metropolitan scale because it is a surface measure, and fails to capture the dynamics, or churn, of the economy below the surface. As an aside from agglomeration effects, this dynamicism identified by Lee, as reflected by churn of employment and internal migration, even if only of short distance, suggests that the urban system may be capable of quite rapid responses to changes in land use or transport systems: these changes would be much more rapid than suggested by a long term population trend line for a particular area. Agglomeration size is found by Lee to be a significant and positive explanatory variable of productivity growth, and substantially larger than (about an order of magnitude) the labour reallocation variable. Of interest is that Lee finds that human capital does not influence a metro-region's productivity – the nature of the measure (population share holding at least a bachelor degree) and the quality of the data is held out by that author as a possible reason for this rather than it not being important.

A recent study of the drivers of economic growth in the Sydney Region (BTRE, 2006), considered that the initial population of an area (in that study, at statistical local area or SLA) could be a driver of growth. Citing Feser (2001), that study posits that '…regions with large estimated resident populations can grow faster because of agglomeration effects including improved productivity because of a larger labour pool, and because of inter-industry knowledge spillovers between co-located industries which can lead to product variety and diversity and overall, better quality of life' (BTRE, 2006, p. 37). A variable for industry agglomeration was also included in their formulation to explain growth in an SLA – using two separate regressions, one to explain growth in estimated resident population and the other to explain aggregate real taxable income. Of interest is that, depending on which dependent variable is being estimated, the significance and sign of the agglomeration variables' coefficient change:

- Estimated resident population: this regression finds that the initial population is not significant. The industry agglomeration variable's coefficient is significant, but has a negative sign.

- Taxable income: this regression finds that initial SLA population is significant, but is negative, indicating that the larger an initial population, the slower the growth experience. The industry agglomeration variable is significant and positive. (BTRE, 2006, p. 43)

Of some importance for the analysis undertaken in the current study, BTRE (2006) found that the industry structure (as measured by the percentage of an SLA's population employed in a certain industry) tends to explain growth in aggregate taxable income – many of the individual industries' variable's coefficients are significant.

In the UK, on-going development of transport appraisal techniques has considered wider economic benefits of transport. SACTRA (2006) concerns itself with the comprehensiveness of cost-benefit analysis and whether there are conditions, such as imperfect competition, where such techniques fail to capture the full effects (costs and benefits) of a project. A section is devoted to agglomeration and geography (pp. 76-81), and discusses a number of theoretical issues, as well as practical difficulties in terms of attempting to identify the effects of transport and agglomeration (e.g., the counterfactual, and attempting to disentangle the various changes along with a transport intervention that may be present). They find that there is a '…real need for a theoretical approach which can be applied in both the before and after cases so that both prediction and evidence can be clearly related to a consistent set of models' (p. 81). SACTRA find that improvements to appraisal should attempt to undertake a more fully specified conventional cost-benefit analysis, plus provide an 'Economic Impact Report', which would, among other things, have a spatial dimension to identify winners as well as losers from the scheme under study (p. 149).

More recently in the UK, Eddington (2006) examines the role played by transport in the economy, with a review of about two hundred years of experience. It is particularly interested in step-changes in economic development and the role played by transport in those step changes. Examples examined include the Lancashire Cotton Cluster and the London Cluster (p. 8) and, of some considerable interest, is the role of transport, especially railways, as part of the Industrial Revolution, which commenced in Britain (p. 7). With railways, it is argued that productivity benefits did not accrue until the railways broadened their service to passengers from freight. That study appears to be casting around to find today's 'step-change' mode (or system) of transport. Importantly, this work finds that poor transport infrastructure is not necessarily at odds with rapid economic growth, citing the well known examples of Ireland and India (p. 12). Clusters / agglomerations are identified as a micro-driver of productivity (p. 23), and they go on to describe the types of benefits that might accrue from agglomeration:

- Better matching of people to jobs and access to skilled labour, as a result of dense labour markets
- Connection to suppliers and markets
- Information spillovers between firms
- Consumption benefits from access to a broader range of activity opportunities (p. 26).

Eddington finds that the literature has been largely unsuccessful in answering the specific question of what role transport can play in facilitating productivity benefits in agglomeration (p. 26). Yet, somewhat surprisingly, they state that 'Agglomeration is generally the most substantial impact of transport interventions currently missing from appraisals' (Eddington, 2006, p. 196). In some respects this apparent contradiction is a fair reflection of aspects of this broad literature.

In addition to the above type of studies, the link between transport infrastructure investment and economic performance has been subject to much debate and study, triggered by Aschauer (1989) (this is cited in a number of the studies above) which found very large estimated elasticities of output with respect to public infrastructure capital in the US (between 0.38 and 0.56, as reported in Crafts and Leunig (2005)). The econometrics of Aschauer's paper were found to be controversial and commenced a flurry of academic activity. A more recent study by Kamps (2004) found an output elasticity of closer to 0.2 across an OECD panel, but, interestingly, still found a very high value for the US of 0.79 (which seems to support Aschauer's original work).

Views of the legacy of the Aschauer paper vary, with Crafts and Leunig (2005) taking the view that, 'Aschauer's paper has, however, proved very fruitful in terms of subsequent research which it has stimulated.' This is in marked contrast to Gramlich's (observation, stated in BTCE (1996)), that these '…macroeconomic studies have already commanded resources 'way out of proportion' to whatever might be learned from them' (Gramlich, 1995).

Like the aspatial productivity studies, this literature does not directly mention agglomeration as a driver of productivity growth.

Recent work on London's Cross-Rail, quoted by DFT (2005), identifies that substantial benefits due to agglomeration externalities were estimated as part of that appraisal. These amounted to approximately 25% of the total transport user benefits from a conventional appraisal. This is a very considerable additional benefit (approximately 3 billion pounds, around AUD6.5 billion over the appraisal period) to be claimed from a source that, it appears, is rather controversial. DFT (2005) is a guidance document for economic appraisal which describes, in detail, how to calculate the wider economic benefits of transport projects. The first wider economic benefit (WB1) for the analyst to consider is agglomeration externalities.

Land Transport New Zealand's Economic Evaluation Manual (LTNZ, 2006) states that:

> *'In some rare situations, it is possible that increased economic activity within an area resulting from a transport improvement may give rise to economies of scale and therefore, additional economic efficiency improvements. If these efficiency gains can be clearly identified, they can also be included as benefits in the analysis.'*
>
> *(LTNZ, 2006, p. 2-5)*

According to this guidance, this is tempered by a need to consider consequent creation of diseconomies elsewhere and the need for a clear connection between the project and the economies of scale. The real difficulty is to clearly identify such efficiency gains.

However, these benefits are not mentioned directly in the NSW Treasury Economic Appraisal Guidelines (NSW Treasury, 2007), or NSW RTA Economic Analysis Manual (RTA, 1999). Direct guidance on dealing with these benefits could not be found in all five volumes of the Australian Transport Council's National Guidelines for Transport System Management in Australia (ATC, 2006). ATC does, however, provide guidance on issues such as threshold cases (Volume 5, p. 64-65), the effect of connectivity as a secondary impact (Table 2.1, Volume 3, p. 53) and points to UK Guidance (Volume 3, p. 39, citing DFT, 2006) and to BTE (1999), both of which provide a discussion of agglomeration externalities (see below). It also provides general guidance on the need to deal appropriately with externalities (Vol. 3, p. 13).

Austroads (2005) Guide to Project Evaluation does mention agglomeration effects through a reference in volume 5 (p. 6); it also mentions economies of scale, in terms of increased scale for firms that could now access additional markets as a result of a reduction in transport costs (p. 14).

An influential Australian publication on cost benefit analysis (BTE, 1999) also mentions agglomeration externalities. It states that under certain circumstances, which BTE cites from Beimborn and Horowitz (1993, pp. 19-20), such as '… a concentrated land-use pattern also can lead to more interpersonal contacts, increased networking, productivity and community interaction' which can lead to some agglomeration economies which escape measurement in a conventional BCA (BTE, 1999, p. 179). This concession is qualified by the proviso that '…only some transport projects foster agglomeration; others may cause dispersion…'. This suggests, like the New Zealand guidance cited above, if an analyst can clearly identify agglomeration effects of a project and quantify the same, then an argument might be mounted for their inclusion in the project's appraisal – the implication is that the onus is very much on the analyst to make the case. Further, such effects may turn out to be negative.

Three broad categories of agglomeration benefits can be found in the literature and could be thought of as mechanisms by which such economies might act. The first, that of economies of scale could relate to plant size, where the larger the potential customer base in the surrounding catchment (agglomeration) then the larger scale of production and hence the lower the costs. Such an example is quoted above from Austroads (2005, p. 14). From a transport perspective, if the transport system were developed to provide better accessibility to fringe areas, and hence increase the size of the agglomeration, then (if these scale economies were at work) there would be an increase in productivity.

Another mechanism is that of intra-industry agglomeration, which Porter tends to focus on in the analysis of specialised industry clusters. The German printing machine manufacturing cluster (Porter, 1990, pp. 180-195) or the Italian ceramic tile making cluster (Porter, 1990, pp. 210-225) are examples, as is the Venetian Arsenal example quoted above from Norwich (2003) and the Lancashire cotton cluster (Eddington, 2006). Here the mechanisms are thought to involve a high degree of specialisation by firms within an industry (with the agglomeration characterised by 'vertical' specialisation) and co-location of expertise in all aspects of the particular industry. This would result in linkages between steps of production, or spillovers of knowledge between steps in the process (e.g., the thread spinners knew precisely what the weavers required within the Lancashire cotton cluster).

Inter-industry agglomeration is where, through co-location or a range of different industries, economies are derived. A large city with a high concentration of producer services, such as finance, legal, marketing, software, etc; all available to support a range of different industries who perceive a need to use these services is an example – these could be thought of as 'horizontal' specialisation. In some ways this could be seen as economies of scope. London and New York are long established examples of this, with Shanghai and Mumbai emerging as possible future clusters. Sydney CBD's concentration of employment in Finance and Insurance and Property and Business Services could be seen as a similar type of agglomeration (for a discussion of Sydney's Economic Geography see SGS, 2004).

Hall (1998), through case studies, provides a comprehensive description of a number of cities at different stages of their development. This work is within the urban planning and development paradigm rather than the economic development and econometric paradigms, but nonetheless it provides a detailed description of the manner in which particular urban structures and their economic activity developed and then died away. In the case of a number of cities it describes how a re-birth subsequently occurred. Through its broad perspectives on development (encompassing social, historical, public administration, strategic positioning, chance, geography, technical development, systems of production, initial factor endowments and the quality and cost of those endowments and ability to attract additional factors, etc;) it is clear that determinants of successful city economies are extremely complex. Perhaps this is why the productivity literature presents a mixed view of the role of a single dimension of city development, such as degree agglomeration.

However, in Hall's descriptions of different features of city development, agglomeration economies become evident, ranging across scale, intra-industry and inter-industry mechanisms. In his description of the development of the motion picture industry in Los Angles, The Dream Factory (Hall, 1998, pp. 520-552) there are clear intra-industry agglomerations, as picture makers were attracted to Los Angles and the studio system developed, but there are also scale economies that emerge as part of that story. In Hall's description of the emergence of Detroit as the US centre for automobile manufacture and Henry Ford's role in that development, one can discern all three of these mechanisms:

- Scale economies through a clear vision that automobiles had a large mass market and by 1903 the fact that it made the cheapest cars was due, in part, to '…internal economies of scale, since it was producing two-fifths of all the [US's] cars…' (p. 403).

- Inter-industry agglomeration through tapping into Detroit's long established manufacturing base, especially in machine tool shops, permitting standard components to be sourced. These shops could produce parts for any industry requiring machined components.

- Intra-industry scale as other automobile manufacturers located there, developing a large specialised industrial base, overtime.

(The Mass Production of Mobility, Hall 1998, pp. 396-422)

Similar multi-faceted interactions emerge in a number of his other case studies.

In some ways, this complexity suggests that distinguishing rigidly between economies of scale, intra-industry and inter-industry agglomeration economies, while potentially useful from an econometric perspective, may tend to overlook some important elements of behaviour by economic agents. Also, from a policy perspective and a project appraisal standpoint, it may be better to think of overall agglomeration externalities, as a transport system improvements' contribution to agglomeration potentially would be available to all three mechanisms.

Summary

This area is controversial. There is a lack of agreement about the existence or the direction of operation of agglomeration externalities, their possible magnitude (if they exist), which mechanisms of benefit might be valid and whether they are already reflected in other benefits of a project. Further, if these economies of agglomeration do operate, then if they are fostered and supported, say through improved transport infrastructure or better network operation, it is an open question as to whether they weaken agglomeration economies in locations from which activity might be diverted by such policy action.

If agglomeration externalities exist, then would an increase in agglomeration as a result of a transport improvement, or a land use policy, such as urban containment, necessarily lead to higher overall productivity? At this stage, this could be best described as an open question.

That productivity, which is a very important driver of economic well being, is so difficult to identify and explain, especially for services, suggests there is a need for great caution when considering the work described in this paper. It also suggests that there is a need for a lot of further work, although some commentators may well take the view that it will be a waste of time, and that the resources may be better deployed improving the always-criticised elements of conventional social cost benefit analysis.

3 Study motivation

Notwithstanding the mixed picture that emerges from the overview of the literature, the prime motivation for this study revolves around the rapid and unexpected (at least in some quarters) increase in employment in Sydney's central business district (CBD) to 2001 and which apparently continued through to 2006 at least. With additional congestion from additional employment in the CBD, why would a business locate there?

Further, if additional employment in the CBD is to be supported into the future, it will need some substantial investment in transport facilities. If agglomeration benefits are evident, could these be weighed in appraisals of such projects?

Following on from this, it was considered worthwhile to endeavour to gain an appreciation of the shape of agglomeration measures or economic density within Sydney which, like Melbourne, is greater than a population of 2 million, which Segal (1976) believed was a threshold associated with a productivity shift.

As noted in the next section, data limitations preclude estimation of production functions. However, using information on employment and incomes from published data, even with some substantial limitations, an indication of variations in measures of income could be regressed against measures of agglomeration to see if it might be a significant variable.

4 Method and Data

4.1 Method

The method adopted in the study was to calculate a number of measures of agglomeration for Sydney, with analysis against indirect measures of output – namely gross individual income. If there are benefits of agglomeration, then it was expected, a priori, that some measures of income would be likely to increase as the degree of agglomeration increased – ideally direct measures of output would be used, but this is not available for Sydney at a fine level of geographic resolution. If businesses locate in congested locations, paying higher rents and paying higher employee compensation, then there must be some advantage to them, or their competitors located elsewhere would out-perform them.

Two similar measures of agglomeration were contemplated for this study: effective density and market potential. From the perspective of a business, effective density considers the economic opportunities around their location. Typically this uses jobs as a measure of activity. This paper only reports on effective density, with market potential left to a later date.

$$U_i = \frac{E_i}{r_i} + \sum_{j}^{i<>j} \left((E_j) / D_{ij} \right)$$ (Equation 1, from Graham, 2006)

where:

U_i is the effective density
E_i is the employment in SLA_i
R_i is radius of SLA_i
E_j is the employment in SLA_i
D_{ij} is the distance between SLA_i and SLA_j

In this study the variables used for E are jobs, hours worked, and total gross individual income of workers; all these variables are measured at the SLA of employment using Census Working Population Profile data (ABS, 2008b). The additional measures seek to better capture the level of economic activity:

- Hours worked seeks to control for under- and over-employed workers' jobs
- Total gross individual income provides an indication of the value of economic activity in surrounding SLAs, controlling for high and low paid jobs

The units of effective density depend on the basis of calculation, and here are:

- Jobs per kilometre
- Hours worked per kilometre
- Total income per kilometre

From the perspective of the analysis in this paper the effective densities are treated as non-dimensional numbers. This paper reports results using effective density measures of agglomeration for jobs, hours of work and total income, based on crow-fly distances.

The initial step was to calculate effective density using the above variables for each SLA in Sydney. Then, variations in measures of income were tested against variations in effective density to see what correlation might be evident, if any.

Subsequently, regressions were run of the following form:

Industry Structure	*Equation 1*	*Equation 2*
Explained variable	Average income per week	Average income per hour
Explanatory variables	Log of effective density	Log of effective density
	Industry structure variables	Industry structure variables

Occupational Structure	*Equation 1*	*Equation 2*
Explained variable	Average income per week	Average income per hour
Explanatory variables	Log of effective density	Log of effective density
	Occupation structure variables	Occupation structure variables

Each of the three measures of effective density (jobs, hours worked and total income) were run in each of the equations, producing 12 sets of coefficients. Regression analysis uses least squares regression function in Microsoft Excel (linest); where two explanatory variables display a high degree of collinearity, one is automatically excluded from the estimation, where this was the case, it is identified in the results below.

The use of linear regression is limited as the relationship between agglomeration and income may be non-linear and may vary with different degrees of scale. Indeed, Segal (1976) found that, when comparing metropolitan areas, there was a step change in productivity at a threshold of around 2 million resident population.

There are a number of other limitations in the analysis, including endogeneity, possibly where, for whatever reason, highly productive firms tend to locate in dense areas, whereas the less productive might choose sparsely developed areas – if this were the case, then higher output might not be at all related to agglomeration. A speculative mechanism for this might be that managers of successful (i.e., productive) firms, might be better able to afford to live in desirable locations within Sydney, which just happen to also be close the CBD. This proximity of the CBD to desirable residential locations might be the reason for them to locate their businesses in the CBD, rather than because of some characteristic of agglomerative density of the CBD. That much of the aspatial productivity literature does not mention agglomeration or city size in its explanation of productivity differences, this sort of behaviour might be a material risk.

Another analytical issue, that of spatial autocorrelation, is a potential problem with comments under Figure 7 below indicating that the sheer size of the CBD's employment flows across strongly into the effective density values calculated for smaller, but proximate, areas. A potential strategy to test for this is to use more finely coded jobs and income data from the journey to work dataset (when they become available) to permit sensitivity testing of the effect of different geographic aggregation schemes on results. More sophisticated econometrics may also assist to at least detect the presence of spatial autocorrelation.

4.2 Data

Ideally this study would use a method similar to Graham (2006), where a detailed production function was estimated for firms at a fine level of geographic resolution to examine how productivity varies with change in a measure of agglomeration for that area, along with variables that describe inputs to the production process. Unfortunately this level of data is not readily available at such a fine geographic resolution for Sydney. Consequently, the study uses information on population, employment, workforce, income, hours of work, industry and occupation from the 2006 Census of Population and Housing (ABS, 2008a and 2008b) and ABS' Regional Population Growth series (ABS, 2008c).

Income is a poor surrogate for output in an area of heterogeneous economic activity, because factor returns vary by industry. Consequently, if particular industries with proportionally high factor returns to labour tend to locate in dense areas and industries with lower factor returns to labour tend to located in less dense areas, then use of income would tend to distort the picture[1].

[1] A strategy to deal with this is to expand wages data by industry to reflect total industry output applying weights which reflect industry specific factor returns to labour. However, income data available by industry in working population profiles from the 2006 census do not provide income by industry, rather they provide income by occupation.

Analysis was undertaken at statistical local area (SLA) level for the sixty-four SLAs in Sydney statistical division. This level of analysis is the smallest at which employment and individual gross income (at the work place) was available. Of note is that this level of spatial data has been used previously in research into economic drivers of growth, as described in Section 2 (BTRE, 2006), albeit using data from previous Censuses.

Information on proximity was drawn from three sources: crow-fly distances; an estimate of network distances from a highway network model; an estimate of highway travel times, also from a highway network model. Due to space limitations, results based on crow-fly distances are reported here.

Industry structure variables were derived using the proportion of workers in an SLA in each of 19 industries. Following exploration of the data, several industries were aggregated, leaving 15 industry groups. Occupation structure variables were derived using the proportion of workers in an SLA in each of seven broad (major) occupational categories reported in the Census.

This study considered the Sydney statistical division, ignoring interactions across boundaries with the Illawarra and Lower Hunter. While this is an apparent short-coming, because of Sydney's quite marked geographical containment and associated relative isolation from adjoining areas, if there was an effect due to this omission it is likely only to influence the economic density of edge SLAs, such as Sutherland, Gosford, Wyong and possibly Wollondilly, and such an effect is likely to be small, as a result of large interstitial distance and the relatively small-scale of the adjoining areas.

In addition to issues noted above there are a number of limitations in the data:

- Measures of income and hours worked involve estimating averages from banded data presented in the Census.

- The measure of income reported in the Census is gross personal income, which may include income components (e.g., interest, dividends, etc) that are not derived from a worker's employment in the Census SLA. It may also not include total compensation from their employment, such as bonus payments, equity options, or fringe benefits.

- The Working Population Profile data generally suffers from under-enumeration – this has not been taken into account in the analysis.

5 Results

5.1 The shape of inputs

The variables used in the calculation of effective density display a degree of variation. The following four charts show the ranking of average hours worked per worker, average gross personal income of workers, the number of jobs in an SLA and the total of gross personal income of workers in an SLA. These charts help in understanding the results of the analysis. It should be noted that the ranking of individual SLAs varies by measure, with the exception of Sydney Inner, which is consistently the highest ranked SLA.

Figure 1 shows that the average hours worked by SLA in Sydney ranges from around 29.6 hours per week in Gosford East through to 38.9 in Sydney Inner.

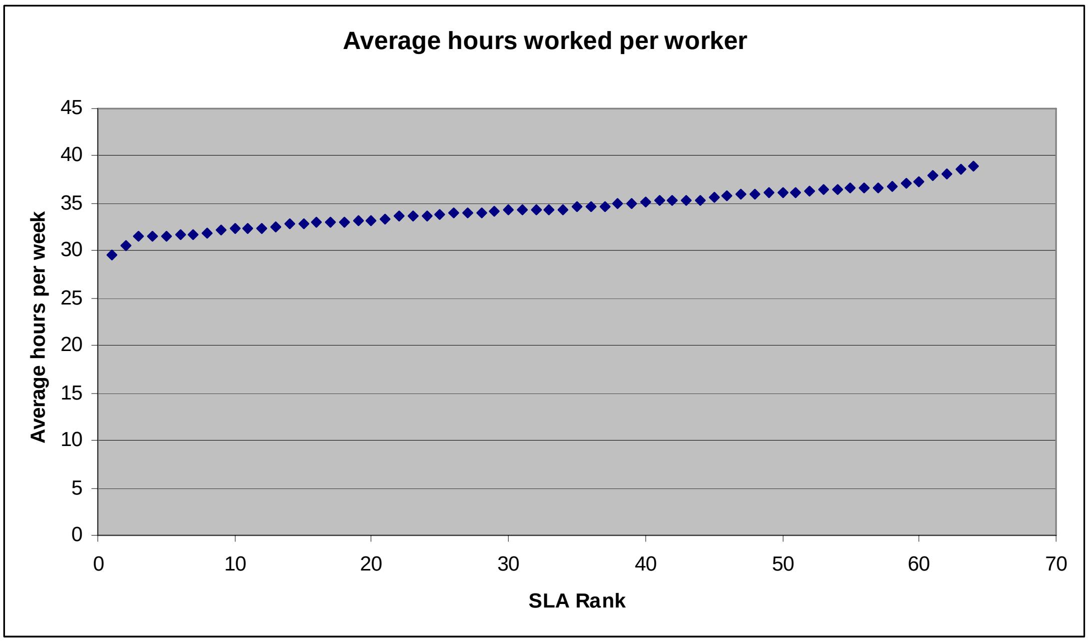

Figure 1 – Average hours worked per week per worker ranked by SLA

Figure 2 shows that the average gross personal income ranges from $688 per week in Gosford East through to $1,507 per week in Sydney Inner.

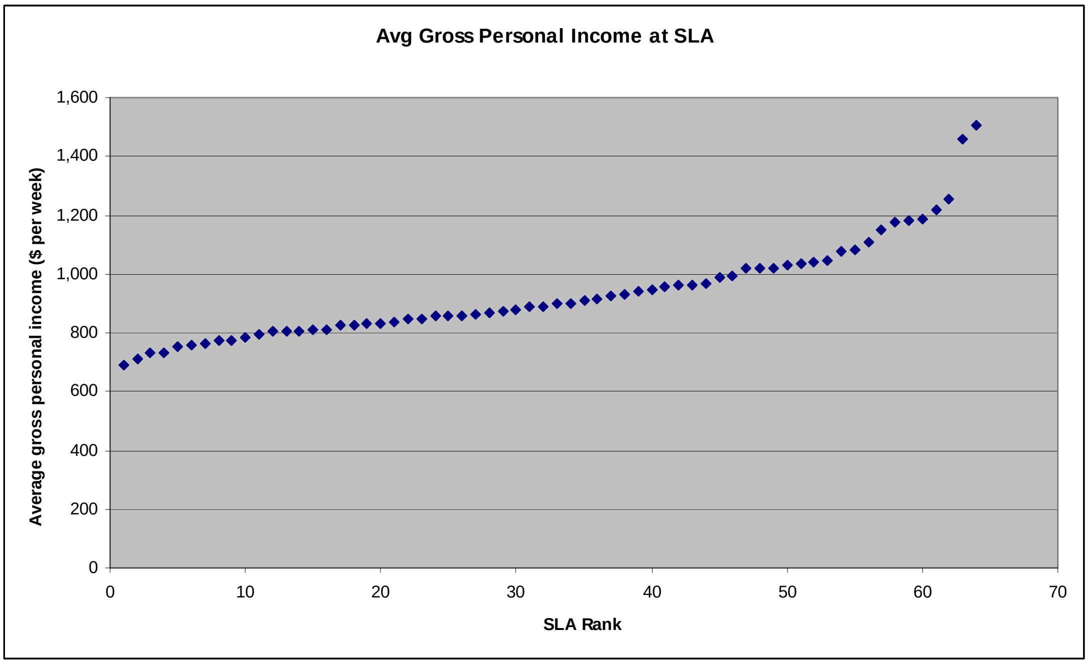

Figure 2 – Average gross personal income per week per worker ranked by SLA

Figure 3 shows that the number of jobs in an SLA varies from less than 4,000 in Hunters Hill through to 231,500 in Sydney Inner.

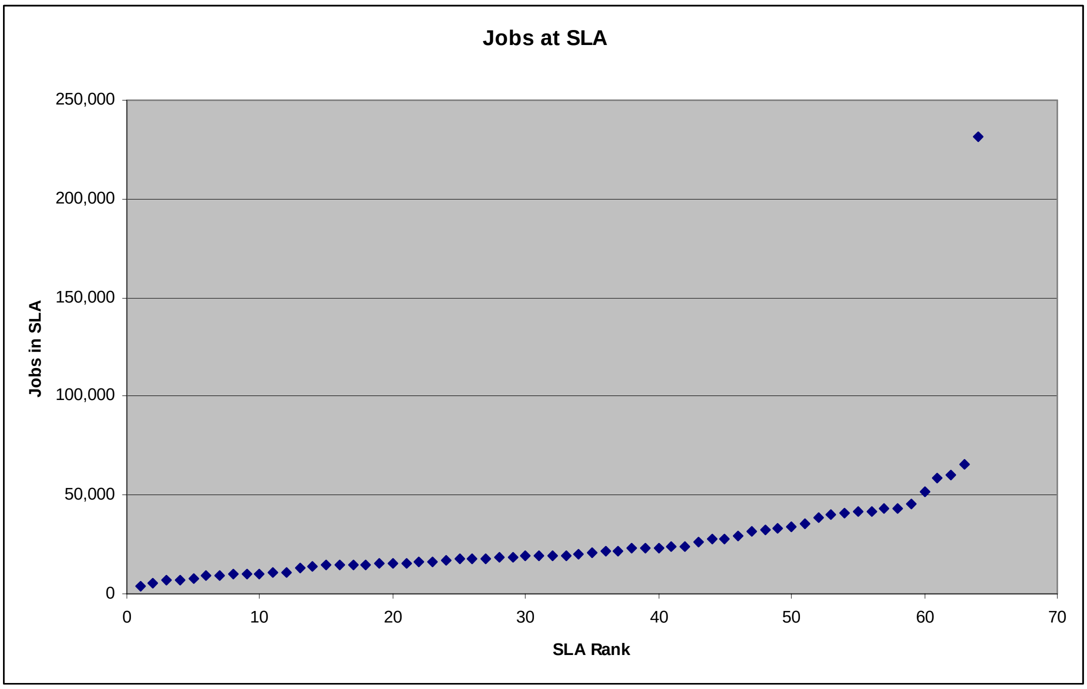

Figure 3 – Workers in each SLA ranked by SLA

As a consequence of the higher average income in Sydney Inner, and the very high number of jobs there, the aggregate income per week in Sydney Inner completely dwarfs the total income of any of the other SLAs in Sydney, as shown in Figure 4.

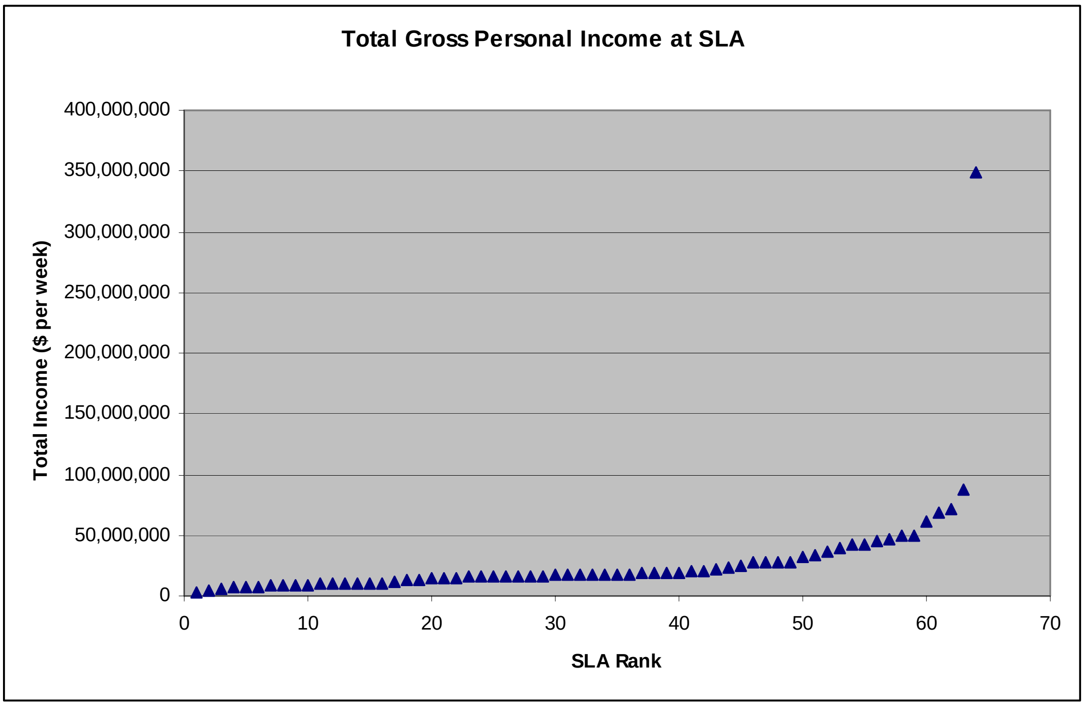

Figure 4 – Total gross personal income per worker per week ranked by SLA

5.2 The shape of effective density

Figure 5 shows effective density using jobs in surrounding SLAs and crow fly distance between SLAs as a measure of proximity.

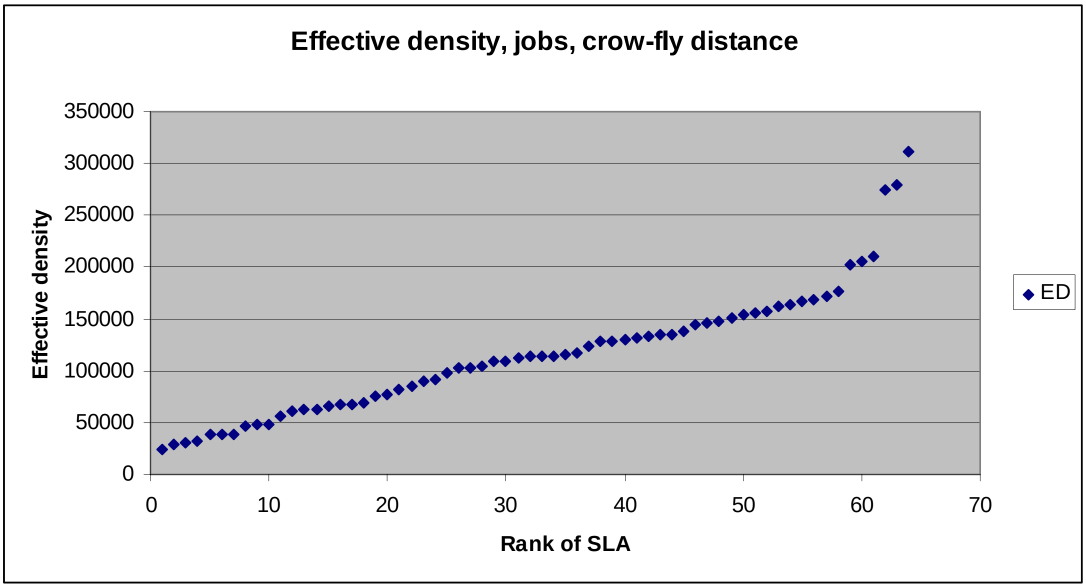

Figure 5 – Effective density (jobs and crow-fly distance) ranked by SLA

Of interest are the six ‘high’ data points to the right that are above the rest of the series:

- Highest – Sydney Inner SLA
- 2nd – Sydney East SLA
- 3rd – Sydney West SLA
- 4th – Sydney South SLA
- 5th – Leichhardt SLA
- 6th – North Sydney SLA

These reflect the concentration of jobs in Sydney CBD, located in Sydney Inner SLA. It also reflects the relatively small size of that SLA, at 4.2 sq km (ABS, 2008b), meaning that surrounding activity is in relative proximity.

Figure 6 shows a similar plot, this time using hours worked, rather than jobs. There is little difference between the shape of this and the previous plot.

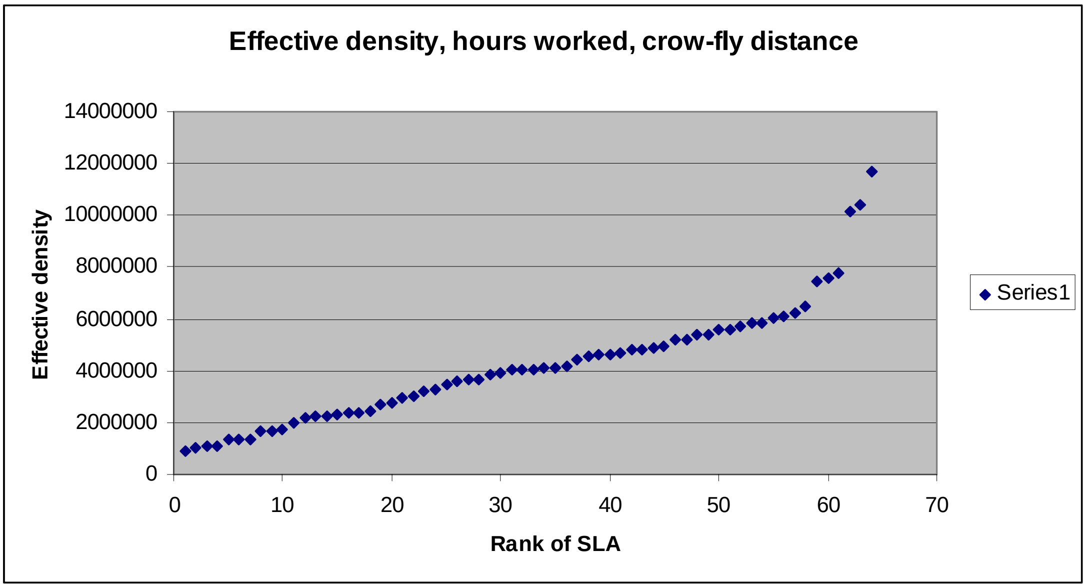

Figure 6 – Effective density (hours worked and crow-fly distance) ranked by SLA

Figure 7, a plot of economic density based on total income, shows a different shape. The flatter profile was an initial surprise, because of the dominance of Sydney Inner's total gross personal income, it was expected to be far and away above the next nearest SLA. However, it is because Sydney Inner has such a substantially higher aggregate income and so many more jobs, that it makes a relatively large contribution to the effective density of surrounding SLAs, 'drawing up' their effective density.

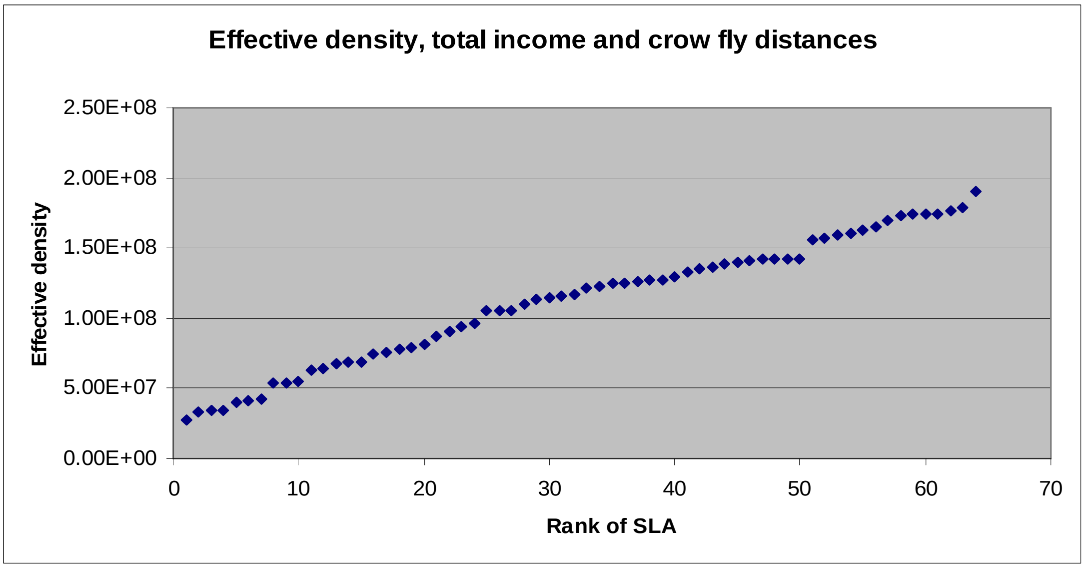

Figure 7 – Effective density (total income and crow-fly distance) ranked by SLA

5.3 How do variations in effective density relate to variations in gross personal income?

Figure 8 plots effective density against average gross personal income per week.

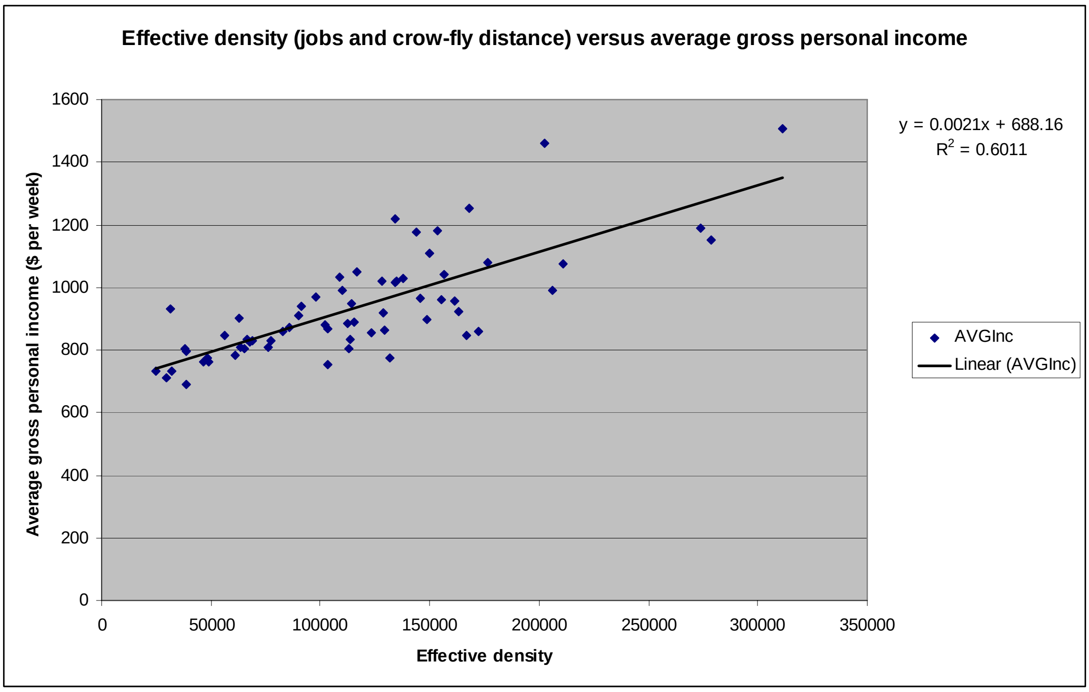

Figure 8 – Scatter plot of effective density (jobs and crow-fly distance) and average gross personal income per week

This scatter plot shows that variations in effective density explain some of the variation in average gross personal income across the SLAs in this study. This simple analysis indicates that, among the scatter, as effective density increases average gross personal income also shows a rising trend.

Figure 9 plots the effective density against gross personal income per hour worked.

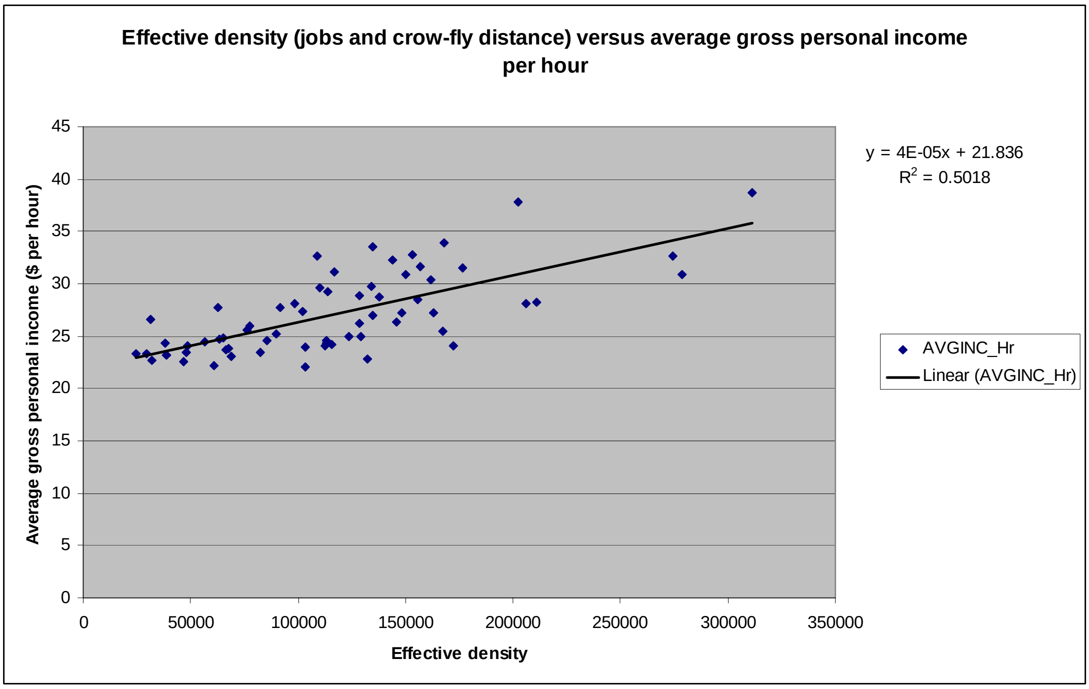

Figure 9 – Scatter plot of effective density (jobs and crow-fly distance) and average gross personal income per hour

This shows a similar trend to Figure 8, however, with effective density explaining less of the variation in the income variable.

Scatter plots were prepared for the two other measures of effective density, but are not included here for brevity. For effective density calculated using hours worked and crow-fly distance the scatter plots are very similar to the above two charts, with similar correlation coefficients (0.60 and 0.50 respectively). For effective density calculated using total income and crow-fly distance, the scatter of data points flatten out and the correlation coefficients are extremely poor (0.43 and 0.35).

5.4 Industry and occupational structure of workers, effective density and income

The results of the regression analysis above show a mixed view of the role of effective density in explaining variations in income. In the regressions that use industry structure variables, the logarithm of effective density is significant and positive when explaining variations in average income per week for effective density calculated on the basis of jobs and hours worked. It is not significant when considered against effective density calculated on the basis of total income. Effective density is not significant for all three measures (jobs, hours worked and total income) when attempting to explain variations in average hourly income.

Few of the industry structure variables are significant in the regressions: the proportion of Professional and Scientific, and Information and Media are significant and positive in each of the tests; all other industry variables are not.

In the regressions of occupation structure, the logarithm of effective density is significant and negative when explaining variations in average income per hour for the three measures of effective density (jobs, hours worked and total income). It is also significant and negative when explaining variations in average weekly income for effective density calculated on the basis of total income. Generally, around half the occupation variables are significant.

Table 1 and Table 2 report the results of the analysis for regressions with industry structure variables (equations 1 and 2 as described in Section 4.2 above).

Table 1 – Results of regression analysis effective density (jobs and distance), industry structure

	Average income per week			*Average income per hour*		
Explanatory variables	*Coefficient*	*SE*	*t-stat*	*Coefficient*	*SE*	*t-stat*
Health_Care	ns	ns	ns	ns	ns	ns
Education	ns	ns	ns	ns	ns	ns
Professional_Scientific	1512.80	625.08	2.42	38.90	16.60	2.34
Real Estate	ns	ns	ns	ns	ns	ns
Finance Insurance	ns	ns	ns	ns	ns	ns
Info Media	1839.95	739.91	2.49	ns	ns	ns
Transport	ns	ns	ns	ns	ns	ns
Accommodation	ex	ex	ex	ex	ex	ex
Retail	ns	ns	ns	ns	ns	ns
Wholesale	ns	ns	ns	ns	ns	ns
Construction	ns	ns	ns	ns	ns	ns
Manufacturing	ns	ns	ns	ns	ns	ns
Arts_Other	ns	ns	ns	ns	ns	ns
Admin_PubAdmin	ns	ns	ns	ns	ns	ns
Ag_mining_utilities	ns	ns	ns	ns	ns	ns
Log Effective Density	56.68	26.65	2.13	ns	ns	ns
Const	ns	ns	ns	ns	ns	ns
r-squared	**0.90**			**0.87**		

ns – not significant at 5% probability; ex – excluded because of high collinearity with another independent variable

The results in Table 1 for average income per week indicate a better model fit in terms of the correlation coefficient, and that log of effective density is significant and positive. However, that only two industry structure variables are significant was unexpected: this may reflect, at least for some distributed industries, like retail, a relatively homogenous distribution of employment across Sydney SD.

In terms of explaining income per hour effective density is not significant; when one considers that income per hour might be a better measure of actual productivity than income per week, this tends to undermine the notion of agglomeration externalities.

Table 2 presents a very similar result to Table 1, using hours worked rather than jobs as the basis for calculation of effective density. Similarities in co-efficient values and statistics indicate little difference between the two measures of effective density.

Table 2 – Results of regression analysis effective density (hours worked and distance), industry structure

	Average income per week			*Average income per hour*		
Explanatory variables	*Coefficient*	*SE*	*t-stat*	*Coefficient*	*SE*	*t-stat*
Health Care	ns	ns	ns	ns	ns	ns
Education	ns	ns	ns	ns	ns	ns
Professional_Scientific	1513.81	622.88	2.43	38.94	16.56	2.35
Real Estate	ns	ns	ns	ns	ns	ns
Finance Insurance	ns	ns	ns	ns	ns	ns
InfoMedia	1834.43	738.64	2.48	ns	ns	ns
Transport	ns	ns	ns	ns	ns	ns
Accommodation	ex	ex	ex	ex	ex	ex
Retail	ns	ns	ns	ns	ns	ns
Wholesale	ns	ns	ns	ns	ns	ns
Construction	ns	ns	ns	ns	ns	ns
Manufacturing	ns	ns	ns	ns	ns	ns
Arts_Other	ns	ns	ns	ns	ns	ns
Admin_PubAdmin	ns	ns	ns	ns	ns	ns
Ag_mining_utilities	ns	ns	ns	ns	ns	ns
Log Effective Density	56.48	26.14	2.16	ns	ns	ns
Const	ns	ns	ns	ns	ns	ns
r-squared	**0.90**			**0.87**		

ns – not significant at 5% probability; ex – excluded because of high collinearity with another independent variable

Table 3, indicates that effective density is not a significant explanatory variable for either weekly or hourly average income. The appropriateness of using income in the effective density as an explanatory variable to explain average income per week and average income per hour must be re-considered, but also the linear profile for effective density based on total income (Figure 7) indicates less heterogeneity and possibly affecting the correlation.

Table 3 – Results of regression analysis effective density (total income and distance), industry structure

	Average income per week			*Average income per hour*		
Explanatory variables	*Coefficient*	*SE*	*t-stat*	*Coefficient*	*SE*	*t-stat*
Health Care	ns	ns	ns	ns	ns	ns
Education	ns	ns	ns	ns	ns	ns
Professional_Scientific	1570.46	665.85	2.36	40.97	17.47	2.35
Real Estate	ns	ns	ns	ns	ns	ns
Finance Insurance	ns	ns	ns	ns	ns	ns
InfoMedia	1982.00	760.20	2.61	ns	ns	ns
Transport	ns	ns	ns	ns	ns	ns
Accommodation	ex	ex	ex	ex	ex	ex
Retail	ns	ns	ns	ns	ns	ns
Wholesale	ns	ns	ns	ns	ns	ns
Construction	ns	ns	ns	ns	ns	ns
Manufacturing	ns	ns	ns	ns	ns	ns
Arts_Other	ns	ns	ns	ns	ns	ns
Admin_PubAdmin	ns	ns	ns	ns	ns	ns
Ag_mining_utilities	ns	ns	ns	ns	ns	ns
Log Effective Density	ns	ns	ns	ns	ns	ns
Const	ns	ns	ns	ns	ns	ns
r-squared	**0.90**			**0.87**		

ns – not significant at 5% probability; ex – excluded because of high collinearity with another independent variable

The following three tables report the results of the regressions with occupation structure variables (equations 3 and 4 as described in Section 4.2 above).

Table 4 shows that log effective density is not significant when explaining average income per week, but is significant when explaining average income per hour. However, it has a negative sign, which suggests that as effective density increases, average income per hour tends to decrease (i.e., dis-economies of agglomeration). A larger proportion of occupation variables are significant than the industry structure variables in Tables 1 to 3 above and they are all positive except for the proportion of labourers, which suggests that the higher the proportion of labouring jobs in an SLA, the lower the average income per hour. Sales and Community occupations do not have significant coefficients – again, as commented above under Table 1 about the distribution of retail industry jobs – this may reflect relatively homogenous distributions of these two occupations across Sydney SD.

Table 4 – Results of regression analysis effective density (jobs and crow-fly distance), occupation structure

	Average income per week			*Average income per hour*		
Explanatory variables	*Coefficient*	*SE*	*t-stat*	*Coefficient*	*SE*	*t-stat*
Labourers	ns	ns	ns	-62.47	25.24	-2.48
Mach_Op	3186.11	697.08	4.57	48.30	17.58	2.75
Sales	ns	ns	ns	ns	ns	ns
Clerical	2228.82	575.54	3.87	31.25	14.51	2.15
Community	ns	ns	ns	ns	ns	ns
Tec_Trades	ex	ex	ex	ex	ex	ex
Prof	1964.67	442.96	4.44	38.29	11.17	3.43
Managers	4634.68	812.57	5.70	76.94	20.49	3.76
Log Effective Density	ns	ns	ns	-1.36	0.60	-2.26
Const	ns	ns	ns	ns	ns	ns
r-squared	**0.90**			**0.88**		

ns – not significant at 5% probability; ex – excluded because of high collinearity with another independent variable

The results in Table 5 reflect a similar situation as those in Table 4 – this largely reflects similarities in the effective density variable whether constructed from jobs (Table 4) or hours worked (Table 5).

Table 5 – Results of regression analysis effective density (hours worked and crow-fly distance), occupation structure

	Average income per week			*Average income per hour*		
Explanatory variables	*Coefficient*	*SE*	*t-stat*	*Coefficient*	*SE*	*t-stat*
Labourers	ns	ns	ns	-62.44	25.25	-2.47
Mach_Op	3181.14	700.06	4.54	48.50	17.64	2.75
Sales	ns	ns	ns	ns	ns	ns
Clerical	2226.43	576.52	3.86	31.30	14.52	2.16
Community	ns	ns	ns	ns	ns	ns
Tec_Trades	ex	ex	ex	ex	ex	ex
Prof	1965.26	443.86	4.43	38.40	11.18	3.43
Managers	4638.11	815.94	5.68	77.34	20.55	3.76
Log Effective Density	ns	ns	ns	-1.34	0.59	-2.25
Const	ns	ns	ns	ns	ns	ns
r-squared	**0.90**			**0.88**		

ns – not significant at 5% probability; ex – excluded because of high collinearity with another independent variable

Table 6 shows log effective density is significant and negative when explaining both average weekly and hourly income. It also shows a high degree of significance for most of the occupation structure variables.

Table 6 – Results of regression analysis effective density (total income and crow-fly distance), occupation structure

	Average income per week			*Average income per hour*		
Explanatory variables	*Coefficient*	*SE*	*t-stat*	*Coefficient*	*SE*	*t-stat*
Labourers	ex	ex	ex	ex	ex	ex
Mach_Op	5057.40	1074.30	4.71	108.23	27.53	3.93
Sales	2033.22	777.78	2.61	61.76	19.93	3.10
Clerical	4058.94	788.56	5.15	92.58	20.21	4.58
Community	3232.31	975.80	3.31	87.50	25.00	3.50
Tec_Trades	ns	ns	ns	62.96	24.92	2.53
Prof	3752.72	740.03	5.07	99.06	18.96	5.22
Managers	6362.49	829.82	7.67	134.01	21.26	6.30
Log Effective Density	-54.07	23.21	-2.33	-1.44	0.59	-2.42
Const	-1517.18	590.16	-2.57	-31.78	15.12	-2.10
r-squared	0.88			0.88		

ns – not significant at 5% probability; ex – excluded because of high collinearity with another independent variable

Overall this mixed picture suggests broad occupation classifications are a better explanation of income than industry of employment (especially at the aggregate industry level). Intuitively this makes some sense as it would be expected that there would be a greater range of income within an industry than within an occupation (i.e., occupational labels would be more closely correlated with income bands than industry labels). In terms of the role of effective density in explaining income (as a proxy for output), with some formulations indicating significant and positive influence; others indicating a significant and negative influence; and others with no significance, suggests a need for more research to explore:

- A more robust theoretical foundation for the work
- Better data
- Improved econometrics, including a more detailed exploration of model specifications

That effective density is found to be significant as an explanatory variable, even if negative in sign under some formulations, does suggest it is probably worth pursuing further. In some ways the contradictory results tend to fit with the varied views of agglomeration externalities that emerge from the literature.

6 Discussion

The analysis reported above indicates that there are substantial variations in effective density across SLAs in the Sydney statistical division. These reflect considerable variations in the underlying inputs of jobs, average hours per week and average income, as well as spatial irregularities in the distribution of SLAs.

There is a correlation between average income and effective density and between average income per hour; these simple analyses explain only a part of this variation. Measures of effective density (based on jobs and based on hours worked) show the best correlation with average income per week – nonetheless they leave about 40% of the variation unexplained.

Introducing industry structure variables and occupation variables into the analysis sought to explain variations in income due differences in either industry structure, or occupational structure. While increasing the amount of variation explained, these structural variables present conflicting views of the role of effective density in explaining variations in income. Two of the regressions that include the industry structure variables suggest that effective density is a significant and positive variable in explaining variations in income – broadly that the higher the effective density the higher the income. This seems to fit well with the simple scatter plot analysis of effective density and incomes. It also seems to 'fit' the role of agglomeration in boosting productivity that is prevalent in some of the literature.

The occupation structure regressions also explain more of the variation in incomes than the simple scatter plots, and more of the occupational variables have significant coefficients than in the industry structure variables. When regressed with occupational structure variables, it results in effective densities' coefficient becoming significant and negative. A potential reason for this is that agglomeration might provide higher benefits on an industry basis.

If agglomeration economies are operating in Sydney, as our basic and limited analysis suggests might be the case, then the implications for transport policy are that such policy should broadly seek to maintain and improve accessibility to high and dense concentrations of activity, such as the CBD and some of the larger sub-regional centres. Such policies would essentially increase effective density by bringing activities 'closer together'.

For land use policy, it suggests that densification within the existing urban fabric, as long as it does not overload existing infrastructure, may achieve similar effects by placing more activity within the same spatial configuration. It also has the implication that proposed large scale transport schemes' effects on agglomeration ought to be at least investigated.

However, apart from methodological issues and data limitations, there is a broader issue, which is quite pertinent to Australia with its very high degree of urbanisation and unusual distribution of city size rankings (Ellis and Andrews, 2001:15). This issue is one raised in Land Transport NZ (2006), among others, and relates to diversion of activity: it is not clear that, even if higher degrees of agglomeration in Sydney achieved higher output and productivity, these would simply not represent diversion of activity (at least in part) from regional and rural areas and potentially create dis-economies in those locations. Even if it did not 'draw-in' existing activity from such locations, it might result in Sydney retaining a higher proportion of activity than would otherwise be expected to drift to smaller centres interstate, regional and rural centres.

7 Conclusion

The literature that deals with agglomeration presents a broad range of data and views on the importance or otherwise of agglomeration as an explanation for productivity. Links between transport and agglomeration and higher productivity are evident in case studies presented in the literature, although more controversial when considered empirically. There is debate as to whether such agglomeration effects are already accounted for in conventional cost benefits analysis, or whether they do represent a potential source of substantial benefits under particular circumstances. Despite this rather puzzling picture, agglomeration benefits have been claimed in at least one major overseas transport project's appraisal, and, with a flexible interpretation of the Austroads guidance, an argument might be made for their inclusion, under certain circumstances, in local practice.

Clearly, if agglomeration externalities represent a net increase in overall productivity, then transport policy which seeks to foster and develop such externalities, through measures such as improved interconnectedness between fringe areas and the centre of major Australian cities, could probably rightly claim such externalities in their appraisal.

This study's analysis indicates that effective density, as a measure of agglomeration, could be a useful variable in explaining part of the variations in incomes, as a proxy for productivity. This is tempered by the limitations of the method and data. Methods to develop a refined measure of output at a spatially disaggregate level using adjusted income data, potentially from the journey to work dataset, needs to be tested. This would seek to overcome the limitation of income data due to its different rate of factor return by industry. A strategy to conduct sensitivity tests, again using data at a finer level of spatial resolution from the journey to work dataset, offers a possibility to test for influences of spatial autocorrelation in the models. Further work must also seek to deal effectively with endogeneity, perhaps through a combination of more sophisticated econometrics and a more robust theoretical approach to the problem. There is also scope to test additional specifications, possibly with an initial focus on some of Sydney's secondary economic concentrations at its sub-regional centres, to establish what type of relationship might be evident between the variables at a sub-regional scale. There is also scope to use other measures of agglomeration, such as market potential.

There are many dimensions in which this research could be pursued further: different measures of proximity could be used in the calculation of effective density; better data on incomes and output, perhaps directly related to wages / employee compensation earned at the job in the SLA, rather than gross personal income; introducing a time series component into the analysis to examine how trends have developed; inclusion of other geographic areas in the analysis may provide some insights into how these variables might be statistically related; differences in effective density may also assist to explain differences in income inequality.

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