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Investigating the relationships between travel patterns and social exclusion of children in Sydney

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Abstract

The term social exclusion in its most general sense refers to a lack of engagement with broader society. This can arise through an absence of opportunities for employment or study, or though barriers to participation in social or recreational activities, among many other causes. Recently, work has been undertaken to develop small area indicators of social exclusion risk specific to children, an area where there has been a historical lack of research in Australia.

Using data for Sydney, this paper investigates the extent to which social exclusion in children is related to their travel behaviour. Overall results show that children living in areas of highest child social exclusion risk travel significantly less than children living in other areas of Sydney. The analyses also identify a number of factors which affect children's propensity to travel.

1 Introduction

This paper examines the travel behaviour of children aged 5 to 14 years using detailed data collected in the Household Travel Survey (HTS) in Sydney between 2001 and 2006 (BTS 2011). The travel behaviour of children is of interest because of the "importance of independent mobility for children's personal, intellectual and psychological development" (Tranter 1994, p. 527) and because it provides insight into children's participation in leisure, social and educational activities, and thus their social inclusion (Davies et al 2008).

The HTS data is analysed to determine which factors influence the trip propensity (defined below) of the children surveyed. Work recently undertaken at the National Centre for Social and Economic Modelling (NATSEM) on small area measures of child disadvantage has resulted in an index of Child Social Exclusion (CSE) risk (Harding et al. 2009); this is incorporated by examining what differences in trip propensity exist between regions with different levels of child social exclusion risk. Whether this child-specific measure of social exclusion risk outperforms existing measures of general socio-economic disadvantage in predicting differences in the travel behaviour of children is also investigated. The results of the analyses are presented and their implications for public policy in Australia discussed.

This section presents some background information, including definitions and an overview of literature related to transport and disadvantage/social exclusion, and outlines the general approach adopted. Section 2 describes the data used and presents some basic descriptive statistics. Section 3 examines the HTS datasets and identifies significant factors affecting trip propensity for the whole Sydney Statistical Division. Section 4 investigates differences between socially excluded and other regions in Sydney. Sections 5 and 6 discuss the results obtained and present conclusions.

1.1 Background

The closely related concepts of socio-economic disadvantage and social exclusion are not easily or concisely defined—there exist many definitions that have been used historically in various contexts and for different purposes. In formulating their 2006 SEIFA indexes—or Socio-Economic Indexes for Areas (ABS 2008a)—the ABS attempts to capture the concept of relative socio-economic disadvantage in terms of both “access to material and social resources” and the “ability to participate in society” (ABS 2008b). Harding et al. (2009) adopt the definition of the British Social Exclusion Unit index to underpin their CSE index. Although this definition emphasises the multitude of possible causes of or contributors to social exclusion, the underlying concept is analogous—a lack of means of financial and/or social support. As this paper engages with the concepts of socio-economic disadvantage and social exclusion primarily through the SEIFA and CSE indexes, the definitions above are used here.

Previous work dealing with disadvantage or social exclusion specifically as it relates to transport constitutes only a small fraction of the vast quantities of work on social exclusion and disadvantage more generally (a quantity too vast to sensibly be reviewed here). A key finding of that literature is that a lack of transport can be a barrier to participation in employment, education and social and recreational activities (e.g. Bradshaw et al 2004, Hurni 2006, Spoehr 2007, Stanley and Stanley 2004). Of particular note is Monash University work examining links between social exclusion, well-being and self-reported transport disadvantage in adults in Melbourne (e.g. Currie et al. 2010; Delbosc and Currie 2011). Another relevant study is Davies et al (2008) which focused on exclusion of children aged between 9 and 12 from school, social activities and social networks in a disadvantaged part of Melbourne. Amongst the identified barriers to social inclusion for these children were transport constraints on participating in social activities outside of school, and concerns about traffic and safety.

The travel behaviour and transport use of children has been investigated by several authors. Tranter (1994) considers the freedom of primary school children to travel around their own neighbourhood without adult supervision, with evidence from Australian, New Zealand, British and German cities indicating that children’s levels of independent mobility have decreased compared to the previous generation. The car dependency of children’s travel partly reflects the parents’ perceptions of traffic danger (Tranter 1994, Timperio et al 2004). Hurni (2006) reports that children who live in transport-disadvantaged parts of Western Sydney miss out on opportunities for extra learning and physical activity when their parents do not have a car. Lyth-Gollner and Dowling (2002) explore how the presence of children in a household influences the travel patterns of adults in Sydney, finding that men and women in households with children tend to travel more by car, especially for ‘serve passenger’ trips.

1.2 Approach used

The primary analytical focus of this paper is the concept of individuals’ trip propensity, which is defined here as the expected number of trips per day for an individual. This is estimated for a particular group of individuals using a weighted mean of the number of trips taken by individuals in the HTS sample who are members of that group. Groups can be defined by one or more factors related to persons or households (e.g. age group, vehicle ownership), and trip propensity can be calculated based on all trips or only trips of certain types (e.g. trips taken by private vehicle, trips taken for social/recreational purposes).

Comparisons of trip propensity are conducted using Welch’s t-test (Welch 1938). See the appendix for details on this test. Explicit adjustments for multiple comparisons are not used, but the discussion of results is primarily qualitative with the greatest emphasis placed on those results which are highly significant ($P < 0.001$).

2 Data sources

The primary data sources used in this study are:

- SEIFA Index of Relative Socio-economic Disadvantage (ABS 2008a)
- Child Social Exclusion index (updated version 2, NATSEM 2011)
- Sydney Household Travel Survey (BTS 2011).

Each of these is described in more detail below. Additional data on 2006 Estimated Resident Population (ABS 2007b) were also used to benchmark the HTS sample.

2.1 Measures of disadvantage and exclusion

The SEIFA Index of Relative Socio-economic Disadvantage (IRSD) is one of four socio-economic indexes produced by the ABS based on data from the Census of Population and Housing. It is an areal measure of disadvantage which combines a range of socio-economic indicators for each area (such as the proportion of households in public or community housing, and the proportion of people aged 15 years and over without a post-school qualification) into an index which can be used to compare areas according to their level of disadvantage. ABS (2008b) contains an overview of the use of IRSD and other ABS indexes, and a detailed account of the construction of the indexes can be found in ABS (2008c).

The NATSEM CSE index is conceptually similar to IRSD and incorporates many of the same variables. However, as it is intended to measure social exclusion in children aged 15 and under, rather than in the population more generally, the variables used in its calculation measure characteristics of children in each area, rather than of the general population. The index used is a work-in-progress update of that described in Harding et al. (2009).

IRSD scores for Statistical Local Areas (SLAs) are used in order to match the geographic scale of the CSE index. Both IRSD and CSE indexes are based on the Australian Standard Geographic Classification 2006 edition (ABS 2006).

Particularly in the context of this work (but also more generally), it is important to recognise that the IRSD and CSE indexes are both areal measures, meaning they summarise a wide variety of characteristics of each area in aggregate. According to Adhikari (2006), even if an area is identified as being (comparatively) highly disadvantaged, that “should not be presumed to apply to *all* individuals living within the area”. This caveat applies equally to the CSE index, for precisely the same reasons.

Many different variables are used to calculate both of these indexes, meaning that (for either index) two areas scored equally may be very different in character—they may have obtained their scores for very different reasons. Furthermore, the reasons behind a specific area’s high or low IRSD score may or may not directly relate to the children living in that area: “…An area may have a low SEIFA score because it is largely populated by older Australians on low incomes rather than because it contains disadvantaged children” (Harding et al. 2009).

It is also important to acknowledge that both indexes are at best imperfect measures of the highly complex and arguably unmeasurable underlying concepts: “No single measure can fully capture the concept of relative socio-economic disadvantage” (ABS 2008b).

2.2 Defining the Aggregate Regions

The geographical scope of this study is the Sydney Statistical Division. Ideally, the travel behaviour of children could be compared to IRSD and CSE indexes at the small-area level. However, due to the requirement to maintain the confidentiality of HTS respondents this was not possible. Instead, the HTS sample was split across 5 non-contiguous Aggregate Regions which are mutually exclusive and collectively exhaustive with respect to the Sydney Statistical Division. Each Aggregate Region was defined by the SLA-level IRSD and CSE index scores, and their compositions are detailed in Table 1, while Figure 1 displays the spatial distribution of each of these Aggregate Regions.

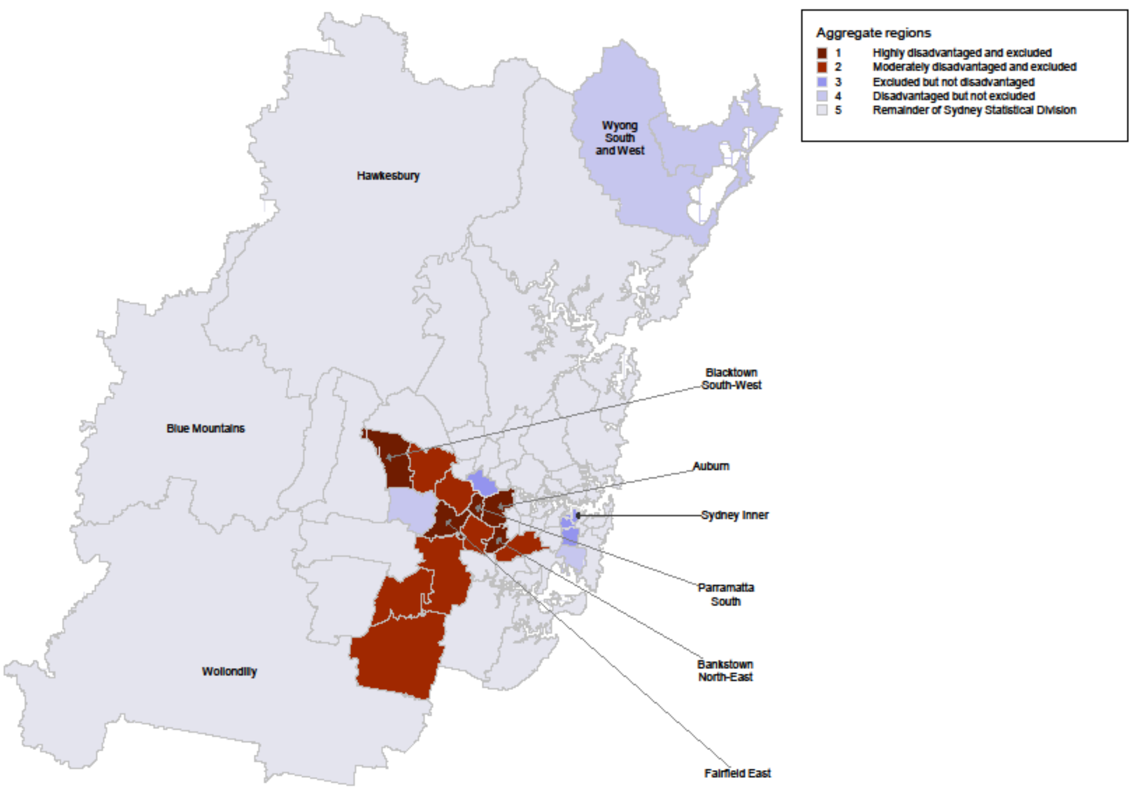
The choice of Aggregate Regions was intended to facilitate two types of comparison: Firstly, to compare both CSE-excluded and IRSD-disadvantaged SLAs against the remainder of the Sydney Statistical Division; and secondly, to compare regions scored substantially differently by IRSD and CSE against each other. However, in practice the sample size obtained for Aggregate Region 3 was insufficient for this second aim—see Table 2 below, and the results presented in the first part of Section 4.

Table 1: Composition of Aggregate Regions

Aggregate Region	Description	Criteria	SLA composition	Population share, 2006 (per cent)
1	Highly disadvantaged and excluded	IRSD: decile 1 CSE: decile 1	Auburn Bankstown—North-East Blacktown—South-West Fairfield—East Parramatta—South	8.6
2	Moderately disadvantaged and excluded	IRSD: quartile 1 CSE: quartile 1 Not in Aggregate Region 1	Bankstown—North-West Blacktown—South-East Campbelltown—North Campbelltown—South Canterbury Holroyd Liverpool—East	14.8
3	Excluded but not disadvantaged	IRSD: quartile 2+ CSE: quartile 1	Parramatta—Inner Sydney—Inner Sydney—South Sydney—West	3.7
4	Disadvantaged but not excluded	IRSD: quartile 1 CSE: quartile 2+	Botany Bay Fairfield—West Wyong—North-East Wyong—South and West	5.9
5	Remainder of Sydney Statistical Division	IRSD: quartile 2+ CSE: quartile 2+	Remaining 44 SLAs	67.0

Source: Authors' analysis of ABS 2008a, ABS 2008d and NATSEM 2011.
Note: Index percentiles are calculated based on the 64 SLAs in the Sydney Statistical Division (from ABS 2006).

Figure 1: Map displaying SLA membership of five Aggregate Regions



Source: Authors' analysis using ABS 2006 Australian Standard Geographical Classification boundaries.

2.3 Sydney Household Travel Survey

The source of information on travel behaviour used in this study is disaggregated data from the Sydney Household Travel Survey (BTS 2011). This data was provided on request by the Bureau of Transport Statistics (request number 11_130), and consists of pooled data from 5 waves of the survey from 2001–02 to 2005–06. The survey collects detailed information from each respondent about their travel on a particular day—their assigned “travel day”.

The data used is based on linked trips. Trips with the purpose “change mode” are collapsed into adjacent trips, assigning the mode for the linked trip according to a decision rule which gives priority to modes “with the largest likely (but not necessarily actual) duration” (TDC 2010, p. 49). Trips with purpose “return home” remain separate trips but have their purpose re-assigned to that of a previous trip according to another decision rule.

This data includes all respondents to the HTS between the ages of 5 and 14 years, and all trips taken by those respondents. Respondents in this age group typically respond by proxy: A parent or other adult provides responses on their behalf. Table 2 details sample sizes for the data used, by Aggregate Region.

Table 2: Household Travel Survey sample of children aged 5 to 14 by Aggregate Region

Aggregate Region	Person observations	Trip observations	Mean trips per child (unweighted)
Total	**4 860**	**15 393**	**3.2**
1. Highly disadvantaged and excluded	415	1 224	2.9
2. Moderately disadvantaged and excluded	832	2 373	2.9
3. Excluded but not disadvantaged	59	185	3.1
4. Disadvantaged but not excluded	318	1 023	3.2
5. Remainder of Statistical Division	3 236	10 588	3.3

Source: Authors’ analysis of BTS 2011.

A wide range of factors relating to the attributes of the households, persons, and trips in the dataset were included, and those that were used in the analysis are detailed in Table 3. Information on departure and arrival times was provided, but was not analysed for this paper.

Table 3: Household Travel Survey factors used

Factor	Applies to	Levels
Age group	Person	“5 to 9 years”, “10 to 14 years”
Travel day	Person	“Weekday”, “Weekend”
Dwelling structure	Household	“Separate house”, “Semi-detached”, “Flat/unit”, “Other”
Household type	Household	“Couple with children”, ”One parent with children”, ”Other”
Household size	Household	“2 persons”, “3 persons”, “4 persons”, ”5 persons”, ”6+ persons”
Number of vehicles	Household	“0 vehicles”, ”1 vehicle”, ”2 vehicles”, ”3+ vehicles”
Distance	Trip	“1km or less”, “>1km-2km”, “>2km-5km”, “>5km-10km”, “>10km-20km”, “>20km”
Duration	Trip	“5min or less”, “6-10min”, “11-20min”, “21-30min”, “31-40min”, “41+min”
Mode	Trip	“Vehicle passenger”, “Train”, “Bus/ferry”, “Walk”, “Bicycle”, “Other”
Purpose	Trip	“Education/childcare”, “Shopping”, “Personal business”, “Social/recreational”, “Sport (participate)”, “Sport (other)/entertainment”, “Serve passenger”, “Other”

Source: BTS 2011.

In this paper special focus is given to trip purpose, and in particular those defined as “leisure” purposes: “sport (participate)”, “sport (other)/entertainment”, and “social/recreational”. It is assumed that the number of trips for these purposes is a good proxy for levels of participation in the associated activities, and as such that a conceptual alignment exists with the engagement and connectedness aspects of social exclusion.

Furthermore, there was an *a priori* expectation that any variations would be greater for trips with these purposes, as activities of these types are in some sense “optional” as compared with “education/childcare” and “shopping”. For the purposes “personal business”, “serve passenger” and “other” it was unclear what these meant either in the context of children or more generally.

2.3.1 Weighting in the Household Travel Survey

Each respondent in the person dataset is assigned a person weight. These weights are calculated to expand the sample to match 2006 Estimated Resident Population (ABS 2007b) based area of residence, gender, and age group.

Each trip is further weighted based on whether the travel day of the respondent is a weekday or weekend day to correct for the relative number of people assigned weekday versus weekend travel days. This is necessary because no information on weekend trips is collected from people who are assigned a weekday travel day, and vice versa. As such, even though the sample as a whole has been expanded to match the population, the sub-sample of people with weekday travel days represents only a proportion of the population. This proportion must be expanded again to estimate total trips per weekday for the whole population, and similarly for weekend trips.

The expansion factors used in the source data are 1.4 for weekday trips and 3.5 for weekend trips, implying 2.5 persons with weekday travel days per person with a weekend travel day (i.e. that 5 out of every 7 respondents in the sample are allocated a weekday and 2 are allocated a weekend day). However, the data used in this study is a small subset of the overall HTS sample, and the relative proportions of weekend and weekday travel days in this subset do not correspond to those implied by the travel day expansion factors as shown in Table 4.

The corrected expansion factors are applied to the person weights to produce day weights, which are then used to calculate the weighted mean number of trips. This has no effect on the result for weekend or weekday trips in isolation (see appendix), but prevents weekends from being over-represented when a mean for the whole week is calculated.

Table 4: Summary of adjustment to Household Travel Survey day weights

	Weekday sub-sample	Weekend sub-sample
Number of observations (persons)	3 422	1 438
Sum of person weights	384 509	163 195
Trip expansion factor	1.400	3.500
Implied weighted sample fraction (%)	71.4	28.6
Actual weighted sample fraction (%)	70.2	29.8
Corrected expansion factor	1.424	3.356

Source: Authors’ analysis of BTS 2011.

This does not guarantee a consistent weekday/weekend split for smaller sub-samples of the dataset (e.g. for individual Aggregate Regions).

2.3.2 Benchmarking Household Travel Survey data by Aggregate Region

Weighting is assigned to HTS responses to match 2006 Estimated Resident Population (ABS 2008d) by gender, age category, and area of residence. However, the age category used to calculate the weights is “0 to 14 years”, which is broader than that in the data used in this study. This could result in a mismatch between survey-based estimates of population totals and the actual population. Table 5 examines this.

Table 5: Comparison of 2006 Estimated Resident Population and Household Travel Survey estimates of population by Aggregate Region

	Aggregate Region					Total Statistical Division
	1	2	3	4	5	
Persons aged 5 to 14 years						
Estimated Resident Population 2006	56 973	90 416	8 322	35 749	350 349	541 809
HTS estimate	53 275	99 801	7 990	37 851	348 786	547 704
Standard error (HTS)	2 598	3 434	1 042	2 108	6 076	7 788
Persons aged 5 to 9 years						
Per cent of total Estimated Resident Population aged 5 to 14	50.7	50.3	52.8	48.0	49.8	49.9
Per cent of HTS total aged 5 to 14	47.9	50.2	56.2	47.2	50.2	49.8
Standard error (HTS %)	2.5	1.7	6.5	2.8	0.9	0.7

Source: Authors' analysis of BTS 2011 and ABS 2008d.

As shown, for the Sydney Statistical Division the HTS only slightly overestimates the number of people aged 5 to 14 years compared to 2006 Estimated Resident Population. For individual aggregate regions, there are some more noticeable differences. The HTS estimate for Aggregate Region 2 is substantially greater than the 2006 Estimated Resident Population figure, although the split between persons aged 5 to 9 and those aged 10 to 14 is very close to the Estimated Resident Population figures. Overall the split between the age groups is very close to the benchmark, although it is slightly off for the regions with smaller samples (particularly Aggregate Region 3).

3 Household Travel Survey analysis

This section investigates the relationships between the factors in the HTS data and trip propensity, both overall and for various specific types of trip.

3.1 Person-level factors

Table 6 compares trip propensity by age group and travel day for total trips and trips for leisure purposes only, while Table 7 examines trip propensities by age group and trip purpose, mode, and duration. It is interesting to note that neither age group nor travel day is a significant factor in determining overall trip propensity. This is somewhat unexpected, particularly in the case of travel day, as the activities generating trips differ substantially between weekdays and weekend days. However they are both significant factors in determining trip propensity for leisure trips, as shown.

Table 6: Trip propensity by age group and travel day

	Mean trips per day			Test of equality			
	Estimate	SE	N	Welch's t	d.f.	P-value	Sig
All trips	3.180	0.031	4 860				
Travel day: Weekday	3.179	0.035	3 422	-0.033	2 305	0.9737	
Travel day: Weekend	3.182	0.065	1 438	0.033	2 305	0.9737	
Age group: 5 to 9 years	3.210	0.043	2 445	0.972	4 844	0.3309	
Age group: 10 to 14 years	3.150	0.045	2 415	-0.972	4 844	0.3309	
Leisure trips only	1.145	0.022	4 860				
Travel day: Weekday	0.856	0.022	3 422	-19.382	2 068	< 0.0001	***
Travel day: Weekend	1.870	0.048	1 438	19.382	2 068	< 0.0001	***
Age group: 5 to 9 years	1.072	0.029	2 445	-3.356	4 814	0.0008	**
Age group: 10 to 14 years	1.218	0.032	2 415	3.356	4 814	0.0008	**

Source: Authors' analysis of BTS 2011.
Notes: Significance levels are *** = 0.0001, ** = 0.001, * = 0.01, · = 0.1. The means for each pair of factor levels are tested for equality against each other. Leisure trips are those with purposes "Social/recreational", "Sport (participate)", or "Sport (other)/entertainment".

When considering the more detailed trip breakdown shown in Table 7, further differences between age groups and travel days become apparent. On weekdays, children aged 10 to 14 take less trips by private vehicle, more trips by active modes, and far more trips by public transport than children aged 5 to 9 (differences which are all highly significant). Children in the older age group also take significantly more long trips and less short trips on weekdays. Differences in distance and duration between age groups are not significant for trips on weekends, and in general the number and type of trips taken on weekends does not differ markedly between the age groups.

The most noticeable results from Table 7 are the differences between weekday and weekend travel by trip purpose, although these could hardly be described as unexpected. Naturally, many trips on weekdays for both age groups are for the purpose of education or childcare, while very few trips for this purpose occur on weekends. On average, more than twice as many trips for leisure purposes occur on weekend days than occur on weekdays. Children in the younger age group take slightly less leisure trips than those in the older age group on weekdays ($P = 0.0005$), but this difference is not significant for weekend days.

There are also some highly significant differences in transport mode between weekday and weekend travel. Comparatively few trips are made by public transport (train, bus or ferry) on weekends by children in either age group, and significantly more trips on weekends are by private vehicle compared with weekdays for children in the older age group (although there is no difference for the younger age group). Trips by train make up less than 25% of total public transport trips in the dataset, with the remainder being either bus or ferry trips. Although bus and ferry trips are not differentiated in the data, it is safe to assume that the vast majority of these trips are by bus.

Table 7: Trip propensity by age group, travel day, and type of trip

Factor level	Mean trips per weekday		Mean trips per weekend day	
	Estimate	SE	Estimate	SE
Age 5 to 9 years	3.210	0.048	3.211	0.090
Mode: Private vehicle	2.425	0.049	2.591	0.084
Mode: Public transport	0.160	0.012	0.037	0.011
Mode: Active (walking/cycling)	0.598	0.025	0.575	0.044
Mode: Other	0.027	0.005	0.007	0.004
Purpose: Education/childcare	1.515	0.024	0.013	0.006
Purpose: Leisure	0.780	0.029	1.810	0.065
Purpose: All others	0.915	0.037	1.389	0.065
Distance: 2km or less	1.494	0.037	1.123	0.057
Distance: 2km to 5km	0.916	0.031	0.834	0.046
Distance: 5km to 10km	0.460	0.022	0.551	0.039
Distance: More than 10km	0.327	0.020	0.681	0.042
Duration: 10 minutes or less	2.017	0.043	1.662	0.067
Duration: 10 to 20 minutes	0.747	0.025	0.845	0.045
Duration: 20 to 30 minutes	0.238	0.014	0.358	0.027
Duration: More than 30 minutes	0.204	0.013	0.346	0.028
Age 10 to 14 years	3.148	0.050	3.153	0.094
Mode: Private vehicle	1.812	0.048	2.421	0.086
Mode: Public transport	0.547	0.022	0.046	0.011
Mode: Active (walking/cycling)	0.747	0.032	0.663	0.051
Mode: Other	0.042	0.007	0.024	0.009
Purpose: Education/childcare	1.435	0.024	0.024	0.009
Purpose: Leisure	0.932	0.033	1.929	0.069
Purpose: All others	0.781	0.035	1.201	0.063
Distance: 2km or less	1.218	0.037	1.117	0.063
Distance: 2km to 5km	0.890	0.030	0.770	0.046
Distance: 5km to 10km	0.547	0.023	0.514	0.035
Distance: More than 10km	0.477	0.023	0.732	0.044
Duration: Less than 10 minutes	1.576	0.044	1.676	0.073
Duration: 10 to 20 minutes	0.755	0.025	0.768	0.042
Duration: 20 to 30 minutes	0.336	0.016	0.397	0.028
Duration: More than 30 minutes	0.482	0.020	0.313	0.025

Source: Authors' analysis of BTS 2011.
Note: Leisure purposes are "Social/recreational", "Sport (participate)", and "Sport (other)/entertainment".

3.2 Household-level factors

This section examines the effects of household factors (household type, household size, dwelling structure, and household vehicles) on overall trip propensity for each age group/travel day subset of the HTS data.

Table 8 shows estimates of mean trips per day for various factor levels, and tests each level for equality against the mean for the level with the most observations. This choice of comparison point is somewhat arbitrary, but for each of the factors below it represents a reasonable "typical" value and has the advantage of producing readily interpretable test statistics. An alternative is to compare each level against the mean for all other levels. In this case the results produced are very similar, but are more difficult to interpret than those presented.

Table 8: Trip propensity by household factors

Factor level	Mean trips per day			Test of equality			
	Estimate	SE	N	Welch's t	d.f.	P-value	Sig
All observations	3.180	0.031	4 860				
Dwelling structure							
Separate house^	3.194	0.034	4 181				
Semi-detached	3.086	0.111	373	-0.925	443	0.3554	
Flat/unit	3.114	0.116	298	-0.660	350	0.5096	
Other dwellings	2.961	0.889	8	-0.261	7	0.8014	
Household type							
Couple with children^	3.232	0.036	3 788				
One parent with children	3.039	0.085	632	-2.097	866	0.0363	·
Other households	2.776	0.098	440	-4.382	561	< 0.0001	***
Household size							
2 persons	3.111	0.196	138	-0.631	154	0.5290	
3 persons	3.306	0.089	554	0.674	897	0.5004	
4 persons^	3.238	0.048	1 946				
5 persons	3.262	0.061	1 346	0.311	2 766	0.7560	
6+ persons	2.816	0.075	876	-4.770	1 619	< 0.0001	***
Household vehicles							
0 vehicles	2.711	0.121	225	-4.729	286	< 0.0001	***
1 vehicle	3.072	0.057	1 483	-3.432	3 110	0.0006	**
2 vehicles^	3.318	0.044	2 536				
3+ vehicles	3.083	0.086	616	-2.427	954	0.0154	·

Source: Authors' analysis of BTS 2011.
Notes: Significance levels are *** = 0.0001, ** = 0.001, * = 0.01, · = 0.1. The mean for each factor level is tested for equality against the mean for the level with the largest N (which is denoted by the ^ symbol).

As shown, even those differences in trip propensity that are highly significant are relatively small in magnitude—half a trip per day at most. Some levels have comparatively high standard errors associated with their estimates, so a larger sample may have revealed additional differences that are not apparent from this data.

Dwelling structure has no level which has a significantly different trip propensity to Separate House, and in fact no two levels are significantly different to each other.

In contrast, household type and household size both have a noticeable impact on trip propensity. The difference in trip propensity between "Couple with children" households and the other levels is significant, although in the case of one parent households only marginally so. There is also a marginally significant difference between "Other households" and one parent households. Children in large households (6 members or more) have noticeably lower trip propensity than 3, 4 or 5 person households. The sample for 2-member households is too small to produce a particularly reliable estimate. It is worth noting that all 2-member households are also "One parent with children" households.

Finally, there are significant differences in trip propensity between various levels of the household vehicles factor. Trip propensity is significantly lower for children in households with 0 vehicles and higher for those living in households with 2 vehicles than it is for 1 vehicle or 3+ vehicle households.

4 Results by Aggregate Region

This section investigates what differences exist in trip propensity between different Aggregate Regions, controlling for the effect of the factors examined in Section 3 where necessary. The overview examines differences between the Aggregate Regions at a broad level and assesses whether either CSE or IRSD is measurably better than the other as a predictor of children's trip propensity. More detailed comparisons below focus on the differences in trip propensity between socially excluded areas according to the CSE index (Aggregate Regions 1, 2 and 3)—which will subsequently be referred to as the excluded statistical local areas—and the remainder of the Sydney Statistical Division (Aggregate Regions 4 and 5).

For certain factors, there is evidence to suggest that the distribution of observations across factor levels may differ between Aggregate Regions. In particular, each level of the household vehicles factor cannot be assumed to contain the same proportion of total observations for each Aggregate Region. This is due to both IRSD and CSE index incorporating vehicle ownership into the construction of the index. Due to the significant differences observed in trip propensity across different levels of household vehicles in Section 3, different levels of vehicle ownership are examined separately in some of the more detailed analysis in this section.

Although age group was found to be significant factor for certain types of trip, the distribution of observations between age groups is relatively constant across Aggregate Regions (see Table 5 above). As such, there was thought to be no need to control for this factor (although some results are presented by age group).

As discussed in Section 3, travel day has a major effect on trip propensity for particular modes and trip purposes. The day-adjustment applied to the weights allowed trip propensity to be estimated across an entire week for the Sydney Statistical Division as a whole. However, this adjustment was applied to the whole dataset, not at the level of individual Aggregate Regions. As such, when comparing Aggregate Regions, the results for weekend and weekday travel days are examined separately.

In addition to the results presented below, differences in trip distance and duration were also examined. It was found that trip durations did not vary significantly between excluded and other SLAs. For children in excluded SLAs, a slightly larger proportion of their trips were short trips (less than 2km), and a slightly smaller proportion were between 5km and 20km. These differences were not highly significant, and are not further considered here.

4.1 Overview

Table 10 summarises overall trip propensity by Aggregate Region and travel day, and tests the means for Aggregate Regions 1 to 4 for equality with Aggregate Region 5. As shown, the estimate for Aggregate Region 5 is higher than for each of the other aggregate regions. However, only the estimates for Aggregate Regions 1 (weekends) and 2 (both travel days) are significantly different from that for Aggregate Region 5.

In order to determine whether the CSE index performs better than the IRSD in predicting the travel behaviour of children a comparison was made between Aggregate Regions 3 and 4. These Aggregate Regions contain the eight SLAs which were scored in the bottom quartile in the Sydney Statistical Division by only one of the two indexes. Among these SLAs, the difference between the indexes ranged from 8 to 40 percentile points with the mean absolute difference being 17 percentile points.

Comparing Aggregate Regions 3 and 4 directly shows that the differences in trip propensity evident in Table 10 are not significant ($P = 0.5292$ for weekdays and $P = 0.8635$ for weekends). This provides no evidence of a systematic difference between these regions. However, even at the travel day sub-sample level the standard errors associated with estimates of means are relatively large compared to the magnitude of variations in trip propensity observed elsewhere. Variations due to different household and person factors were less than 0.5 trips per day in most cases. In other words, the estimates of mean trips per day for these regions are not precise enough to detect differences on the scale of those that might reasonably be expected to exist. As such, this result should be considered inconclusive.

Table 10: Trip propensity by aggregate region and travel day

Aggregate region	Mean trips per day			Test of equality			
	Estimate	SE	N	Welch's t	d.f.	P-value	Sig
Weekdays							
1. Highly disadvantaged and excluded	3.094	0.100	288	-1.599	409	0.1105	
2. Moderately disadvantaged and excluded	2.949	0.078	604	-3.580	1032	0.0004	**
3. Excluded but not disadvantaged	2.898	0.355	28	-1.037	28	0.3089	
4. Disadvantaged but not excluded	3.142	0.145	225	-0.841	268	0.4012	
5. Remainder of Statistical Division	3.269	0.044	2277				
Weekend days							
1. Highly disadvantaged and excluded	2.669	0.204	127	-3.274	167	0.0013	*
2. Moderately disadvantaged and excluded	2.670	0.147	228	-4.287	375	< 0.0001	***
3. Excluded but not disadvantaged	3.210	0.419	31	-0.414	32	0.6813	
4. Disadvantaged but not excluded	3.299	0.305	93	-0.277	105	0.7825	
5. Remainder of Statistical Division	3.387	0.080	959				

Source: Authors' analysis of BTS 2011.
Notes: Significance levels are *** = 0.0001, ** = 0.001, * = 0.01, · = 0.1. The means for aggregate regions 1 to 4 are tested for equality against the mean for aggregate region 5.

No further attempts were made to compare Aggregate Regions 3 and 4 directly, as any disaggregation of the sample by other factors results in unacceptably small sub-samples. This was particularly true for Aggregate Region 3: the result of disaggregating Aggregate Region 3 by age group as well as travel day is four sub-samples each containing between 12 and 19 observations—not nearly sufficient to detect differences of the magnitudes observed elsewhere.

For the remainder of this section comparisons focus on the excluded SLAs (i.e. Aggregate Regions 1, 2 and 3). These Aggregate Regions contain the 16 SLAs representing the most socially excluded quartile based on the CSE index values for SLAs in the Sydney Statistical Division. The excluded SLAs are compared as a group against Aggregate Regions 4 and 5, which represent the remainder of the Sydney Statistical Division. The excluded SLAs are characterised by high proportions of children living in:

- families where no one has completed Year 12
- low income households
- dwellings with no internet connection (McNamara et al 2008).

As Table 11 above shows, estimates of trip propensity for this group of excluded SLAs are significantly lower than other SLAs for both weekend and weekday trips. These differences are also significant when considering only trips for leisure purposes, which represent participation in activities which are linked to the concepts of social exclusion of children.

These differences are also all moderately to highly significant for the subset of children in the 5 to 9 years age group. Differences are smaller in magnitude and generally not significant for the older age group on its own.

Children in excluded SLAs take approximately 10% fewer trips on weekdays and 20% fewer trips on weekends than children in other areas of Sydney. Looking only at leisure trips, children in excluded SLAs take approximately 15% fewer trips on both weekday and weekend travel days. The significantly lower rate of trips by children in the excluded SLAs is consistent with previous analysis of the HTS undertaken by Lyth-Gollner and Dowling (2002), which identified a gap between the relatively high motor vehicle trip rates of women with children aged 0 to 14 in some of Sydney's more affluent areas (e.g. Northern Beaches, Eastern Suburbs) and the lower trip rates in the more disadvantaged central western and south western suburbs.

Table 11: Trip propensity by person factors, comparison of excluded and other SLAs

Factor level	Mean trips per day				Test of equality	
	Excluded SLAs		Other SLAs			
	Estimate	SE	Estimate	SE	P-value	Sig
All trips						
Weekdays, all ages	2.994	0.061	3.256	0.042	0.0004	**
Weekdays, ages 5 to 9	2.959	0.079	3.312	0.060	0.0004	**
Weekdays, ages 10 to 14	3.027	0.092	3.200	0.060	0.1159	
Weekends, all ages	2.715	0.115	3.379	0.078	< 0.0001	***
Weekends, ages 5 to 9	2.628	0.158	3.471	0.107	< 0.0001	***
Weekends, ages 10 to 14	2.809	0.167	3.291	0.113	0.0175	·
Leisure trips only						
Weekdays, all ages	0.750	0.042	0.900	0.026	0.0022	*
Weekdays, ages 5 to 9	0.620	0.052	0.844	0.035	0.0004	**
Weekdays, ages 10 to 14	0.874	0.065	0.956	0.038	0.2727	
Weekends, all ages	1.635	0.084	1.969	0.057	0.0010	*
Weekends, ages 5 to 9	1.509	0.115	1.944	0.078	0.0019	*
Weekends, ages 10 to 14	1.768	0.121	1.993	0.084	0.1279	

Source: Authors' analysis of BTS 2011.
Notes: Significance levels are *** = 0.0001, ** = 0.001, * = 0.01, · = 0.1. Leisure trips are those with purposes "Social/recreational", "Sport (participate)", or "Sport (other)/entertainment". Excluded SLAs are those classified to Aggregate Regions 1, 2 or 3. Other SLAs are those classified to Aggregate Regions 4 or 5.

4.2 Trip purpose

Table 12 examines trip purpose in more detail. On weekends, there are highly significant differences in trip propensity for trips with purposes "sport (participate)", "sport (other)/entertainment" and "serve passenger" between excluded and other SLAs. On weekdays, there is also a highly significant difference in trip propensity for "serve passenger" trips, and a moderately significant difference in "sport (other)/entertainment" trips. In each of these cases, children in excluded SLAs take fewer trips on average.

Also on weekdays, there is a moderately significant difference in trips for the purpose of "Education/childcare". This is the only combination of purpose and travel day for which the mean for excluded SLAs is significantly higher than for other SLAs.

Table 12: Trip propensity by trip purpose, comparison of excluded and other SLAs

Trip purpose	Mean trips per day				Test of equality	
	Excluded SLAs		Other SLAs			
	Estimate	SE	Estimate	SE	P-value	Sig
Weekday trips	2.994	0.061	3.256	0.042	0.0004	**
Education/childcare	1.548	0.032	1.445	0.020	0.0068	*
Social/recreational	0.424	0.033	0.475	0.019	0.1759	
Sport (participate)	0.174	0.018	0.206	0.012	0.1338	
Sport (other)/entertainment	0.152	0.020	0.219	0.013	0.0052	*
Shopping	0.120	0.017	0.115	0.009	0.8250	
Personal Business	0.071	0.012	0.087	0.008	0.2536	
Serve passenger	0.503	0.036	0.698	0.028	< 0.0001	***
Other purposes	0.003	0.003	0.011	0.004	0.0884	·
Weekend trips	2.715	0.115	3.379	0.078	< 0.0001	***
Education/childcare	0.015	0.009	0.019	0.007	0.7072	
Social/recreational	1.088	0.071	1.032	0.046	0.5072	
Sport (participate)	0.127	0.023	0.281	0.022	< 0.0001	***
Sport (other)/entertainment	0.420	0.047	0.656	0.034	< 0.0001	***
Shopping	0.291	0.044	0.295	0.024	0.9251	
Personal Business	0.078	0.019	0.106	0.014	0.2322	
Serve passenger	0.682	0.060	0.975	0.048	0.0001	**
Other purposes	0.014	0.010	0.014	0.005	0.9471	

Source: Authors' analysis of BTS 2011.
Notes: Significance levels are *** = 0.0001, ** = 0.001, * = 0.01, · = 0.1. Excluded SLAs are those classified to Aggregate Regions 1, 2 or 3. Other SLAs are those classified to Aggregate Regions 4 or 5.

Table 13 assesses whether differences still exist between excluded and other SLAs when different levels of vehicle ownership are examined separately. As evidenced by the size of the standard errors for many of the estimates in Table 13, these results are near the limit on the level of detail that can sensibly be extracted from the HTS dataset used. For many of the results presented previously, standard errors greater than 0.1 trips per day would have obscured the differences observed. It is reasonable to conclude that this may be occurring here, particularly for weekend trips by households with zero vehicles or 3+ vehicles for which sample sizes for excluded SLAs are particularly small (29 and 33 observations respectively).

Despite this, there are enough significant results showing fewer trips by children in excluded SLAs to be confident that overall differences in trip propensity between excluded and other SLAs are due to more than differences in vehicle ownership.

Some of the other estimates from Table 13 are also worth comment. The results for weekday trips for children in zero-vehicle households are interesting, and not entirely expected. For excluded SLAs, this figure appears extremely low, and despite the large standard error is significantly lower than the estimates for each of the other levels of vehicle ownership. However, the corresponding estimate for non-excluded SLAs appears odd, as it is significantly greater than the estimate for 1 vehicle households.

Why children in zero-vehicle households should take significantly more trips than households with one or more vehicles is unclear, and it would not be entirely naïve to make *a priori* assumptions that directly contradicts these results. It may be the case that this result is a minor statistical oddity; the difference would still be significant (although only moderately so) if the zero-vehicle estimate was consistent with the other estimates for non-excluded SLAs (i.e. in the range 0.8 to 0.9). However, it is also possible that zero-vehicle ownership implies something fundamentally different for households in excluded areas than it does for households in other areas of Sydney. This is supported by Hurni (2006), who found that the relationship between the proportion of zero-vehicle households and household income was not consistent across different areas of Sydney. In particular, in some areas of Sydney households with weekly income above $1500 were more likely to own zero vehicles than households earning between $500 and $1500 per week.

Table 13: Trip propensity by purpose and household vehicles, comparison of excluded and other SLAs

Trip purpose	Mean trips per day				Test of equality	
	Excluded SLAs		Other SLAs			
	Estimate	SE	Estimate	SE	P-value	Sig
Weekday trips						
0 vehicles: Leisure purposes	0.377	0.101	1.202	0.162	< 0.0001	***
1 vehicle: Leisure purposes	0.708	0.065	0.797	0.045	0.2608	
2 vehicles: Leisure purposes	0.841	0.067	0.946	0.035	0.1654	
3+ vehicles: Leisure purposes	0.931	0.145	0.859	0.070	0.6562	
0 vehicles: Non-leisure purposes	2.086	0.099	1.920	0.154	0.3683	
1 vehicle: Non-leisure purposes	2.221	0.080	2.352	0.066	0.2105	
2 vehicles: Non-leisure purposes	2.361	0.069	2.355	0.045	0.9390	
3+ vehicles: Non-leisure purposes	1.838	0.134	2.486	0.091	0.0001	**
Weekend trips						
0 vehicles: Leisure purposes	1.385	0.351	1.725	0.293	0.4605	
1 vehicle: Leisure purposes	1.370	0.121	2.008	0.115	0.0002	**
2 vehicles: Leisure purposes	1.871	0.123	2.121	0.076	0.0848	·
3+ vehicles: Leisure purposes	2.106	0.349	1.250	0.126	0.0262	·
0 vehicles: Non-leisure purposes	0.682	0.203	1.269	0.234	0.0614	·
1 vehicle: Non-leisure purposes	1.048	0.125	1.518	0.113	0.0056	*
2 vehicles: Non-leisure purposes	1.235	0.120	1.394	0.076	0.2631	
3+ vehicles: Non-leisure purposes	0.900	0.246	1.292	0.127	0.1632	

Source: Authors' analysis of BTS 2011.
Notes: Significance levels are *** = 0.0001, ** = 0.001, * = 0.01, · = 0.1. Leisure purposes are "Social/recreational", "Sport (participate)" and "Sport (other)/entertainment". Excluded SLAs are those classified to Aggregate Regions 1, 2 or 3. Other SLAs are those classified to Aggregate Regions 4 or 5.

For weekend trips, sample sizes are too small (and therefore SEs too large) to detect any difference in trip propensity for zero-vehicle households. However, there are significant differences for 1-vehicle households, with those in excluded SLAs taking fewer trips than those in other SLAs both for leisure and non-leisure purposes.

The results for 3+ vehicle households are also inconclusive despite the size of the difference in estimates. The reason behind the comparatively low estimate for non-excluded SLAs is again unclear, but many of the same points discussed above in the context of weekday trips by zero-vehicle households also apply here.

4.3 Mode of travel

Finally, differences in mode of travel between excluded and other SLAs are briefly examined. Rather than the average number of trips, the proportion of total trips (the "trip share") for each mode is the metric used for comparisons by mode. The estimates are calculated in a similar manner as average number of trips: As a weighted mean of the trip shares by mode for each respondent. Each observation is weighted by both the adjusted person weight and by the total number of trips that observation represents.

Table 14: Leisure trip shares by mode, comparison of excluded and other SLAs

Mode of travel	Mean trips per day				Test of equality	
	Excluded SLAs		Other SLAs			
	Estimate	SE	Estimate	SE	P-value	Sig
Weekdays	1.000		1.000			
Private vehicle	0.622	0.026	0.682	0.013	0.0384	·
Public transport	0.055	0.012	0.043	0.005	0.3390	
Active modes	0.315	0.024	0.258	0.012	0.0365	·
Other	0.008	0.005	0.018	0.004	0.1184	
Weekend days	1.000		1.000			
Private vehicle	0.738	0.024	0.757	0.014	0.5125	
Public transport	0.015	0.006	0.016	0.004	0.8115	
Active modes	0.247	0.024	0.220	0.013	0.3227	
Other	nil	n.a.	0.007	0.002	n.a.	

Source: Authors' analysis of BTS 2011.
Notes: Significance levels are *** = 0.0001, ** = 0.001, * = 0.01, · = 0.1. Excluded SLAs are those classified to Aggregate Regions 1, 2 or 3. Other SLAs are those classified to Aggregate Regions 4 or 5.

There are marginally significant differences in the proportion of weekday leisure trips by private vehicle and active modes between socially excluded and other areas of Sydney (see Table 14 above). For children living in excluded areas, 31.5% of their weekday leisure trips were walking/cycling trips, compared to 25.8% for other areas. The link between active travel and social exclusion is of particular relevance in the context of rising obesity levels amongst Australian children (Salmon et al 2005), with previous studies providing mixed evidence as to whether active travel is more or less common amongst children from lower socio-economic status backgrounds (e.g. Carlin et al 1997, Timperio et al 2004). There is no significant difference in trip share for weekend leisure travel.

Excluding responses by the small number of children from households with zero vehicles has no qualitative effect on these results. This suggests that differences in the rate of vehicle ownership between the two groups of SLAs are not responsible for the observed differences in trip shares.

5 Discussion

This paper presents some exploratory analysis of the travel behaviour of 5 to 14 year old children from the HTS, and attempts to identify what (if any) differences exist between areas of high or low disadvantage/social exclusion. In particular, analysis of the number of trips for "leisure" purposes is used to make inferences about the relative levels of participation in the associated activities. These activities (recreation, sport, entertainment) are most closely related to the engagement and connectedness aspects of social exclusion.

Analysing the HTS data for the Sydney Statistical Division as a whole (Section 3) reveals some expected and unexpected results. Although overall the average number of trips per day did not differ between weekdays and weekend days, it is clear that the activities generating trips on weekdays are quite different to those on weekends. Predictably, trips for education/childcare represent nearly half of all weekday trips but virtually no trips on weekends. Some of the other differences between weekdays and weekends (such as differences in modes) are also explained indirectly by the differences in trip purpose: While public transport (particularly bus) is a relatively common way for children to travel to school, it is thought to be less typical for children to use public transport to attend other activities. This is particularly true of children towards the younger end of the age range under study.

Some of the less expected results are perhaps more accurately described as an absence of results. Dwelling structure is notable for its lack of effect on trip propensity, while the difference between couples with children and single parent households might have been expected to be larger than that observed. Household size might also have been expected to have a stronger effect than measured here, with children in households of size 2 to 5 persons having essentially equal trip propensity to each other. Finally, although vehicle ownership strongly affects trip propensity, the relationship is clearly complex. This complexity likely arises from inter-relationships between vehicle ownership and other (unmeasured) factors.

The comparison of trip propensity between regions with different levels of exclusion or disadvantage also provided some interesting results. Excluded SLAs were defined as the 16 SLAs representing the most socially excluded quartile based on the CSE index values for SLAs in the Sydney Statistical Division. Firstly, it is clear that on average, children living in excluded SLAs take somewhat fewer trips on weekdays and substantially fewer trips on weekends than children living in other areas of Sydney, with both of these differences being statistically significant. This remains the case when considering only trips for leisure purposes, suggesting that children living in areas of relatively high social exclusion risk have significantly lower participation in leisure activities than children in other areas of Sydney.

This difference is particularly noticeable for sport and entertainment purposes on weekends, for which children from non-excluded SLAs take nearly twice as many trips per day as children from excluded SLAs. Participation in such activities is recognised as an important factor in both school-age child and adolescent development (see Mahoney et al. 2005 for a detailed discussion in the American context). The relative lack of participation may have adverse effects that persist into adulthood.

Looking at the two age groups separately, for the Sydney Statistical Division overall there is a difference in trip propensity for leisure trips (with 5 to 9 year olds taking significantly less trips than 10 to 14 year olds). However, when excluded and other SLAs are examined separately it is found that no difference in trip propensity between age groups exists for non-excluded SLAs. This suggests that it is the level of participation in the younger age group in particular that is affected by factors contributing to social exclusion risk.

It is clear from some of the more detailed investigations conducted that the relationships between vehicle ownership, disadvantage/exclusion, and travel are highly complex. Based on the results presented here there is evidence to suggest that zero vehicle ownership is a good indicator of leisure trip propensity (and therefore the related aspects of social exclusion) in certain circumstances, but that this relationship does not appear to be universal. Similarly, there is no simple relationship between high vehicle ownership (3+ vehicles), although it does have significant effects. To further unpick this complexity requires additional data than used here, but these results provide some insights into what is clearly an interesting area for further study.

Finally, a comparison between the IRSD and CSE indexes did not conclude that either one is a better predictor of trip propensity amongst children than the other. This was due in large part to the lack of data for the specific regions which are scored differently by the two indexes.

6 Conclusions

This work has clearly demonstrated that links exist between the travel behaviour of individual children in Sydney and small-area measures of both child social exclusion (the NATSEM Child Social Exclusion index) and more general socio-economic disadvantage (the IRSD).

The results presented raise some concerns about the average relative level of participation in “leisure” activities by children from areas of high social exclusion risk compared to other areas of Sydney, and the long-term effects this may have on their development.

More work is needed to determine whether the CSE index performs significantly better than IRSD as a predictor of trip propensity in 5 to 14 year old children. In particular, more precise estimates are required for areas which are scored differently by the two indexes.

It is suggested that future studies focus on providing more spatial detail, as well as undertaking more detailed investigation of the factors found to be correlated with trip propensity.

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Appendices

Mean and variance estimates for weighted samples

Estimates of population and sub-population variances based on the weighted HTS sample are calculated in this paper using the following estimator (see Galassi et al. 2011, p267):

$$\hat{\sigma}^2 = \frac{\sum w_i}{(\sum w_i)^2 - \sum w_i^2} \sum w_i \, (x_i - \hat{\mu}_w)^2$$

$$= \frac{\sum w_i}{(\sum w_i)^2 - \sum w_i^2} \left(\sum w_i x_i^2 - \frac{(\sum w_i \, x_i)^2}{\sum w_i} \right)$$

where x_i is the value of the i^{th} observation, w_i is the non-negative weight associated with the i^{th} observation, and $\hat{\mu}_w$ is the weighted mean of x_i (i.e. $\hat{\mu}_w = \frac{\sum w_i x_i}{\sum w_i}$).

This is an unbiased estimator for weighted data with unknown mean, and reduces to the more familiar variance estimator when w_i are equal (which is equivalent to an unweighted sample). It can also easily be shown that this estimator is invariant under scalar transformations of the weights $w_i^* = cw_i$ for any positive constant c, such as the relative corrections applied to weekday and weekend weights (see Section 2.2).

The standard errors of sample means or proportions are simply:

$$SE(\hat{\mu}) = \sqrt{\frac{\hat{\sigma}^2}{n}}$$

Hypothesis testing without an assumption of equal variances

Welch's t-test (Welch 1938) is an adaptation of “Student's” t-test which is robust to violations of the assumption of equal variances required for the latter. Assumptions of the independence and normality of observations within each sample are still made.

To perform Welch's t-test the following statistic is calculated:

$$t = \frac{\hat{\mu}_1 - \hat{\mu}_2}{\sqrt{\frac{\hat{\sigma}_1^2}{n_1} + \frac{\hat{\sigma}_2^2}{n_2}}}$$

This statistic is then compared to a t-distribution (as per Student's t-test) with degrees of freedom ν approximated using the Welch-Satterthwaite equation:

$$\nu = \frac{\left(\frac{\hat{\sigma}_1^2}{n_1} + \frac{\hat{\sigma}_2^2}{n_2}\right)^2}{\frac{\hat{\sigma}_1^4}{n_1^2(n_1 - 1)} + \frac{\hat{\sigma}_2^4}{n_2^2(n_2 - 1)}}$$

As with Student's t-test, Welch's t-test is relatively robust with respect to modest violations of the normality assumption but not the independence assumption. In the data used, there exist strong correlations between observations at the trip level (i.e. for different trips taken by the same respondent). However, independence of observations at the person level can be assumed to hold for this dataset, and these are the observations on which all t-tests are conducted.

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