

Matt Adams and Ralph Chapman

Do Denser Urban Areas Save on Infrastructure?

Evidence from New Zealand territorial authorities

How urban planners shape urban form and long-lived infrastructure in these coming few years will largely determine whether the world gets locked into a traditional model ... or moves onto a better path, with more compact, connected and liveable cities, greater productivity and reduced climate risk.

— Global Commission on the Economy and Climate, 2014, p.41

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Compact (dense) urban form presents an alternative to the sprawling city development that characterises many younger cities around the world. Sprawl is low-density, car-oriented, dispersed or leapfrog development, typically with segregated land uses (Litman, 2015). Compactness is argued to be an important component of sustainable urban form, other elements of which include destination accessibility, design of street networks, diversity (mix) of land use, density of intersections (connectivity), and distance to destinations by walking and cycling (Ewing and Cervero, 2010). Benefits of sustainable urban form and design, it is claimed, can extend to energy saving, emission reduction, more available green space and even improved community interaction (Jabareen, 2006; Joffe and Smith, 2016; Litman, 2012; Talen, 1999). For example, the Global Commission on the Economy and Climate (2014) argues that: ‘more compact, more connected city forms allow significantly greater energy efficiency and lower emissions per unit of economic activity’ (p.41). Other literature reinforces the significance of the potential economic, environmental and social gains (Creutzig et al., 2015; Ewing et al., 2011; Holman et al., 2015; OECD, 2012).

Arguments for compactness include the agglomeration benefits arising from higher employment density and the easier exchange of ideas, information and services, driving a more productive urban economy (Grimes, 2010). Other arguments include the support of public and active transport modes, meaning fewer cars on the road, shorter commutes, fewer vehicle kilometres travelled, reduced energy consumption and carbon emissions, and healthier lifestyles (Cameron, 2011; Chapman, 2008), as well as more space at the urban periphery for agriculture, biodiversity protection and outdoor recreation. On the other hand, intensification brings greater change for

but an analysis is beyond the scope of this article.

Compactness and infrastructure

In principle, mid- to high-density development means more people can be served by a given investment in networked infrastructure such as roads and water supply. Cities of higher density are argued to have lower infrastructure costs per capita, making them more economically efficient than lower-density development. Higher density can in principle leave local councils more resources to allocate to other services. As cities develop, making good use of the excess capacity of existing infrastructure is preferable to building

expenditures (Litman, 2016, p.43). In short, the evidence base is improving (Litman, 2012; Global Commission on the Economy and Climate, 2014), and grey literature, based on business consultancy studies, provides additional if less robust evidence (e.g. Centre for International Economics, 2015).

The present study examines economic efficiency in relation to the provision of infrastructure by New Zealand's territorial authorities (TAs), considering four key assets: roading, water supply, waste water and storm water. To examine economic costs we use depreciation, an accounting measure that spreads the cost of an asset over its life, as a proxy for the (annual) economic cost of each asset. There is conceptual support for using depreciation as an indicator of the economic cost of replacing infrastructure assets at current service levels (Office of the Auditor-General, 2014, paragraph 2.64).

The rest of this article is structured as follows. First, the methodological approach taken by studies on compactness and infrastructure is briefly examined. Second, the methods used in the present study are detailed. Empirical results are accompanied by a discussion of limitations and implications.

Approach taken by the literature on infrastructure costs

Early US work (Burchell and Mukherji, 2003) used a simulation approach to costs of 'public services' (including infrastructure) for conventional (sprawling) development patterns, comparing them with those of a managed growth (higher density) scenario over 25 years. Burchell and Mukherji took into account lower public service costs associated with sprawl arising from a 'reduced need for a deep public service base' (p.1534), and the higher costs of administering managed growth.

Other research examined the consistency of any relationship between infrastructure costs and density: they found that the cost curve might be U-shaped, first falling and then rising as density increased (Ladd, 1992, 1994). Carruthers and Úlfarsson (2008, 2003) considered how the form of urban

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existing communities (Mead and Ritchie, 2011). There is a need for research to provide planners and local authorities with an evidence base for shaping development to be economically efficient as well as socially and environmentally sustainable. In New Zealand, local authorities spend collectively about \$8 billion annually on infrastructure assets (Department of Internal Affairs, 2013) and their configuration matters economically.

Significant questions relating to compact development include whether, even if it is more economical in some sense, such development is also attractive to people choosing where to live (Arbury, 2005; Carruthers and Úlfarsson, 2008, p.1816). How do people trade off neighbourhood type against housing attributes, and transport factors, for example? There is emerging evidence on this (Dodge and Chapman, 2015; Dodge et al., 2014; Yeoman and Akehurst, 2015),

new infrastructure in areas further from employment. Such new and distant infrastructure may be poorly utilised, especially if growth slows.

The empirical evidence on infrastructure savings from compactness rests largely on some key studies mainly from the United States (e.g. Carruthers and Úlfarsson, 2008, 2003). Recent Spanish research on costs for water supply, sewerage and other services (Prieto, Zofío and Álvarez, 2015) found that infrastructure costs per capita fall as population increases (economies of scale), reinforced by increased density (economies of density), and concluded that most cities studied were below the optimum density for these infrastructure services. Litman's review (2015) indicates that sprawl typically increases the costs of providing a given level of infrastructure by 10–40% (p.28). Litman also refutes the findings of Cox and Utt (2004), who found little effect of density of US municipalities on public service

development (including density) was related to a range of public expenditures (including roadway and sewerage costs) across 283 metropolitan US counties (over 1982–92). They used regression analysis, controlling for property values and other confounders, finding that the cost per capita of most public services fell as density rose. While roading costs declined with density, sewerage costs (waste water and storm water combined) rose with density, although not significantly. The authors concluded that this latter relationship arises because low-density areas tend to use private rather than public facilities. Carruthers and Úlfarsson also noted that regression-based analyses can produce conflicting evidence, partly because of methodological differences but also because of differences in the way the character of urban development is measured (2003, p.507). They noted that density is only one factor characterising urban areas and that other aspects should be considered; and that the use of counties (analogous to TAs in New Zealand) can be problematic where their large size obscures urban density. We minimise this latter difficulty in the present study by using a population-weighted density measure for TAs.

Urban densities (whether dwelling or population densities) are measured in the literature in various ways, including gross, net and population-weighted density. Gross density is simply the number of people or dwellings in a geographic zone (e.g. a region, a district, a census area unit or a meshblock) divided by the zone's land area. It includes land areas of all uses, whether urban, suburban, rural or wilderness. Accordingly, the existence of parks, natural environments and undeveloped land within a set zone can skew results (Nunns, 2014). Net density includes only zones of a particular land use (Zhao, Chapman and Howden-Chapman, 2011): exclusion of open space or parks within a city's boundary arguably gives a more accurate portrayal of the density experienced by a city's population.

Population-weighted density assigns a weight to each zone of a city's land area based on that zone's population. This weight is applied to the average density of the zone, and zones are then summed

to give the city's overall population-weighted density. This accords greater salience to those areas of high population. An advantage of this measure is that it indicates better how density varies across a city (Mead, 2014) and considers where people actually live. If population growth occurs at lower densities (for example, in greenfields), the lower-density area will gain a higher weighting, thus bringing down the population-weighted density of a city. Also, population-weighted density better indicates the density residents experience, and thus more typical economic and liveability impacts. But it is more difficult to compute (Litman, 2015) and, in New Zealand, accurate calculations are limited to census years.

Method

Density

We calculated population-weighted densities using 2013 census data for every territorial authority, with meshblock zones for weight calculations. Meshblock land areas were obtained from Statistics New Zealand,² as were population data (Statistics New Zealand, 2013). Densities were calculated at TA level to match the financial information on infrastructure costs (in required audited public reports) only publicly available at TA level. Thus we could compare TA density to infrastructure costs.³

Financial data

We used depreciation for infrastructure assets presented in TA financial statements as a proxy for annual infrastructure costs. Depreciation spreads an asset's capital costs over its useful life. The result is an annual expense which reduces an asset's carrying value (asset cost or value less depreciation accumulated since the asset was recognised) in the financial statements.⁴ Typically, this depreciation is calculated on a straight-line basis.⁵ (Supplementary

Table 1: Top five densest New Zealand territorial authorities (people per hectare)

Territorial Authority	Population-weighted density people per ha
Wellington City	57.40
Auckland	46.33
Dunedin City	34.09
Christchurch City	30.00
Hamilton City	29.91

information on depreciation is available from the authors.)

Depreciation was chosen over other potential measures of infrastructure costs, such as operating and capital

The fast-growing TAs of higher density maintain roading costs lower than those of more dispersed TAs.

expenditure, for several reasons. Firstly, in a recent report on the management of road and three waters (water supply, waste water and storm water) infrastructure, depreciation is identified as an appropriate estimate of the expenditure required to maintain infrastructure asset service capacity (Office of the Auditor-General, 2014).⁶ Second, both capital and operating expenditure fluctuate as asset replacement and new development become necessary and as maintenance schedules come due (not to mention emergency expenditure from natural disasters). Depreciation smooths such effects. Third, maintenance costs are not consistently reported separately in the financial statements of all councils, whereas infrastructure depreciation must be disclosed. Lastly, items of capital and operating expenditure from the activity funding impact statements are not subject to the same accounting and audit rigour as the main financial statements. On the other hand, a weakness is that depreciation omits certain aspects, such as land (relevant to the true economic cost of such assets).⁷

Growing territorial authorities

As this research addresses the way New Zealand cities are growing, and the economic costs of doing so, we also examined the relationship between rapid population growth and infrastructure costs. Ladd notes that ‘rapid population growth is associated with large increases in per capita spending’ (Ladd, 1992, p.274). Examination of growth over the intercensal 2006–13 period showed a cluster of TAs growing at 9% or above. We investigated whether this cluster had higher (or lower) depreciation.

Results

Density

Table 1 shows densities for the five most densely populated TAs.⁸ Wellington City

is densest, with a population-weighted density of 57.4 people/ha, almost double that of Hamilton City which rounds out the top five.⁹ The mean weighted density of all TAs is 18.3 people/ha.

Roading

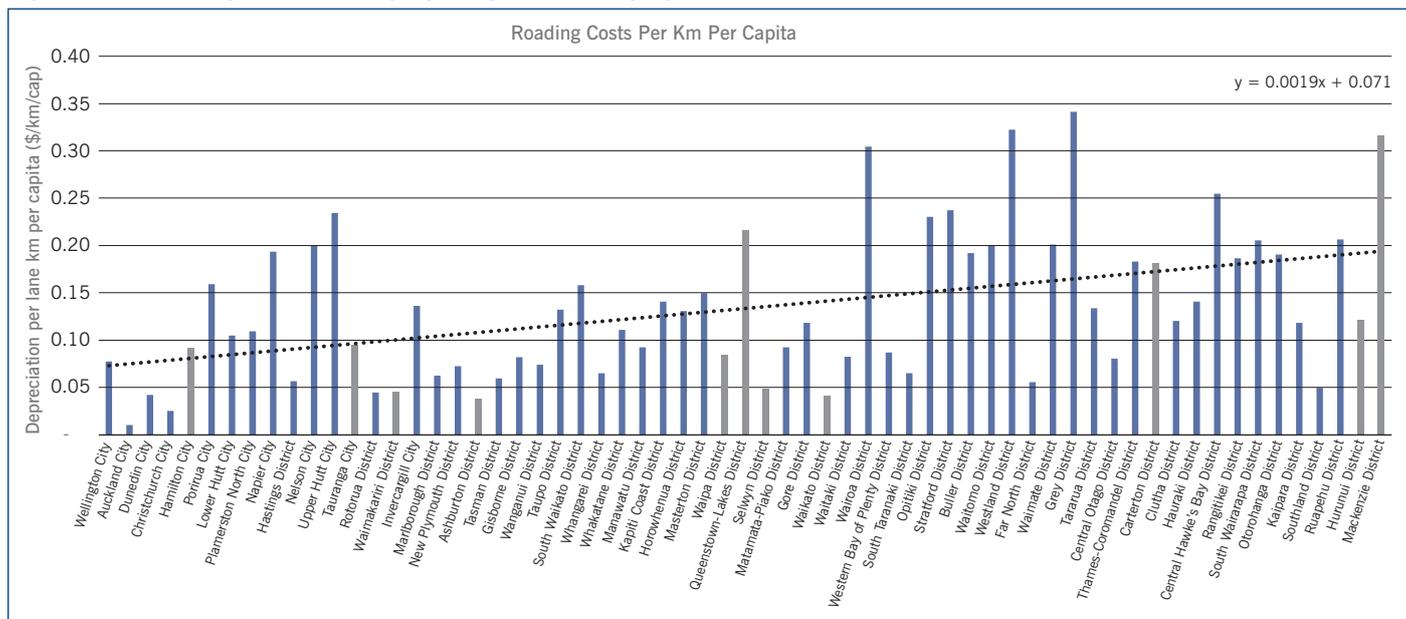
Figures 1–5 allow visual comparison between TA density and infrastructure costs, with infrastructure costs per capita on the vertical axis and the TAs arranged on the horizontal axis in descending order of density. Fitted lines indicate how costs vary as density falls. Positive slope lines (as for roading) indicate that infrastructure costs per capita rise as density falls, while negative slopes show costs falling with density falling.

Figure 1 shows that roading costs per km of lane length per capita are lowest in

Wellington City, and rise as density falls to the least dense district (Mackenzie District). Figure 1 uses costs per km of lane length per capita rather than simple road length, as higher-density roading is more likely to be multi-laned and would therefore be under-represented if simple road length was used. Figure 2 illustrates more simply the inverse relationship between TA roading costs per capita and TA density.

Narrowing the comparison to just the fast-growing TAs, the roading cost gradient with density is *more* pronounced (data not shown). The fast-growing TAs of higher density maintain roading costs lower than those of more dispersed TAs. Most TAs fit the pattern well. Ashburton and Waikato are the only districts well

Figure 1: Road costs per km lane length per capita (excluding significant outliers of Kawerau and Kaikoura District Councils)



Note: those coloured grey have populations which have grown by more than 9% since the 2006 census.

Figure 2: TA road depreciation costs per capita, against TA density

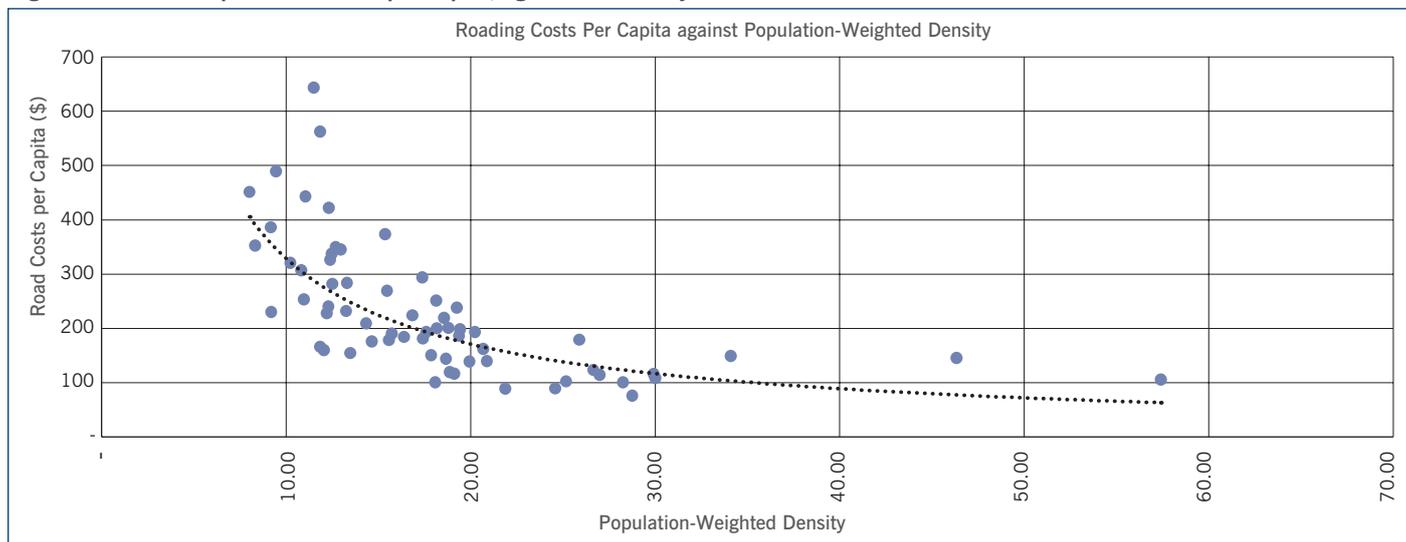
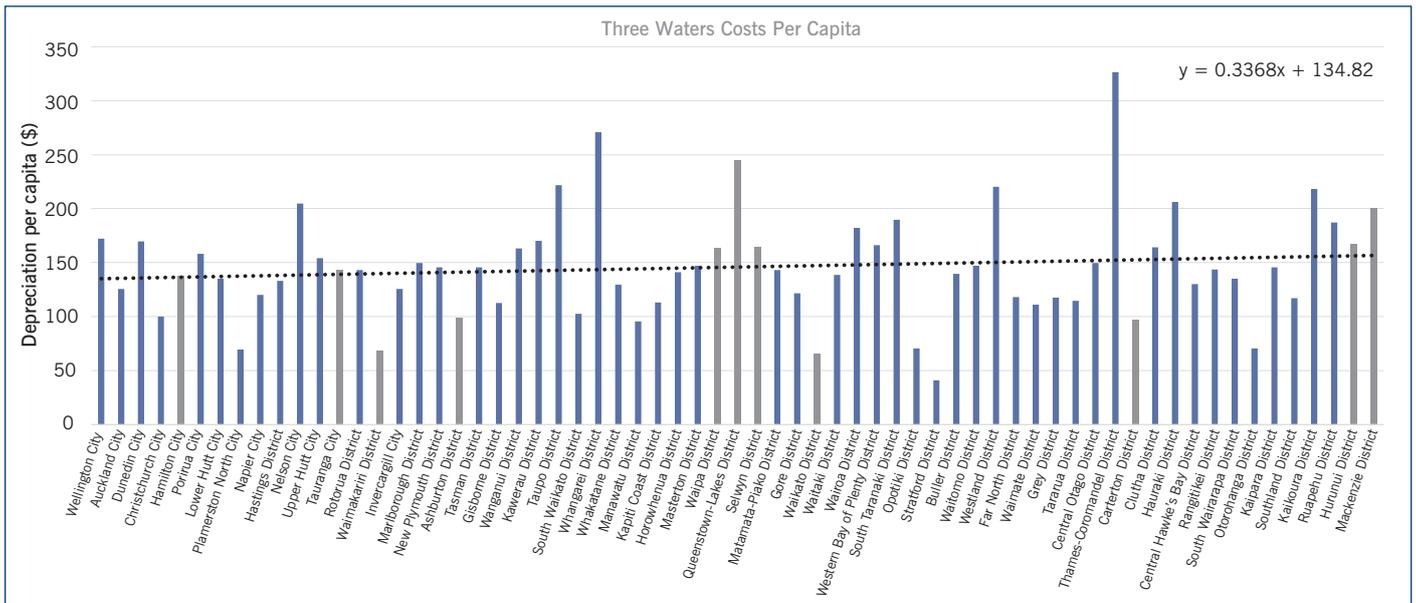
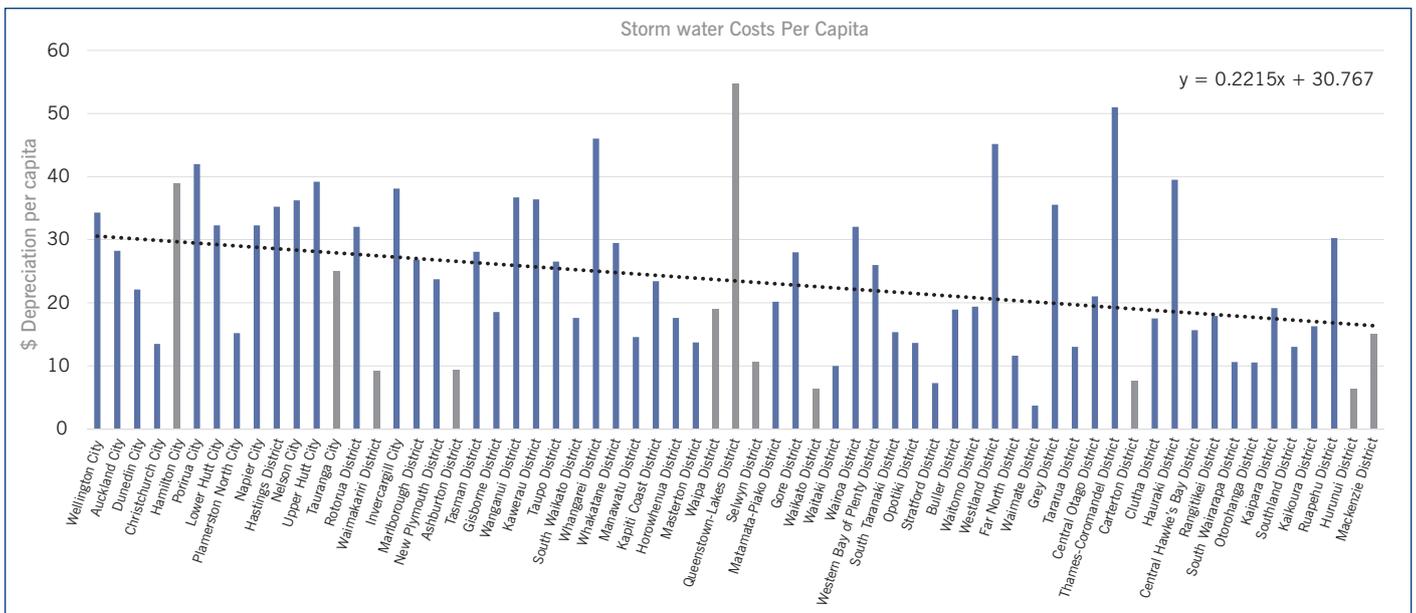


Figure 3: Combined three water costs per capita



Note: those coloured grey have populations which have grown by more than 9% since the 2006 census

Figure 4: Storm water costs per capita



Note: those coloured grey have populations which have grown by more than 9% since the 2006 census

below the fitted line and Mackenzie and Queenstown districts are well above.

Three waters

The combined three waters costs (Figure 3) show that the less dense TAs face marginally higher costs per capita for their three water services combined. However, this gradient is not as steep as with roading. Figures 4 and 5 show storm water and water supply costs separately. Storm water costs (Figure 4) actually fall as density falls. Waste water costs are flat (not shown). The storm water relationship runs counter to that observed with roading. Water supply costs, like

roading costs, increase as density declines. This gradient is strong enough that the combined three waters cost gradient in Figure 3 remains marginally positive.

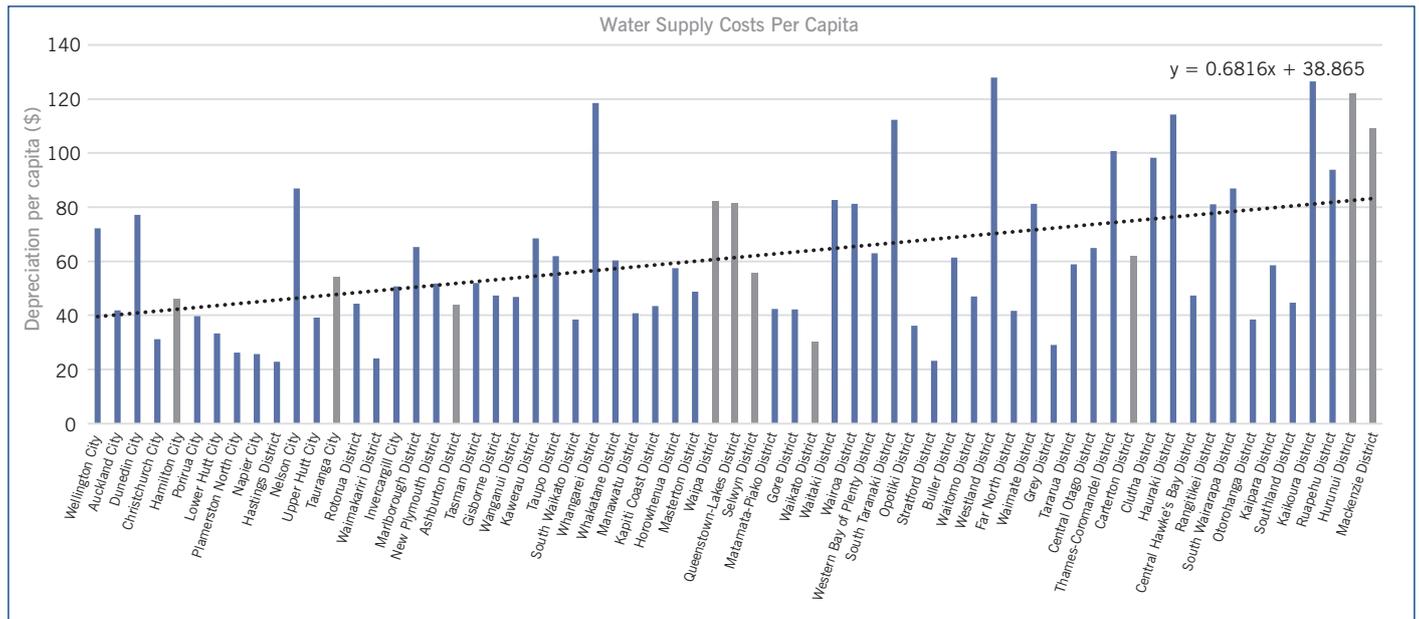
The grey coloured bars in the figures, representing faster-growing TAs, illustrate that such areas do not differ markedly in three waters cost terms from other TAs not experiencing equivalent growth. Queenstown Lakes is an exception: it is a clear outlier in terms of storm water costs (Figure 4).

Grouping TAs by growth

We also compared high-growth TAs (greater than 5% growth pa) with

medium- (between 1 and 4.99%) and low-growth (less than 1%) ones (data not shown but available from the authors). Across all growth categories, roading costs per capita consistently rise as density declines. Freshwater supply costs also increase, although the trend is much flatter for medium-growth TAs. Storm water costs decline as density declines. This relationship is steepest for storm water in high- and medium-growth TAs. Waste water costs in low-growth areas increase marginally as density decreases, whereas they decrease in the medium- and high-growth areas.

Figure 5: Water supply costs per capita



Note: those coloured grey have populations which have grown by more than 9% since the 2006 census

Discussion

Density and infrastructure costs

The gradients observed show that the costs of infrastructure do vary with TA density. TAs of higher density have generally lower infrastructure provision costs per capita, a pattern consistent with the literature and sustainable urban growth principles. The waste water cost gradient is insignificant, but storm water costs do rise noticeably with density. For the US, Carruthers and Úlfarsson (2003) found that waste water plus storm water system costs rose with density, as noted earlier. The relationship in New Zealand may be partly explained by the use of above-ground storm water systems in areas of lesser density. Further research is required to confirm this. But taking the three waters costs together, water supply costs dominate and costs decline marginally as densities rise.

Growing TAs follow a similar pattern to other TAs. Those with denser development tend to have lower infrastructure costs. This appears to contradict the finding of Ladd (1992) and suggests that rapidly growing TAs (above a threshold for ‘rapid growth’) do not experience infrastructure costs that differ from other TAs’ costs. Moreover, grouping TAs by the level of growth experienced over 2006–13 shows that the cost patterns do not change significantly with growth.¹⁰ The rate of population

growth appears to have little effect on TAs’ per capita spending on infrastructure.

Examination of TA infrastructure costs against density highlights numerous outliers. Clearly, other factors influence the cost of supplying infrastructure, and not all can be easily controlled. Prieto and colleagues (2015) identify soil hardness and topography as two such factors affecting the cost of infrastructure installation. Other factors, such as local climate, local industries and proximity to raw material suppliers, could also affect infrastructure asset life and installation costs. Network variables, such as the number of pump stations or treatment plants, will directly influence infrastructure costs and are likely linked to urban compactness. As an example, Westland is an outlier in regard to three waters costs. This TA is the longest in New Zealand and its high costs may relate to the need for nine separate water treatment plants and nine storm water networks (Westland District Council, 2014) to service the small urban areas along the West Coast. In contrast, Wellington City, with almost 23 times the population of Westland, is served by only four treatment plants.

Limitations

Setting aside the matter of other variables influencing TA infrastructure costs, only four types of infrastructure cost (albeit

the major ones) have been measured. Public infrastructure costs were proxied by depreciation only. Private and social costs (as well as benefits) are excluded; the calculation of these would be complex and is beyond the scope of this research. Further, for the reasons given, operating costs were not measured (e.g. the electricity required to operate pump stations and the wages of pump station workers). Such costs could be related to factors such as density, population (use) and topography.

In addition, the quality of service received by each TA from its infrastructure was not gauged. The quality of infrastructure systems across TAs varies as each strives to meet objectives laid down in their individual long-term plans, and other standards, for example those set by the Ministry of Health. Some TAs may be performing well and some may be performing poorly; this is not measured by cost estimates. On the other hand, the Office of the Auditor-General recently found that there was ‘little relationship between asset expenditure and service-level performance in public information’ (Office of the Auditor-General, 2014, p.5).

Not all roading costs have been measured. Understandably, private roads are ignored, but state highways, owned and managed by the New Zealand Transport Agency, are also excluded.¹¹

These state highways serve TAs to varying extents, and have varying traffic flow and expenditure. However, the motivations for state highway building differ significantly from those for local roads, and their costs may vary in a different way with TA density.

Implications

This research investigated the link between urban density and the costs of providing major infrastructure. Although a number of variables affect the cost of infrastructure provision, this research suggests that roading and water supply costs fall with increasing density. While storm water and waste water costs may or may not increase with density, they matter less in terms of costs.

Such relationships are consistent with a literature that largely accepts that public services can be delivered more efficiently (economically, socially and environmentally) at higher density, up to a point. The overall picture of costs falling with density provides support to those councils espousing and following 'smart growth' plans that seek to utilise the excess capacity in existing infrastructure as opposed to continuing dispersed development. It may also help underpin the setting of higher development contributions for areas sprawling away from established infrastructure.

Councils encouraging lower-density development could be seen as falling short in terms of section 10 of the Local Government Act 2002. That section identifies the purpose of local government and requires delivery of 'good-quality' infrastructure that is effective, efficient, and appropriate for

current and future populations. The present study is not conclusive, as not all factors affecting infrastructure costs have been considered, but it does raise important questions about the practice of many local governments subsidising sprawl in New Zealand.

Conclusion

The purpose of this research was to examine the link between density and the costs of providing infrastructure in New Zealand. Clearly a link exists. That is, higher-density TAs incur lower infrastructure costs for roading and water supply than TAs of lower density. The relationship is stronger for these forms of infrastructure than it is for storm water, the costs of which increase comparatively slowly as density increases (waste water costs appear unrelated to density).

Considerable 'noise' is evident in the outliers of the illustrated patterns. This is understandable: density is important but not the only variable describing urban areas, and does not solely drive infrastructure costs. However, the analysis establishes that density does influence the cost of infrastructure provision. Further research, taking a bottom-up or longitudinal approach, may help to confirm these findings and strengthen the evidence base.

In interpreting these results, it is worth remembering that the relationship between density and infrastructure costs seen at the 'wider' territorial authority level may be different at the neighbourhood level, where the principles of compact development are often considered. The onus is now on those working at the neighbourhood level

to show that the 'default' relationship between more dispersed development and higher costs does *not* apply.

The findings have backing within the international literature, and have relevance to local government in New Zealand. They provide significant evidence to local government planners that compact urban form is likely to be more economically efficient than dispersed development.

- 1 This article draws on work Matt Adams undertook as part of postgraduate study at Victoria University of Wellington, with Associate Professor Ralph Chapman (supervisor), Director of Environmental Studies at Victoria. Thanks to the Ministry of Business, Innovation and Employment for supporting the research through funding of the Resilient Urban Futures programme. Input from Nadine Dodge (VUW PhD candidate) and support of Professor Philippa Howden-Chapman are acknowledged.
- 2 J. Alexander, personal communication with N. Preval, 14 October 2014.
- 3 Using TAs is a minor departure from the approach of Nunns (2014), who split New Zealand into 15 main urban areas; accordingly, population-weighted densities calculated here differ slightly from Nunns'. In line with Nunns, meshblocks with fewer than three people/ha (unurbanised areas) were excluded from the analysis.
- 4 When an asset is depreciated, its value is decreased in the statement of financial position. The depreciation amount is recognised each year as an expense in the statement of financial performance.
- 5 The annual amount expensed equals asset cost minus residual value, divided by useful life.
- 6 Note that the report identifies that asset renewal expenditure is currently below asset depreciation in local governments, suggesting underinvestment in infrastructure.
- 7 Litman includes it in his analysis of the costs of sprawl in the United States: see Litman (2015). Valuing road land is not trivial, as values would be much lower without road access.
- 8 A complete list of TA densities is available from the authors.
- 9 As indicated in note 3, the method of calculation is close to that used by Nunns (2014), who identified Auckland as densest (43.1 people/ha). The notable difference is in area selection. Nunns identified 15 main urban areas; this research analyses all 67 TAs. The Wellington main urban area used by Nunns includes Wellington City, Hutt Valley and Porirua, treated separately in the present study as they form separate TAs.
- 10 A possible exception is that the per capita water supply cost gradient in the medium-growth grouping is flatter than for the other groups (data not shown).
- 11 The annual depreciation for state highways on NZTA's books for 2013/14 was \$465 million. This is equivalent to around 70% of the annual depreciation expense of all TAs put together (\$677 million).

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