Logistics sprawl and social equity in New Zealand: Preliminary results (confidential)

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1. Introduction

Urban logistics systems have been adapting to sprawling populations, supply chain globalisation, changing consumer behaviour, and prescriptive land use planning for the past few decades (Aljohani and Thompson, 2016; He et al., 2018; Sakai et al., 2015; Kang, 2020a). With a few notable exceptions such as Seattle (Dablanc et al., 2014), evidence from Europe (Dablanc and Rakotonarivo, 2010; Kumhálová et al., 2019; Strale, 2020), North America (Cidell, 2010; Jaller et al., 2017; Kang, 2020a,b,c), Asia (He et al., 2019; Lim and Park, 2020; Sakai et al., 2015, 2017), India, Australia, and South Africa (Coetzee and Swanepoel, 2017) (nmt: ref in print article) shows that these systems adapt by moving their facilities — particularly warehouses and distribution centres — further away from densely populated city centres. This trend of decentralisation is labelled "logistics sprawl". (nmt: Paragraph to be paraphrased, it's a copy from a paper in review.)

The impact of logistics sprawl is felt by both public and private urban freight stakeholders. The private stakeholders are the logistics companies who own or rent the logistics facilities. The impact on them is primarily economic as they trade off costs within the context of land use regulation, pricing, and opposition from communities (**?**). The public stakeholders can be categorised as a) the communities who benefit from these sprawling logistics facilities, and b) the communities who suffer the externality costs of being co-located with logistics facilities. The benefits could include: better access to consumer goods, employment in the logistics sector, and general upliftment due to increased economic activity in an area. The externality costs could include: increased emissions, road wear, congestion, noise pollution, and land devaluation around facilities. Because of the

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distributed nature of modern supply chains (Cidell, 2015), the communities who benefit and the communities who pay for those benefits are not always the same. This disproportionate distribution of benefits and costs raises concerns about the social justice of logistics sprawl (Cidell, 2015; Yuan, 2018). In this study we address two questions:

1. *What has been the extent of logistics sprawl in New Zealand between 2000–2020?*
2. *Which communities have been impacted by logistics sprawl?*

To study the extent of logistics sprawl, we use geospatial analysis and related metrics. We measure the sprawl of logistics facilities — specifically retail, wholesale, and transport, warehouse, & distribution facilities — in absolute terms, but also relative to other phenomena like population sprawl and overall business facility sprawl.

To determine which communities have been impacted by sprawl, we use spatial correlation models and census data to determine the relationship between the number of logistics facilities in an area and the level of deprivation of a surrounding community.

2. What drives logistics sprawl?

Costs are a crucial decision driver in the selection of locations for logistics facilities. Location-specific costs are multi-faceted. First there is the cost of establishment. Here the price of land and cost of construction are key. Second there are the direct operational costs of the facility — utilities, insurance, climate control, labour etc — which also differ by area. Third, there is the supply chain cost of having a facility in a specific location, specifically the transport and inventory cost implications across the regional or global supply chain. With these location-specific costs to consider, it makes sense that locations with a low price of land (termed *land rent*), established access to utilities, and good access to transport infrastructure — especially highways — would be attractive for logistics facilities.

Modern logistics facilities are also much larger than their predecessors thanks to supply chain globalisation and the economies of scale driven by population growth and heightened consumerism. Therefore areas with large available land tracts are also enticing. The combined pull factors of cost and available land align well with the conditions in suburban and exurban areas — areas on the edges of cities.

Unfortunately, the same factors that draw logistics facilities (with the exception of large available land tracts) also draw poorer communities. Low(er) rent, cheap(er) utilities, and reasonable access to a transport network that enables connection to urban jobs are characteristic of poorer communities. This leads to a potential clash between wealthy corporations who wish to optimise their global supply chains and the poorer communities who wish to preserve or improve their standard of living.

3. Data sources and data sets

There are four sources of data for this study. Firstly, data regarding business facilities and employee counts — differentiated by the Australia and New Zealand Standard Industrial Classification (ANZSIC) codes — are from the annual Business Demography snapshot taken each February by Statistics New Zealand (StatsNZ). Secondly, the New Zealand Deprivation (NZDep) index data, which are calculated from the census statistics, are publicly available from the Health Inequalities Research Programme at the University of Otago (nmt: insert ref). The third source of data is the national census statistics published by StatsNZ. Finally, transport infrastructure data are drawn from OpenStreetMap (OSM).

3.1. Business demographics data

The business demographics data have been published annually by StatsNZ since 2000. Relevant to this study, these statistics track the number of business facilities, employment per facility, and the number of "births" and "deaths" of business facilities.

For confidentiality purposes, the published data is aggregated geographically and functionally. The lowest level of geographic aggregation publicly available is at the Statistical Area 2 (SA2) level. To serve the purposes of census data collection, SA2s are defined based on population counts and thus vary greatly in terms of area. As an illustration, Figure 1 compares the size of SA2 in the city of Christchurch compared to the size of SA2s in the rest of the region. On a functional (SyndicateQ: is this the correct word?) level, the data is aggregated according to the ANZSIC codes.

Which ANZSIC codes should be considered "logistics facilities" is not immediately obvious. Consider the supply chain of flour for household use. Wheat is moved from farms to mills where it is transformed into flour and packaged for sale in grocery stores. Mills are the "manufacturing

(a) Christchurch (b) Canterbury

Figure 1: Illustration of the geographic scale of SA2s in an urban area (Christchurch) compared to an entire region (Canterbury). (SyndicateQ: This figure is a draft. These are screenshots from StatsNZ and can be neatly redrawn. BUT, is it useful to include or redundant info?)

facilities" in this supply chain. From the mill, pallets of packaged flour travel to a warehouse or distribution centre that is positioned closer to the consumer market. From there, flour can be transported to wholesale or retail outlets (or first to a wholesale and then to a retail outlet) where final consumers purchase the product. In this case the farm, the mill, the warehouse and/or distribution centre, the wholesale outlet, the retail outlet and any transport terminals involved are all logistics facilities.

In studies of logistics sprawl, what constitutes "logistics facilities" is interpreted differently, depending on the data sources. Most commonly, warehouses and distribution centres are considered logistics facilities. Some studies include transport terminals (e.g. road, rail or intermodal terminals). In other words, the facilities required to store and move goods along their journey from supplier to consumer are considered logistics facilities. However, these two groups of facilities hardly address the overall scope of logistics.

In this study, we consider all facilities in the supply chain downstream of manufacturing to be logistics facilities. Manufacturing facilities and the sources of raw materials (farms, mines etc.) are excluded for two reasons. Firstly, the locations of farms and mines are mostly set and not affected by urban development. Secondly, there is less of an incentive for manufacturing facilities to be

"amidst the population". Distance to supplier is often more important than distance to consumer. We align the ANZSIC categories and our interpretation of logistics facilities as follows:

Retail (RET) : Category G (retail trade)

Wholesale (WSL) : Category F (wholesale trade)

Transport, warehouse & distribution (TWD) : Categories I461 (road freight transport), I471 (rail freight transport), I481 (water freight transport), I51 (postal and courier pick-up), and I53 (warehousing and storage)

We also define a fourth category **COMBO** which represents all logistics facilities and is defined as: COMBO = RET + WSL + TWD.

3.2. New Zealand Deprivation index

When studying the clash between logistics sprawl and poorer communities, empirical studies from around the world typically use household income as the identifying variable. In this study, however, we choose to use a variable that captures a broader notion of deprivation than income alone, namely the NZDep index.

The NZDep index is a census-based, small-area index of relative socio-economic deprivation. This index is frequently used in health and education related policy decisions in New Zealand. The interested reader is referred to (nmt: xx) and (nmt: xx) to read more about the theoretical and methodological underpinnings of the index. Four updates have been published between 2000 and 2020 (the time span of this paper) corresponding with the national census: in 2001, 2006, 2013, and 2018. The NZDep index includes a broad range of deprivation dimensions and quantifies each with one or more variables from the census. The weighting of each dimension is statistically determined. Table 1 shows the variables included in the calculation of the 2018 index. Over time, the list of variables and their weightings have changed to stay abreast of societal developments. For example, not having access to internet at home is regarded an indicator of deprivation in 2018 whereas this was not the case decades earlier when internet at home was a luxury, not a basic necessity. The lists of variables used in 2001, 2006, and 2013 are shown in Appendix A.

To calculate the index on a scale from 1 to 10, the distribution of principal component scores derived from the variables is divided into tenths. The higher the index, the higher the deprivation.

Table 1: The NZDep deprivation dimensions and their concomitant variables for 2018 (ordered according to decreasing weight in the index). (nmt: ref)

Dimension of deprivation	Description of variable
Communication	People with no access to the Internet at home
Income	People aged 18–64 receiving a means tested benefit
Income	People living in equivalised households with income below an income threshold
Employment	People aged 18-64 unemployed
Qualifications	People aged 18-64 without any qualifications
Owned home	People not living in own home
Support	People aged < 65 living in a single parent family
Living space	People living in equivalised households below a bedroom occupancy threshold
Living condition	People living in dwellings that are always damp and/or always have mould greater than A4 size

For example, an index of 10 for an area indicates that the area is in the most deprived 10 percent of small areas in New Zealand (nmt: ref the 2018 report).

In this study we rely exclusively on the NZDep index to investigate the correlation (clash) between deprived communities and logistics facilities, but additional census data is used for further insights.

3.3. Census statistics

The census statistics used in this study relate to total population, ethnicity, employment, personal income, and household income (SyndicateQ: At this stage, only total population is used as an independent variable in the correlation analysis, but I'm curious about your thoughts of unpacking things like education and ethinicity in the last sections of the paper.). This data is publicly available and was downloaded from the StatsNZ website (nmt: url). These publicly available datasets are aggregated geographically and functionally (by ANZSIC code). The data for 2006, 2013, and 2018 was available on the SA2 level. Unfortunately, the data for the 2001 census was not reported according to SA2 level but on area unit level. In addition, the reporting categories for personal income and workforce statistics, among others, were also different. Because we did not know how to map the area units to SA2s or how to reconcile the 2001 categories with the categories used since 2006, we decided to omit 2001 from the analysis and use only data from 2006, 2013, and 2018.

3.4. OpenStreetMap

OSM is a volunteer generated map of the world. It is an open source of geographic data that is regarded as accurate and valid. From OSM, we extracted data relating to New Zealand's transport network. An important decision factor when choosing a location for a logistics facility is quick access to local, regional, and global transport networks (nmt: insert refs). Highway networks are the most ubiquitous and truck transport the most flexible, therefore proximity to a highway network — which can serve as an artery into local markets, connect regionally, or offer a direct route to a sea port or airport — is an influential pull factor (nmt: insert refs). Some studies have also found proximity to airports, railway terminals and seaports to be significantly influential (nmt: refs).

In this study we've extracted the distance to the nearest airport, sea port, and railway terminal from the centroid of each SA2. In terms of the highway network, we've opted to use the density of the highway network instead of the distance to the nearest highway on-ramp (nmt: insert ref that talks about why this is better). We also decided to calculate the highway density for a larger geographic area than the SA2s, namely the *urban* and *rural* demarcations. The SA2s are small, geographically, in and around urban areas. Using such small areas to calculate highway densities would create distortions that imply that a logistics facility only considers the highway network immediately surrounding its facility and not the network in the rest of the urban area.

The geographic data were extracted from OSM in June 2021. Certainly there has been changes to the transport network between 2000 and 2021, but the majority of these changes would be in terms of increasing the capacities of existing infrastructure and not building new airports, sea ports and railway lines. Infrastructure capacity increases does not affect the data used in this study. Highway extensions, however, could affect the highway density data, but given the extent of highway extensions since 2000, we believe the impact is negligible. (nmt: I still have to substantiate this somehow.) Therefore, we use transport-related data from 2021 for all of the time periods in the study.

4. The extent of logistics sprawl in New Zealand

Throughout this study, we investigate logistics sprawl relative to the sprawl of business facilities across all ANZSIC categories (ALL) as well as population sprawl (POP) in order to contextualise

our findings. We first investigate the change in the number of facilities regionally and nationally before considering geographic sprawl.

4.1. The increase in the number of facilities

On a national level, the number of ALL facilities increased by 46% over the period from 2000 to 2020. But these facilities are not spread equally across New Zealand (see Figure 2a), instead their proportions are closely matched to the percentage of the total population in each region (nmt: should I include the stats that back this?). The underlying growth dynamics for ALL facilities in the different regions also differ. Over this period, the Auckland and Otago regions saw the greatest proportional increase in business facilities with growth rates over 60%. Regions with growth rates of over 40% between 2000 and 2020 include the Bay of Plenty, Nelson, and Canterbury while most of the remaining regions saw the number of business facilities increase by 20%–40% over the period. Only Manawatu-Wanganui and the West Coast regions saw low growth rates of under 15% over the 20 years.

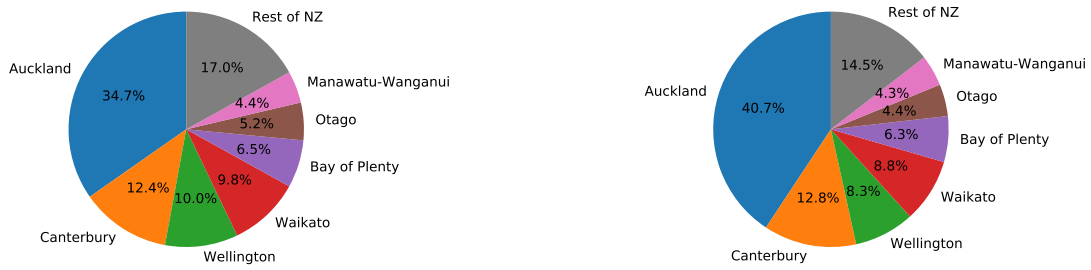
The proportion of ALL facilities that can be classified as COMBO facilities varies across the regions as shown in Table 2 while Figure 2b shows what percentage of the national total of COMBO facilities occur in each region. The observation that the six regions that contain the country's largest cities and highest populations overall also contain the highest proportion of business and logistics facilities is intuitive. Interestingly, COMBO facilities as a percentage of ALL facilities has declined over time in all six regions. (nmt: Not sure how to elaborate on that.)

(SyndicateQ: Is this table / figure combo confusing or redundant? What information does a reader really need to see here to continue the storyline?)

Table 2: COMBO facilities as a percentage of ALL facilities in the six top-ranking regions in terms of ALL and COMBO facilities.

Region	2000	2006	2013	2018	2020
Auckland	17.9	15.7	15.1	13.7	12.9
Canterbury	6.4	5.7	4.8	4.3	4.0
Wellington	5.0	4.0	3.4	2.8	2.6
Waikato	4.3	3.7	3.3	2.9	2.8
Bay of Plenty	3.1	2.6	2.3	2.1	2.0
Otago	2.1	1.8	1.7	1.5	1.4

The overall growth of COMBO facilities over the 20-year period is 8.0%, much lower than that of all business facilities (see Table 3). This explains why COMBO facilities as a proportion of ALL



(a) ALL facilities

(b) COMBO facilities

Figure 2: Percentage of national facilities in each region (2020) (nmt: This should be made prettier and more readable.)

facilities reduced over time in each of the six regions, as shown in Table 2. From 2000 to 2020, the number of RET facilities grew the most (16%), WSL facilities increased by less than 1%, and TWD actually decreased by 2.2%. However, these national averages ill-represent what happened on a regional level where some regions showed booming growth while others withered, as Table 4 illustrates.

Table 3: Comparison of growth rates (%) across facility types and population growth rates

	20-yr growth	CAGR 2001–2006	CAGR 2006-2013	CAGR 2013-2018
ALL	46.2	4.1	0.6	2.2
COMBO	8.0	2.2	−0.4	0.9
RET	16.2	2.6	0.1	1.0
WSL	0.7	1.8	−0.9	0.6
TWD	−2.2	1.4	−1.2	1.0
POP	25.8*	1.5	0.7	2.1

* Population growth is determined from 2001–2018, thus a 17-year growth rate.

Table 4 shows that strong growth in RET facilities occurred in and around the major cities (Auckland, Canterbury, Waikato, and Otago). Two regions that showed strong growth but are unassociated with major cities are the Nelson and Tasman regions. The rest of the regions saw a decline in RET facilities. Intuitively, more RET facilities are expected in areas with high population density and/or among populations with high disposable income. However, the 17-year (2001–2018)

Table 4: Comparison of 20-year regional growth rates (2000-2020) for logistics facilities (nmt: add COMBO column!!) (nmt: add colouring)

	20-year growth rate % 2000-2020				17-year growth rate % 2001–2018
Region	COMBO	RET	WSL	TWD	POP
Auckland	20.6	40.0	7.0	1.1	35.6
Bay of Plenty	8.0	14.5	1.4	−0.9	28.9
Canterbury	5.6	12.1	−3.9	6.8	24.6
Gisborne	2.3	−8.6	−2.2	56.0	8.1
Hawke's Bay	3.7	4.7	3.4	0.8	16.4
Manawatu-Wanganui	−14.0	−12.6	−12.5	−20.0	8.5
Marlborough	10.2	−2.8	33.3	21.6	19.7
Nelson	10.5	15.9	11.4	−7.3	22.4
Northland	4.0	−1.4	10.8	11.7	27.8
Otago	8.8	11.4	8.6	0.0	24.0
Southland	−3.2	−1.7	−3.7	−7.6	7.1
Taranaki	−10.4	−10.4	−16.4	−1.2	14.3
Tasman	23.5	33.3	16.7	3.1	26.7
Waikato	8.2	13.4	5.5	−1.7	28.1
Wellington	−13.4	−2.5	−25.4	−27.1	19.6
West Coast	−12.7	−10.1	−11.8	−22.2	4.2

POP growth across the regions shows that the population grew in each of these regions, therefore population contraction does not explain a reduction in facilities. (SyndicateQ: Should I include statistics on personal or household income here, or is that too much detail?)

Another factor to keep in mind with RET facilities is the increase in online shopping. It could be that access to online shopping options lessened the need for brick-and-mortar RET facilities in areas with a lower population density.

A traditional view of supply chain structure imagines that goods flow from a manufacturer to a wholesaler to a retailer and then to the consumer. If this relationship were intact, one wholesaler would sell to many retailers who sell to even more consumers. One would thus expect many more RET facilities than WSL facilities. But this is not evident from the statistics in New Zealand. In 2000, the ratio of WSL to RET facilities was 1:1.5 nationally. In 2020 it was 1:1.7. On a regional level, the ratio ranges between 1:1.1 and 1:2.6. The data does not support the traditional view of supply chain structure, instead, it suggests that supply chain relationships are far more complex than our textbook examples. Realising this helps to understand why the growth rates for WSL facilities are not in tandem with growth rates for RET facilities — on a national or regional scale.

The number of transport terminals, warehouses/distribution centres in the supply chain would depend on factors like the degree of transport intermodality and strategic decisions around centralisation or decentralisation of supply. A more decentralised supply chain with greater intermodality would require more transport terminals and distribution centres and vice versa. In New Zealand, the ratio of WSL facilities to TWD facilities was 1:0.5 in 2000 and in 2020. On a regional level, the ratios vary from 1:03 to 1:0.9.

The fact that there are fewer TWD facilities than WSL or RET facilities support two intuitions. The first relates to supply chain structure: Transport terminals are predominantly public infrastructure and therefore shared by many wholesalers and retailers while distribution centers are also increasingly shared with the rise of outsourcing and third-party logistics. The second relates to data collection: Many manufacturers may have their warehouses or distribution centres adjoined to their manufacturing facility. Therefore, what we would consider TWD facilities may be classified under other ANZSIC categories.

The fact that TWD facilities have actually decreased over 20 years is noteworthy and does not align with the notion that a growing population results in a growing economy with more supply chains that result in more logistics facilities. The underlying phenomena that drove this decrease requires further investigation.

The long-term change, observed over 20 years, did not occur evenly over time. To align with the demographic data used in this study (2001, 2006, 2013, and 2018), we consider the compound annual growth rate (CAGR) for three periods: 2001–2006, 2006–2013, and 2013–2018. Table 3 shows the CAGR for each facility type during these periods. Across all facility types, it is evident that there was a lull in growth between 2006 and 2013. This lull was most likely caused by the lull in population growth experienced at the same time. (nmt: Is there something more to say here?)

In summary, the overall growth in ALL facilities has been much stronger than the growth of COMBO facilities. In fact, only RET facilities showed prominent growth whereas WSL facilities seemed to stagnate while the number TWD facilities decreased. This suggests a fundamental change in the supply chain structure in New Zealand over the past two decades. Next we consider to what degree facilities sprawled from 2000 to 2020.

4.2. Spatial sprawl of logistics facilities

We study spatial sprawl on a regional level instead of a national level. Furthermore, we limit our investigation to the six regions that have the most significant urban areas, namely Auckland, Canterbury, Wellington, Waikato, Otago and Bay of Plenty.

When studying logistics sprawl, we wish to quantify two phenomena: the centrality of logistics facilities, and their spatial concentration (Kang, 2020a). Centrality is most frequently quantified by calculating the centroid (midpoint) of all logistics facilities in the area. Concentration is most often captured by the average distance between individual facilities and the centroid of all facilities. These are the two metrics used in this study.

To calculate the centroid, one needs to know the location (coordinates) of the facilities. This study's data specify the number of facilities per SA2, not the actual location of these facilities. This is a common aggregation in the study of logistics sprawl. In this case, all the logistics facilities in an SA2 are assigned a coordinate that corresponds with the centrepoint of that SA2. Next, the centroid is defined as the midpoint of all these facility locations.

The movement of a centroid does not, by itself, indicate sprawl. It merely shows that the focus of activity has shifted and this could be due to many reasons. The average distance to the centroid, however, is an indication of sprawl. If the distance reduced, then the cloud of facilities around the centroid concentrated, if the average distance increased, then the cloud of facilities sprawled.

Figure 3 plots the centroid shift (in km) on the horizontal axis against the change in the average distance to the centroid (in km) on the vertical axis for ALL facilities and the COMBO facilities of five of the six urban regions. (Otago is not included in the graph as it is an exceptional case and is discussed separately.) Figure 4 maps the change for the COMBO facilities only. Overwhelmingly, there is little evidence of sprawl for either ALL or COMBO facilities. In fact, the reduction in the average distance to the centroid indicates the opposite: facilities have become more concentrated. This is contrary to the majority of logistics sprawl studies, as Table 5 illustrates.

Auckland showed the smallest centroid shift for ALL and COMBO facilities. Given the geography of Auckland, this makes sense. Hemmed in by a complex coastline, there is not much space to shift into. Interestingly, this is one of only two regions that did exhibit a slight sprawl of its COMBO facilities, even though the cloud of ALL facilities remained static. But compared to the extent of sprawl witnessed in other cities around the world (Table 5), the logistics sprawl of 660 m

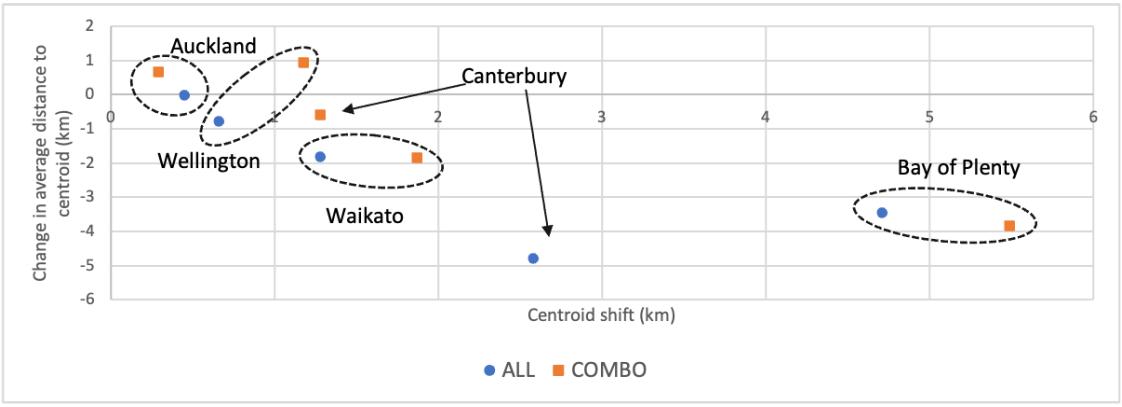


Figure 3: Centroid shift (centrality) versus change in average distance to centroid (concentration/sprawl) for ALL facilities and COMBO facilities. (Otago is an outlier and thus excluded from the graph.) (nmt: This is a draft graph. I will still redraw in python .)

Table 5: The extent of sprawl observed in urban areas globally. Sprawl is measured as the change in average distance to the centroid of the logistics facilities.

Urban area	**Period**	**Overall sprawl (km)**	**Annual sprawl (m)**	**In relation to**	**Reference**
Gauteng	2010–2014	+2.04	+510	centroid	(nmt: under review)
Cape Town	2010–2014	+1.82	+455	centroid	(nmt: under review)
Paris	1974–2008	+10	+294	centroid	Dablanc and Rakotonarivo (2010)
Gothenburg	2000–2014	+4.2	+300	centroid	?
Yangtze River Delta	2005–2015	+4.02	+402	centroid	Heitz et al. (2019)
Southern California	1998–2014	+6.76	+423	centroid	Jaller et al. (2017)
64 US Metros	2003–2016	+4.7	+361	centroid	Kang (2020a)

over 20 years (or 33 per year), seems almost negligible.

Wellington is the other region in which COMBO facilities sprawled outward from its (nearly stationary) centroid, even while ALL facilities did the opposite — concentrating around its centroid. Again, the sprawl, 930 m over 20 years or 46.5 m per year, is not substantial when compared to other global cities.

Canterbury is the region that shows the most disparity between what happened with logistics facilities and what happened with ALL facilities. While the centroids shifted in both cases, the centroid shifted more for ALL facilities. Similarly, while there was concentration for both COMBO facilities and ALL facilities, the concentration for logistics facilities was slight (28.8 m per year)

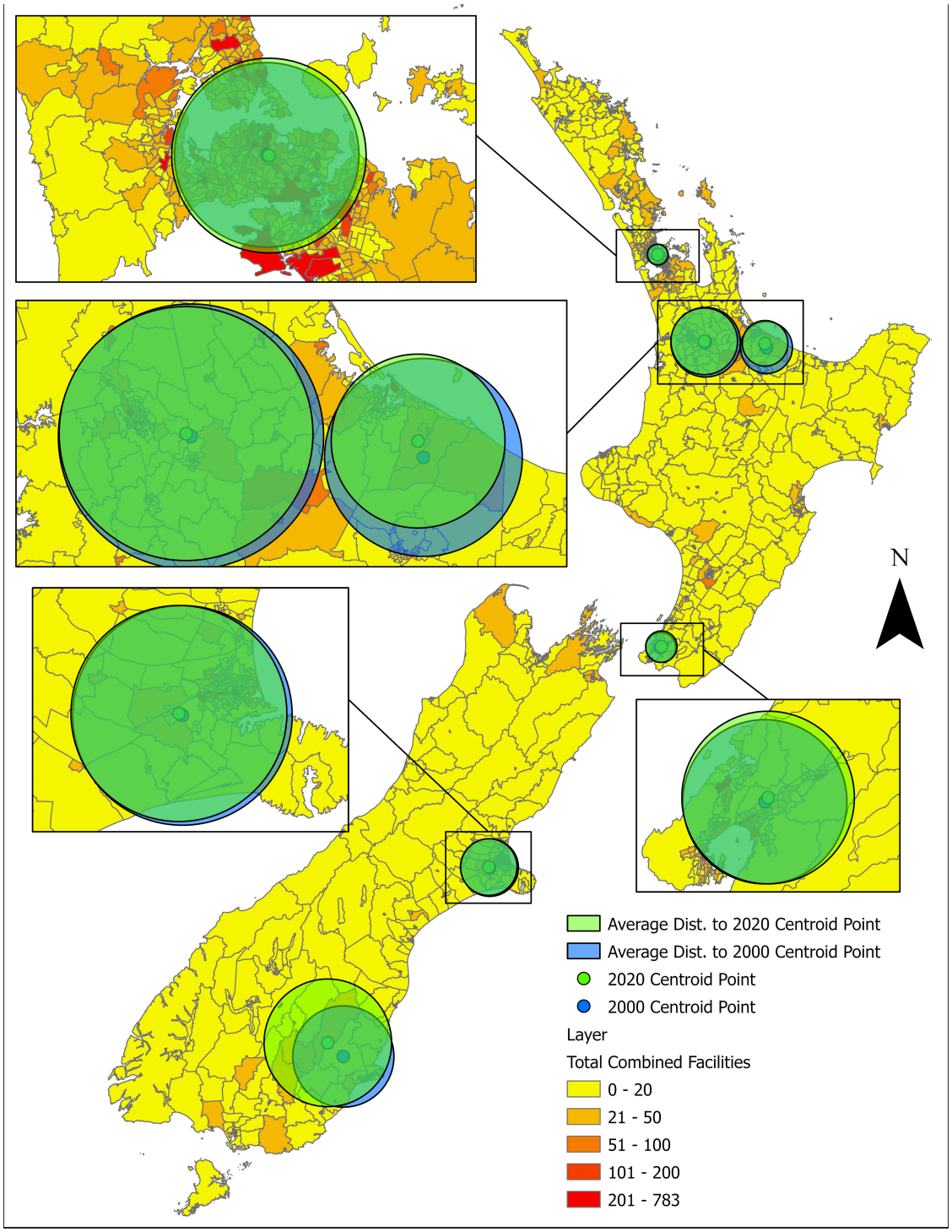


Figure 4: Change in centrality (shift in centroid position) and concentration/sprawl (average distance to centroid) of COMBO facilities in the six regions. The colouring of the SA2s indicate the number of COMBO facilities in the SA2.

while ALL facilities concentrated by 240 m per year (4.80 km over 20 years).

The greatest shift in centrality and concentration of COMBO facilities occurred in Waikato (1.83 km or 91.2 m per year) and Bay of Plenty regions (3.82 km or 191 m per year). In both these regions, ALL facilities also showed a relatively big shift and concentration comparable to what happened with logistics facilities.

(SyndicateQ: Here are some ideas I have to clarify what happened here, but it is based on my limited reasoning:

Port cities: Auckland, Wellington and Christchurch are "port cities" and Tauranga increasingly became a port city over the past two decades. Ports generally act as magnets for economic development until development reaches the point where there is a clash between the port and the city. Then you expect to see an outward sprawl away from the port as there is no more room for expansion. This may be the case in Auckland and Wellington where we are seeing the start of that outward push with logistics facilities that need cheaper land and larger land tracts. One could surmise that in another decade or so, the rate of sprawl would increase, but that's tough to say.

Small cities: New Zealand cities are, in global terms, small cities. So while we are looking at "our biggest cities", it may be that they are still to small from a land area and population density point of view for the sprawl-inducing phenomena to be hard at work.

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Otago paints a very different picture than the other regions because it is home to two urban centres: Queenstown and Dunedin. The data shows that economic activity has definitely shifted towards Queenstown over the past 20 years. The centroid for ALL facilities shifted by 23 km over 20 years while the centroid for COMBO facilities shifted in the same direction by 25 km. Related to this shift is an increase in sprawl: ALL facilities sprawled by 11 km or 550 m per year and COMBO facilities by 16 km or 800 m per year. As the center of activity gradually shifts from one urban centre to another, facilities would shift gradually to follow it. As it happens when a swarm of birds or bees change direction, there is first a sprawling as individuals in the swarm adapt and then a re-concentration. (SyndicateQ: I need to understand the underlying phenomena here)

4.3. Summary

The first question we set out to address was: *What has been the extent of logistics sprawl in New Zealand between 2000–2020?*. We first considered whether the number of logistics facilities had increased at all. While the answer is, yes, there was growth, it was not increased apace with the increase of ALL facilities or the population — neither nationally or regionally. RET facilities showed the strongest growth nationally, but there is great regional variance that cannot easily be ascribed to population growth. The regional variance was also prominent for WSL and TWD facilities with no clear correlations. COMBO facilities are in step with the rest of the economy and population in terms of the pattern of growth from 2006–2018.

With an increase in COMBO facilities, albeit small, the expectation was to observe logistics sprawl in the regions that are home to the country's urban centres. Here the results have been unexpected. There is no strong evidence of sprawl except in the case of Otago, which is an exception due to the shift of economic activity between Queenstown and Dunedin. Not only is there not sprawl, the opposite — logistics concentration — is evident in at least two of the urban regions. (SyndicateQ: This is the curse of the negative result. Since my PhD, every single study I've done since, I've proved myself wrong. If ever you need to prove yourself wrong in research, consider me as a collaborator...)

Next we consider who the communities are that share space with COMBO facilities and whether there are issues of social justice to consider.

5. Logistics facilities and deprivation: Are they neighbours in New Zealand?

(nmt: Actually, that could be a good paper title :)... or popular article title)

We explore the correlation between the different type of facilities and deprived communities at three distinct time points: 2006, 2013, and 2018. The dependent variables in our study are the number of facilities of a certain type in an SA2. The independent variable of greatest interest is the NZDep index (NZDepIndex). By studying this relationship we can understand if and how facilities are co-located with deprived communities. However, to calculate this relationship more accurately, we included other independent variables in our model that are known (from other studies of logistics sprawl) to influence the dependent variables. These are the total population (TOT_POP), the distances from the centroid of an SA2 to the nearest sea port, airport, and railway

terminal (PORT_DIST, AIR_DIST, RAIL_DIST), and the density of the highway network in the overarching urban area that the SA2 is a part of (HWY_AREA).

According to the test for spatial autocorrelation (i.e., Moran's I), all our dependent variables exhibit significant spatial autocorrelation ($p < 0.001$), therefore, a study of the correlation relationships requires a spatial regression approach. Hence, we use the mathematically rigorous geographically and temporally weighted regression (GTWR) model to account for the heterogeneous local spatial and temporal effects.

5.1. Total population (TOT_POP)

Table 6 shows the average and standard deviation of the distributions of the coefficients for the independent variable TOT_POP. The relationship between the total population and ALL facilities differ greatly amongst the regions.

In Auckland and Canterbury, the correlation between the total population in an SA2 and the number of ALL facilities has been negative at all three time points, meaning that facilities are likely to be located in areas with a lower population. In Canterbury, the relationship has strengthened (become more negative) over time, whereas in Auckland it seems to have weakened a little. The specific dynamics in these two cities need to be further explored, but most likely the influx of people without concomitant infrastructure growth is causing pressure for ALL facilities to make way.

Both Wellington and Waikato had a negative correlation with total population in 2006, but this changed over time. For Waikato, the change was slight: from a slight negative correlation to a slight positive correlation. However, for Wellington, the change is drastic from a negative correlation to the second strongest positive correlation among the six regions. (nmt: I can't say why.).

In the Bay of Plenty, the correlation has been positive at all three time points and strengthening over time. This makes sense in light of Tauranga's recent economic development. Businesses are being drawn to the population centres which still have enough space to accommodate both, relatively speaking. (nmt: sense check)

Otago shows the strongest positive correlation by a big margin. This aligns with the underlying shift in economic activity and population towards Queenstown. (nmt: sense check)

In contrast to the relationship between the population and ALL facilities, COMBO facilities

are negatively correlated with TOT_POP in all regions across all time points. Areas with higher populations tend to have relatively fewer logistics facilities. This is curious in the case of RET and WSL facilities as the authors expected facilities that sell goods to consumers to have a positive correlation with consumers. The prevalence of private car transport throughout New Zealand, may partly explain this. Consumers are not reliant on non-motorised forms of transport (which prefer shorter distances) or public transport (which is established along high population density routes) to reach WSL or RET facilities. (SyndicateQ: Does this sound plausible to you?) Another interesting finding is that TWD facilities have a slight positive correlation (average coefficient < 1) with TOT_POP. This could be because postal and courier facilities are included in the underlying ANZSIC categories.

Table 6: Descriptive statistics of the coefficients of the total population variable (TOT_POP) calculated by the GTWR model. The coefficient indicates the change in number of facilities per 1000 change in the population.

Area	TOT_POP					
	2006		2013		2018	
	avg	stdev	avg	stdev	avg	stdev
ALL Facilities						
Auckland	−8.71	0.60	−5.03	0.51	−5.57	0.53
Bay of Plenty	5.13	3.11	7.81	2.97	7.66	3.09
Canterbury	−2.89	3.70	−7.88	5.70	−11.35	6.82
Otago	31.06	15.22	33.95	15.42	33.77	15.22
Waikato	−1.31	3.31	1.81	3.21	1.55	3.45
Wellington	−3.23	0.45	12.77	1.66	17.56	2.18
COMBO Facilities						
Auckland	−11.36	0.24	−12.26	0.27	−12.40	0.29
Bay of Plenty	−6.90	0.93	−7.38	1.02	−7.36	1.06
Canterbury	−7.41	0.76	−9.25	1.10	−8.96	1.25
Otago	−2.64	2.19	−2.98	2.24	−2.41	2.25
Waikato	−8.63	1.24	−9.24	1.38	−9.27	1.44
Wellington	−5.68	0.09	−4.57	0.11	−3.92	0.16

5.2. Transport variables

There are four transport-related variables that are correlated with logistics facilities in intuitive ways. Table 7 reports the average and standard deviations of the coefficient distributions in the six regions.

The highway area in the underlying urban area of an SA2 is positively correlated with all types

of facilities in all six regions except Otago. In Otago, greater highway density is not associated with more ALL facilities in an SA2. We are seeing the overall shift of economic activity and population from Dunedin to Queenstown trump some of the traditional facility location drivers, like road accessibility.

Over time, the positive correlation of ALL facilities and HWY_AREA is getting stronger. Even for Otago, the correlation is becoming less negative. Highway density is believed to be a direct causal factor for business facilities as it provides more efficient transport access for people (workers / consumers) and goods (truck transport).

For COMBO facilities, the correlation between greater highway densities and logistics facilities is positive and relatively stable in all the areas over time. (nmt: is there more to say here?)

Overall, businesses seem to be located further away from the nearest airport in Auckland, Bay of Plenty, Canterbury, and Waikato — evidenced by the positive correlation of AIR_DIST to ALL facilities. In Otago and Wellington, businesses are located closer to the airport. These relationships have remained stable over time.

The negative correlation of AIR_DIST with COMBO facilities show that logistics facilities are located closer to airports. This relationship is remarkably stable across the regions and over time. The stable negative correlation is also evident when considering the logistics categories separately (RET, WLS, TWD). (SyndicateQ: Is it necessary to see the results in table format? I think it would be death by coefficients.)

Different to the case with airports, businesses are located closer to sea ports (negative correlation of PORT_DIST to ALL facilities). The underlying phenomenon here is the port-centric development of New Zealand cities. As mentioned before, cities is New Zealand still show signs of concentration rather than sprawl, which explains the concentration around the ports which are integral to the regional economies. Even in Waikato development favours the direction of the Ports of Auckland (see Figure 4) (nmt: Which is a little contentious because what about Tauranga? One would need to look at the underlying freight flow statistics to know which port is more important to the regional economy). The exception to this is, again, Otago, where development is pulled to Queenstown despite the presence of the Port of Otago in Dunedin. In terms of ALL facilities, the relationships are stable over time.

COMBO facilities feel the same pull towards the ports overall and per category (RET, WLS,

TWD) and this relationship is stable over time and similar across regions. However, the coefficient of the correlation is smaller for COMBO facilities than for ALL facilities, indicating weaker correlation. (nmt: I'm not sure why, one idea is: This is probably the net effect of being simultaneously drawn towards the ports and pushed out of dense or costly urban areas).

ALL and COMBO facilities are located closer to railway terminals. The relationship is stable over time, but there is more variation among regions than for the airport and sea port variables. Furthermore, when comparing the coefficients of the RAIL_DIST and PORT_DIST variables, the correlation with railway infrastructure seems stronger. However, in the context of New Zealand's road-freight reliant economy, we consider that this might be a spurious relationship. Railways have historically been built around the sea ports and as regional and national corridors. Highways have been built along the same corridors and also as networks leading off from these corridors. Therefore, the relationship with railway infrastructure may be due, partly, to the relationship with highway and port infrastructure.

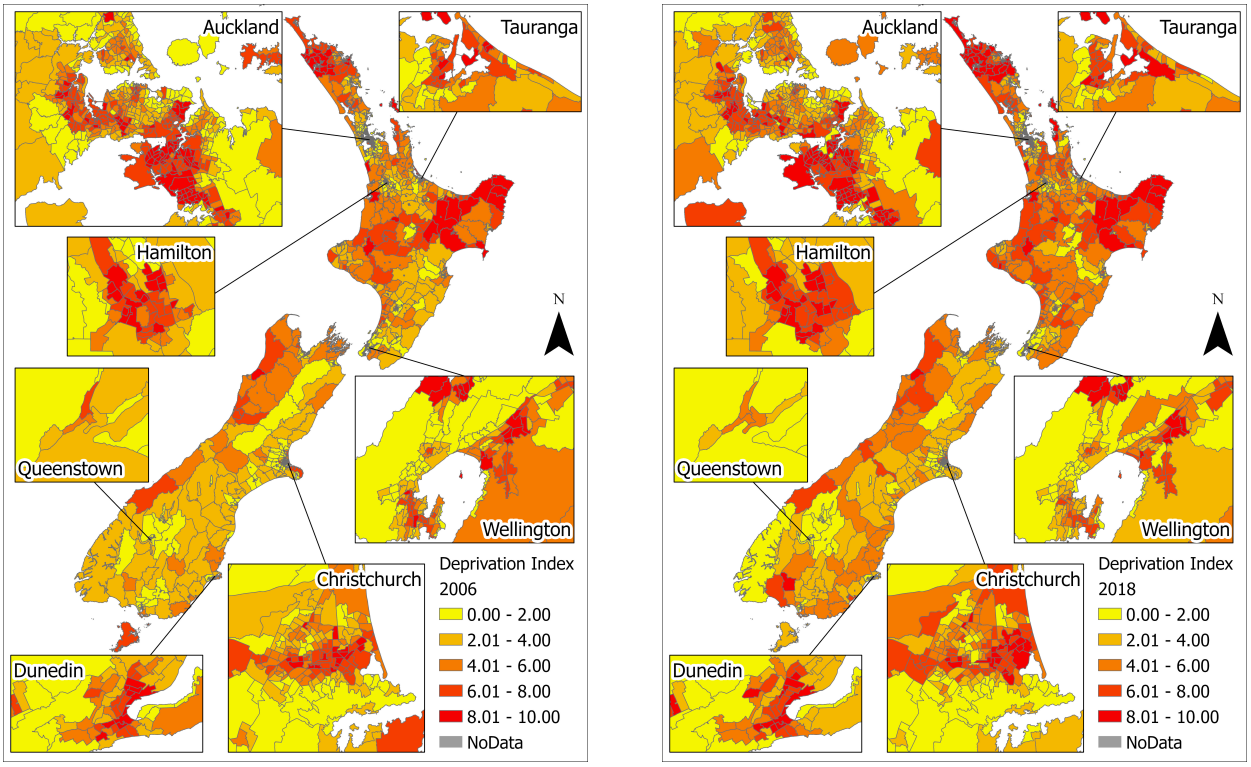
Table 7: Descriptive statistics of the coefficients of the transport-related variables calculated by the GTWR model. Coefficients for HWY_AREA indicate the change in number of facilities per change in highway density (km/km^2). Coefficients of AIR_DIST, PORT_DIST, and RAIL_DIST indicate the change in number of facilities per change in the distance to the infrastructure (km).

Area	Transport coefficients											
	HWY_AREA			AIR_DIST			PORT_DIST			RAIL_DIST		
	2006	2013	2018	2006	2013	2018	2006	2013	2018	2006	2013	2018
ALL Facilities												
Auckland	188.5	197.8	215.7	0.6	0.7	0.6	−0.4	−0.5	−0.6	−1.6	−1.7	−1.9
Bay of Plenty	87.7	97.4	108.7	0.5	0.5	0.5	−0.6	−0.6	−0.7	−1.2	−1.3	−1.5
Canterbury	50.9	72.0	76.5	0.1	0.2	0.1	−0.2	−0.2	−0.2	−1.2	−1.4	−1.4
Otago	−39.8	−29.7	−20.0	−0.3	−0.4	−0.5	0.5	0.7	0.9	−0.8	−0.8	−0.7
Waikato	123.0	133.6	147.7	0.6	0.6	0.5	−0.5	−0.5	−0.6	−1.5	−1.7	−1.9
Wellington	105.4	113.7	116.2	−1.6	−1.6	−1.6	−0.3	−0.3	−0.3	−0.9	−0.8	−0.7
COMBO Facilities												
Auckland	56.7	58.0	56.7	−0.1	−0.1	−0.2	−0.2	−0.2	−0.2	−0.4	−0.4	−0.5
Bay of Plenty	30.0	31.7	30.6	−0.1	−0.1	−0.2	−0.2	−0.2	−0.2	−0.3	−0.4	−0.4
Canterbury	25.2	25.8	21.5	−0.2	−0.2	−0.2	−0.2	−0.1	−0.1	−0.2	−0.2	−0.2
Otago	8.2	10.8	11.6	−0.2	−0.2	−0.2	0.1	0.1	0.1	−0.1	−0.1	0.0
Waikato	40.4	42.0	40.9	−0.1	−0.2	−0.2	−0.1	−0.2	−0.2	−0.4	−0.4	−0.5
Wellington	18.0	18.1	16.0	−0.3	−0.3	−0.3	−0.1	−0.1	−0.1	−0.2	−0.2	−0.2

5.3. NZDep index

A visual inspection of Figures 5a and 5b show that deprivation has increased across New Zealand between 2006 and 2018. This is evident by the greater proportion of darker colours (oranges and reds) — which indicate a higher NZDep index and thus greater deprivation — on

the map. The results in Table 8 show that in Auckland, Bay of Plenty, and Waikato, more ALL facilities are located in less deprived communities (indicated by the negative correlation) and this relationship has strengthened over time. In Canterbury and Wellington, the correlation was initially positive, indicating that facilities were more prone to being established in areas with higher levels of deprivation. However, this relationship switched to a negative correlation (albeit weak) in 2013 and 2018, indicating that ALL facilities co-locate in less deprived communities. Only in Otago has the relationship remained positive throughout.



(a) NZDep index per SA2 in 2006

(b) NZDep index per SA2 in 2018

Figure 5: Some caption

When considering the broad category of ALL facilities, the assumption is that having more facilities in an area is beneficial as it indicates a healthier local economy, more job opportunities, and greater access to products and services. A healthy local economy is expected to result in higher household incomes and lower unemployment. Therefore, the indication that communities with more facilities tend to be less deprived, or said differently, communities with fewer facilities tend to be more deprived, is intuitive.

The case with logistics facilities is different. As Cidell (2015) elaborates, the benefits of logistics

facilities are often not experienced locally, but in some distant market. In Table 8 we see that the correlation between the number of COMBO facilities and the NZDep index is positive across the board. This means that COMBO facilities tend to co-locate with more deprived communities.

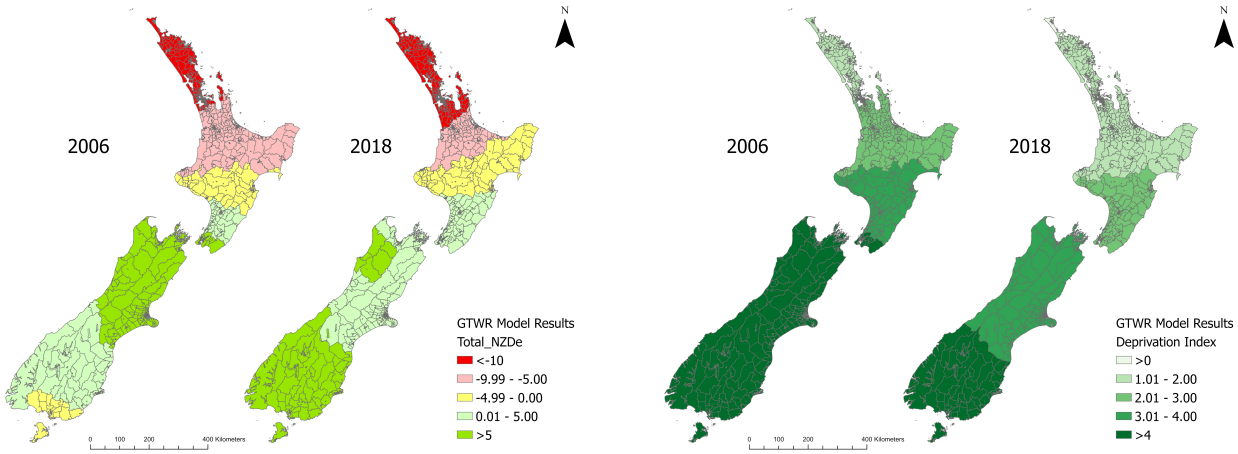
Unlike the discussion of the transport variables, it would be wrong to say that a more deprived community attracts or deters the establishment of COMBO facilities as it is not the people, nor their level of deprivation, that forms part of a company's decision framework. Instead, as discussed before, it is because communities with fewer resources and COMBO facilities value similar things: lower land rent, cheaper utilities with reasonable access to urban economic centres.

Table 8: Descriptive statistics of the coefficients of the NZDep index calculated by the GTWR model. The coefficient indicates the change in number of facilities per change in the NZDep index of an SA2.

Area	NZDep Index					
	2006		2013		2018	
	avg	stdev	avg	stdev	avg	stdev
	ALL Facilities					
Auckland	−10.6	0.3	−15.0	0.2	−17.1	0.2
Bay of Plenty	−7.0	0.6	−11.6	0.8	−12.9	1.0
Canterbury	6.5	0.7	−0.8	0.6	−0.6	1.0
Otago	2.5	0.9	2.2	1.1	5.4	1.6
Waikato	−8.2	1.0	−12.9	1.2	−14.5	1.5
Wellington	5.7	0.9	−2.0	0.3	−2.2	0.1
	COMBO Facilities					
Auckland	2.0	0.1	1.1	0.0	1.2	0.0
Bay of Plenty	2.7	0.1	1.5	0.1	1.5	0.1
Canterbury	5.1	0.1	3.5	0.2	3.5	0.1
Otago	5.4	0.0	4.6	0.2	4.5	0.2
Waikato	2.4	0.2	1.3	0.1	1.3	0.1
Wellington	4.1	0.1	2.6	0.0	2.9	0.0

Figure 6 maps the coefficients of the NZDep index nationally for ALL facilities (Figure 6a) and COMBO facilities (Figure 6b). This figure gives a broader context of the national trend by expanding our view beyond the six regions in question. For ALL facilities, the negative correlation is specific to the North Island with the strongest relationship around Auckland. Between 2006 and 2018, the negative correlation in the center of the North Island seems to have weakened somewhat (evidenced by more yellow replacing light red), but the negative correlation around Auckland has strengthened (indicated by more dark red replacing light red).

In the case of COMBO facilities, the strongest positive correlations are concentrated in the South Island. Nationally, the positive correlations have weakened over time, evidenced by lighter greens replacing darker greens in Figure 6b and confirmed by the average coefficient values in Table 8. Therefore, we observe a trend that, over time, although the correlation remains positive, logistics facilities are less likely to be co-located in communities with high levels of deprivation.



(a) NZDep coefficients for ALL facilities

(b) NZDep coefficients for COMBO facilities

Figure 6: Coefficients of the NZDep variable for ALL facilities and COMBO facilities in 2006 and 2018. A positive coefficient indicates the increase in the number of facilities for each step increase in the index. A negative coefficient indicates the increase in the number of facilities for each step increase in the index. (Higher index levels indicate greater deprivation.)

At this stage, it is not possible to surmise why this has occurred. One idea is that the deprivation of the communities around existing logistics facilities has decreased. This is plausible, but Figure 5 does not confirm broad improvements in the NZDep index from 2006–2018. In fact, it shows worsening deprivation in many areas. Another idea is that the urban fabric in many areas has changed to such a degree that the factors that attract logistics facilities are now found amongst less deprived communities. Further study is required to confirm this. While the underlying phenomena cannot yet be ascertained, we can question whether this trend is good or not.

(SyndicateQ: The only way I can think to quantify benefits or costs at this time with the data at hand is by looking at employment densities for different facilities. This is what I have:)

The national average employment density for ALL facilities remained stable between 2000 (3.94 employees/facility) and 2020 (3.90 employees/facility). Looking at the regional breakdowns only a few regions saw increases or decreases in the ratio of more than 10% namely: Nelson (-11.6%), Taranaki Region (10.4%), Waikato region (12.8%), West Coast region (15.1%), and Northland

region (20.2%).

COMBO facilities employ more people, on average, than ALL facilities do. The national average was 5.16 in 2000 and increased to 5.96 in 2020 (15.5% growth overall). RET facilities have the highest employment density (6.31), followed by WSL (5.74), and then TWD (5.13) facilities.

(SyndicateQ: Thus one could argue that COMBO facilities contribute more employment to an area than other facilities, but how to you argue that it does or does not make up for the costs?)

6. Conclusion

(nmt: New Zealand perplexes me. Healthy population and economic growth did not result in logistics sprawl, I don't know why. While deprivation does seem to be worsening, it does not seem that logistics facilities are increasingly co-locating in deprived communities, instead, it seems like the communities surrounding logistics facilities are less deprived. While this could be a good thing, I am stuck about it.)

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Appendix A. Historical variables of the NZDep index

Table A.9: The NZDep deprivation dimensions and their concomitant variables for 2001 (ordered according to decreasing weight in the index). (nmt: ref)

Dimension of deprivation	Description of variable
Income	People aged 18–64 receiving a means tested benefit
Employment	People aged 18-64 unemployed
Income	People living in equivalised households with income below an income threshold
Communication	People with no access to a telephone
Transport	People with no access to a car
Support	People aged < 65 living in a single parent family
Qualifications	People aged 18-64 without any qualifications
Living space	People living in equivalised households below a bedroom occupancy threshold
Owned home	People not living in own home

Table A.10: The NZDep deprivation dimensions and their concomitant variables for 2006 (ordered according to decreasing weight in the index). (nmt: ref)

Dimension of deprivation	Description of variable
Income	People aged 18–64 receiving a means tested benefit
Income	People living in equivalised households with income below an income threshold
Owned home	People not living in own home
Support	People aged < 65 living in a single parent family
Employment	People aged 18-64 unemployed
Qualifications	People aged 18-64 without any qualifications
Living space	People living in equivalised households below a bedroom occupancy threshold
Communication	People with no access to a telephone
Transport	People with no access to a car

Table A.11: The NZDep deprivation dimensions and their concomitant variables for 2013 (ordered according to decreasing weight in the index). (nmt: ref)

Dimension of deprivation	Description of variable
Communication	People with no access to the Internet at home
Income	People aged 18–64 receiving a means tested benefit
Income	People living in equivalised households with income below an income threshold
Employment	People aged 18-64 unemployed
Qualifications	People aged 18-64 without any qualifications
Owned home	People not living in own home
Support	People aged < 65 living in a single parent family
Living space	People living in equivalised households below a bedroom occupancy threshold
Transport	People with no access to a car