Agglomeration Elasticities in New Zealand

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Abstract

This paper analyses the relationship between firms' multi-factor productivity and the effective employment density of the areas where they operate. Quantifying these agglomeration elasticities is of central importance in the evaluation of the wider economic benefits of transport investments. We estimate agglomeration elasticities using the Statistics New Zealand prototype Longitudinal Business Database: a firm-level panel covering the period 1999 to 2006. We estimate that an area with 10 percent higher effective density has firms with productivity that is 0.69 percent higher, once we control for the industry specific production functions and sorting of more productive firms across industries and locations. We present separate estimates of agglomeration elasticities for specific industries and regions, and examine the interaction of agglomeration with capital, labour, and other inputs.

JEL classification
L25 – Firm Performance: Size, Diversification, and Scope
R12 – Size and Spatial Distributions of Regional Economic Activity
R3 – Production Analysis and Firm Location
R40 – Transportation Systems, General

Keywords
Agglomeration; urban density; transport evaluation; productivity

Contents

1 Introduction

Firms in locations with dense economic activity are more productive than firms in less dense areas. An extensive economics literature exists that quantifies the strength of this relationship, and evaluates alternative explanations. Recent reviews of this literature include Duranton and Puga (2004) and Rosenthal and Strange (2004).

The current paper adds to this literature in several ways. First, it presents the most complete empirical analysis of agglomeration effects for New Zealand, adding to a small existing literature. Second, it presents a microeconometric analysis of the impact of agglomeration on firms' multi-factor productivity using a new longitudinal unit record dataset of firms covering a large proportion of the New Zealand economy. The dataset enables us to examine the strength of agglomeration effects for a comprehensive range of industries, and to test alternative ways of controlling for firm heterogeneity that may bias agglomeration elasticity estimates.

The analysis and findings are of general interest in advancing our understanding of the nature and extent of productivity advantages of urban activity. In addition, the estimates of the elasticity of multi-factor productivity with respect to employment density have specific relevance to the evaluation of transport funding proposals. The New Zealand Transport Agency (NZTA) publishes an Economic Evaluation Manual that includes specific guidance on how to quantify agglomeration impacts as a benefit of transport investment. Following Graham (2005b), the productivity benefits of transport improvements are included as a 'wider economic benefit' of transport improvements. Transport investments serve to facilitate a higher density of economic activity. To the extent that this higher density is associated with productivity improvements, the returns to investments will be greater. The NZTA's manual includes estimates of the relationship between density and productivity for each of nine different industry groups (NZTA 2008, page A10-3). These figures are based on estimates from the United Kingdom, adjusted to reflect the lower levels of density in New Zealand (Graham 2007).

The main focus of this report is on the direct estimation of agglomeration elasticities for New Zealand, for use in the economic evaluation of transport investments. It provides the first set of empirical estimates of agglomeration elasticities based on New Zealand microdata. It confirms the general cross-sectional aggregate and industry patterns found in international studies and extends the literature by exploiting the panel structure of the prototype Longitudinal Business Database data to control for the biases arising from higher productivity firms sorting into denser locations. In deriving these estimates, it highlights a range of conceptual and empirical issues related to the calculation and interpretation of agglomeration elasticities. It examines the influence of non-random sorting of heterogeneous firms across locations and considers variation in agglomeration elasticities across industries and locations. It also discusses the strengths and weaknesses of alternative controls for firm heterogeneity and sorting.

2 Background

Agglomeration economies are positive externalities derived from the spatial concentration of economic activity. When firms locate in close proximity to each other a number of tangible benefits are thought to emerge, for instance, in the form of increased opportunities for labour market pooling, in the sharing of 'knowledge' or technology, in process specialisation within the industry, or in the efficiency of input-output sharing. Thus, spatial concentration gives rise to increasing returns which theory tells us will be manifest in higher productivity and lower average costs for firms. .

Since transport investments can increase the scale and efficiency of spatial economic interactions by lowering travel times and improving connectivity, we might expect positive external effects via agglomeration economies. This is the essence of the case for including 'agglomeration benefits' within transport appraisal. Agglomeration economies are driven by access to economic mass, or in other words, by the access that firms have to other firms in similar or dissimilar industries, to labour markets, and to markets more generally. Transport provision is an extremely important determinant of accessibility and thus exerts a crucial influence on the level of agglomeration experienced by firms. Where there are constraints in the transport system, or where the system works inefficiently, we would expect negative consequences for the generation of agglomeration economies. When we make new investments in transport we change the economic mass that is accessible to firms with positive consequences for the agglomeration economies these firms enjoy.

A key point that should be emphasised in relation to the potential agglomeration benefits of transport investment is that these arise as a result of externalities or market imperfections. This is important because conventional methods of transport appraisal, based on quantification of the value of travel time savings, generally assume perfect markets and constant returns to scale. Thus, any agglomeration effects should, in theory, be additional to the benefits of transport investment captured under a standard approach.

An excellent theoretical account of the link between transport and agglomeration is set out by Venables (2007). He shows that we can quantify the 'agglomeration benefits' of transport investments if we know:

1. the change in access to economic mass that will result from making some transport intervention; and,
2. the amount by which productivity will rise in response to an increase in agglomeration.

This latter quantity, the elasticity of productivity with respect to agglomeration, is the subject of this report.

The economics literature has identified a range of possible sources for higher productivity in more dense areas. A common grouping reflects the work of Marshall (1920), who discussed the advantages of thick labour markets, ease of linkages to input and output markets, and knowledge spillovers arising from proximity to others in the same industry (localisation). Each of these potential sources is consistent with agglomeration effects – the observed positive relationship between agglomeration and productivity. Observing such a positive relationship is thus uninformative about the underlying nature of agglomeration effects. The problem of identification extends also to microeconomic theory. Duranton and Puga (2004) summarise agglomeration theories under the headings of sharing, matching, and knowledge spillovers, and note that more than one mechanism may be consistent with each of the sources that Marshall identified. It is perhaps unsurprising, then, that the empirical literature on agglomeration effects, summarised by Rosenthal and Strange (2004), continues to struggle in identifying the sources of agglomeration effects.

Many studies have, however, quantified the strength of the relationship between economic performance and density of activity. An influential study by Ciccone and Hall (1996) estimates an elasticity of total factor productivity to employment density of 0.04 across US states. Graham (2005b) surveys empirical estimates of agglomeration elasticities and finds that the majority of estimates are between 0.01 and 0.10. In a more extensive meta-analysis, Melo et al. (2009) find a median estimate of 0.041.

One challenge facing many of the reviewed studies is to identify a causal effect of density on productivity. It is clear that denser areas are more productive but this may reflect other factors that are positively associated with both density and productivity. It is more difficult to establish that an increase in density would necessarily lead to an increase in productivity. The challenge is even greater for studies that analyse the relationship between public infrastructure, such as transport infrastructure, and productivity (Eberts and McMillen 1999). In this case, there is the confounding issue that infrastructure investments may be deliberately directed towards high-productivity areas, meaning that simple correlations between investments and performance may further overestimate the productivity impacts of infrastructure. Transport investments will also have wider general equilibrium impacts. Ignoring these may, however, lead to either an overestimate or an underestimate of the true impact. As emphasised by Haughwout (1999), increases in density as a result of transport investments may be offset by reduced density in other areas. In contrast, equilibrium effects may reinforce the 'first-round' benefits. Venables (2007) uses a computable general equilibrium model to demonstrate the compounding benefits of transport investment externalities, which are further reinforced by interactions with the tax system.

There is a small number of empirical studies in New Zealand that estimate the strength of agglomeration effects on productivity. Williamson et al (2008b) report an elasticity of around 0.03 between employment density and average earnings in Auckland using data from the 2001 Census. Williamson et al (2008a) extend this analysis by adjusting for differences in industry and qualification composition of different areas, with a resulting elasticity estimate of 0.099.[1] Maré (2008) examines the relationship between employment density and labour productivity, and estimates a cross sectional elasticity of 0.09 between area units within the Auckland region. Controlling for area fixed effects reduces the estimated elasticity to 0.05 and the relationship becomes insignificant when the relationship is estimated in first

[1] Note that the two estimates are not directly comparable because of differences in specification and evaluation. Williamson *et al* (2008b) reports estimates from an equation of Income = a+b*$\log_{10}$(Density). Williamson *et al* (2008a) estimates ln(Income) = a+b*ln(Density)

difference form. These estimates control for 3-digit industry composition, but not for capital intensity of firms.

The current paper thus extends previous analyses by explicitly estimating a production function that accommodates firm-level variation in productive inputs. It is thus able to estimate the impact of agglomeration on multi-factor productivity. The panel structure of the data in the current paper also permits controls for firm-level heterogeneity.

3 Methods

Agglomeration effects are characterised as the productive impact of employment in surrounding areas on a firm's production technology. It is natural, therefore, to treat local employment density as an input into a firm's production function, as represented by the following equation:

$$Y_{it} = f_i\left(\{E_{dit}\},\{X_{it}\}\right) \tag{1}$$

where Y_{it} is a measure of firm i's gross output in period t; $\{X_{it}\}$ is a vector of inputs into production, and E_{dit} is a vector of employment in surrounding areas, measured at an array of distances d from firm i. In this paper, we measure employment as total employment locally, thus focusing on general agglomeration effects. It is possible that firms benefit particularly from proximity to own-industry employment, the benefits of which will be underestimated by looking only at the relationship between productivity and *total* employment locally.

The strength of employment agglomeration can be summarised in a single index, most commonly by some measure of employment density in a local area. A more general measure is presented in Graham (2005b), who imposes a constant distance decay factor ($\alpha=1$) to derive a measure of *effective density* (U_i):

$$U_i = \frac{E_i}{\left(\sqrt{A_i/\pi}\right)^{\alpha}} + \sum_j^{i\neq j}\left(\frac{E_j}{\left(d_{ij}\right)^{\alpha}}\right) \tag{2}$$

where E_i is a measure of employment in area i and d_{ij} is the distance between area i and area j. A_i is the land area of area i, so that $\sqrt{A_i/\pi}$ is an estimate of the average distance between jobs *within* area i.

Distance decay reflects the smaller influence that more distant employment has, compared with the influence of proximate employment. Distance may be measured as Euclidean (straight-line) distance, by road distance, or by travel time. Travel time adjustments reflect the generalised cost of distance, and the impact of congestion in reducing the influence of distant employment density. Graham (2006b) compares agglomeration elasticity estimates derived with different distance metrics and concludes that, while the estimated elasticities are similar, the use of generalised cost rather than distance yields slightly higher estimates overall and significantly higher estimates in dense urban areas. The processes of sharing, matching, and knowledge spillovers that underlie agglomeration effects probably depend more on generalised rather than straight-line distance. For the purposes of transport appraisal, it is however more appropriate to use straight-line distance in deriving measures of wider economic benefits, as time costs and savings are generally already incorporated in standard transport models (Graham 2005b, p. 118).[2]

The imposition of a constant distance decay factor of $\alpha=1$ for all industries may lead to biased agglomeration elasticity estimates. For instance agglomeration effects that operate only over very short distance will be harder to identify if U_i includes more distant employment that is irrelevant to the performance of firms in area *i*. Direct estimation of variable decay parameters is beyond the scope of the current paper but would be a valuable robustness and sensitivity check in future analyses. Graham et al. 2009 have estimated distance decay factors (α) for four broad sectors of the UK economy: manufacturing, construction, consumer services, and business services. They use a control function approach to address potential sources of endogeneity and to allow for unobserved firm level heterogeneity. A non-linear least squares regression is used to provide a direct estimate of distance decay. The results show an overall agglomeration effect of 0.04 across all sectors of the economy. For manufacturing and consumer services they estimate an elasticity of 0.02, for construction 0.03, and for business services 0.08. The distance decay parameter is approximately 1.0 for manufacturing, but around 1.8 for consumer and business service sectors and 1.6 for construction. This implies that the effects of agglomeration diminish more rapidly with distance from source for service industries

2 We cannot examine the robustness of our findings to the use of generalised costs, since New Zealand does not have a national transport model that could provide the necessary measures.

than for manufacturing. But the relative impact of agglomeration on productivity is still found to be larger for services than it is for manufacturing.

Another important result is that the value of α does not greatly affect the magnitude of estimated agglomeration elasticities. Setting $\alpha=1$ produces elasticity results of much the same order of magnitude. However, the value of α does tend to have an important effect on the assessment of agglomeration benefits from transport investments. Where α is high ($\alpha > 1.0$) agglomeration benefits will also tend to be proportionally higher. The intuition here is that when distance counts more ($\alpha > 1.0$) increases in effective density will tend to give proportionally higher shifts in productivity, although the impact is confined to a smaller geographic area.

Using the summary measure U_i as defined above, Graham and Kim (2007) incorporate effective density as a factor-augmenting input to production in a value-added production function, approximated by a translog form (Christensen et al. 1973):

$$\log Y = \alpha_0 + \sum_{j=1}^{J} \alpha_i \log X^j + \gamma_u \log U + \frac{1}{2} \sum_{h=1}^{J} \sum_{j=1}^{J} \gamma_{hj} \log X^h \log X^j + \sum_{j=1}^{J} \gamma_{ju} \log X^j \log U + \frac{1}{2} \gamma_{uu} (\log U)^2 \quad (3)$$

where the *i* subscript has been suppressed and X^j (j=j . . .J) denotes one of *J* factors of production. The parameters α and γ are production function parameters, which are potentially industry-specific,

A common simplification of this specification is to assume that the productive impact of density is Hicks-neutral rather than factor-augmenting, so that $f_i\left(\{D_{dit}\},\{X_{it}^j\}\right) = g(U_i)h\left(\{X_{it}^j\}\right)$. For instance, Graham (2006a) estimates a restricted form of equation (3), with $\gamma_{ju}=0 \ \forall j$, reflecting the assumption of Hicks neutrality. The added assumption of homogeneity (as in Graham 2005a) results in the familiar Cobb-Douglas specification, with $\gamma_{hj}=0 \ \forall h$ and j. The chosen functional form of the production function can be applied to the relationship between gross output and productive inputs (a *gross output* production function), or between value added and labour and capital inputs (a *value added* production function). The following table summarises the relationship between relevant measures of production, and shows the structure of a gross output production function (*h()*) and a value added production function (*v()*):

Table 1 **Gross-output and value-added production functions**

$$Gross\ Output = Intermediate\ Consumption + \underbrace{\begin{bmatrix} Labour\ Costs + Capital\ Charges + \\ Indirect\ Taxes + Net\ Surplus \end{bmatrix}}_{Value\ Added} \quad (4)$$

Gross Output production function

Gross Output = h(Agglomeration, Intermediates, Labour, Capital)

Value Added production function

Gross Output = Intermediates + v(Agglomeration, Labour, Capital)

Value Added = v(Agglomeration, Labour, Capital)

We use the gross output specification because it is more general and, unlike the value added function, allows for possible substitutability between intermediate consumption and other factors. The gross output specification also has the advantage that we do not have to exclude enterprises with negative value added (the log function is undefined for non-positive numbers), avoiding selection bias.

3.1 Estimation

We estimate agglomeration elasticities using longitudinal microdata on enterprises. Estimation is based on the following estimating equation, which is a form of equation (3), augmented with an appropriate error structure:

$$\log Y_{it} = \alpha_0 + \sum_{j=1}^{J} \alpha_i \log X_{it}^{j} + \gamma_u \log U_{it} + \frac{1}{2} \sum_{h=1}^{H} \sum_{j=1}^{J} \gamma_{hj} \log X_{it}^{h} \log X_{it}^{j}$$

$$+ \sum_{j=1}^{J} \gamma_{ju} \log X_{it}^{j} \log U_{it} + \frac{1}{2} \gamma_{uu} \left(\log U_{it}\right)^2 + e_{it} \quad (5)$$

$$e_{it} = \lambda_i + \tau_t + \varepsilon_{it}$$

Many of our estimates of agglomeration elasticities are based on restricted versions of equation (5). Our initial regression estimates in Table 3 are based on a Hicks-Neutral variant ($\gamma_{ju}=0 \ \forall j \neq u$), with linear rather than quadratic agglomeration effects ($\gamma_{uu}=0$). The production function parameters are also initially constrained to be common for all industries, yielding an aggregate production function. We subsequently allow each two-digit industry to have a distinct production function, while still constraining the agglomeration elasticity to be common across industries.

This is implemented in two stages. First, we estimate the industry-specific production function, omitting the effective density terms. In the second stage, multi-factor productivity (the residuals from the first-stage regressions) is regressed on the effective density term(s). To obtain separate agglomeration elasticity estimates for one-digit industries and for regions, we interact the effective density measures with industry or region dummies in the second stage. Finally, in section 0, we estimate an unrestricted version of equation (5) separately for each one-digit industry to examine the extent to which effective density interacts with other inputs in its impact on productivity.

The assumed error structure also varies across our specifications. All specifications include year effects (τ_t) in addition to the white-noise errors (ε_{it}). The term λ_i represents an enterprise-specific productivity component that is potentially correlated with the productive inputs and effective density. We present a baseline specification, which we refer to as 'pooled', that does not control for enterprise heterogeneity ($\lambda_i = 0$). Failing to control for this heterogeneity will lead to biased parameter estimates. Estimated agglomeration elasticities will be overstated if firms with high idiosyncratic productivity are disproportionately located in areas with high effective density. Such firms would be more productive wherever they operate and we do not want to count the influence of this heterogeneity as an impact of effective density. Controlling for enterprise heterogeneity removes the bias and reveals the firm-level association between changes in effective density and changes in productivity. This is the relationship that is most relevant for the appraisal of transport proposals that may raise effective density.

We consider two treatments of firm heterogeneity. First, we include a full set of enterprise fixed effects, to give estimates that we refer to as 'within enterprise'. The difficulty with this approach is that effective density is highly persistent over time, so that including firm fixed effects essentially removes much of the variation in density. The inclusion of fixed effects can lead to pronounced attenuation bias (bias towards zero) and imprecisely estimated coefficients. These problems are exacerbated for small industries or industries that are highly geographically concentrated, in which case the time-variation in effective density is largely absorbed by the time effects.

Our second treatment of enterprise heterogeneity is to control for it at a group level. Specifically, we include dummy variables for each local industry (combination of two-digit industry and geographic region), to generate estimates that we refer to as 'within local industry'. This will remove the influence of higher productivity firms sorting into higher-density regions. The agglomeration elasticity estimates will still, however, reflect the bias from any sorting that occurs within regions. These estimates represent a trade-off between controlling for the possible endogeneity of effective density and avoiding the attenuation of the enterprise fixed effects estimates.

Other specification and estimation issues that arise in the estimation of equation (5) include the endogeneity of productive inputs, and the dynamics of agglomeration effects. A firm's choice of inputs may depend on productive characteristics that are unobserved by the econometrician, and hence are captured in the error term, but are known to the firm. This would induce a problematic correlation between covariates and the error term e_{it}. Various methods have been proposed to deal with this simultaneity, including fixed effects, various instrumental variables approaches, and the use of variables such as measures of investment behaviour or firm survival that are assumed to be related to the firm's idiosyncratic productivity (Griliches and Mairesse 1998; Olley and Pakes 1996).

If the relationship between effective density and productivity operates with a lag (density changes this year are not reflected in firm performance until next year), enterprise fixed effects estimates will underestimate the long-run impact of effective density on productivity, which is captured by pooled estimates. Enterprise fixed effects estimates may also fail to control adequately for the endogeneity of effective density if short run fluctuations in productivity lead to short run movements in density. This is likely to be a problem for industries such as construction, for which productivity and density rise and fall together in response to building cycles. For such industries, enterprise fixed effects estimates will overstate the strength of the causal relationship from effective density to productivity. Finally, enterprise fixed effects do not adequately control for variation across time in unobserved firm-level productivity characteristics, and tend to magnify the influence of other forms of mis-specification such as measurement errors and errors in variables (Griliches and Mairesse 1998).

On balance, we anticipate that 'within enterprise' estimates will understate true agglomeration elasticities and that 'within local industry' estimates will still be somewhat overstated due to sorting within regions. The tradeoff between bias and sample variability will have the greatest impact on estimates for smaller industries or regions, for which sample variability will be greatest. For aggregate estimates, the 'within enterprise' estimates should give a more reliable indication of the causal relationship between agglomeration and productivity.

4 Data: The Prototype Longitudinal Business Database

The data used in this study are drawn from Statistics New Zealand's prototype Longitudinal Business Database (LBD) for 1999 to 2007. The data were accessed in the Statistics New Zealand Data Laboratory under conditions designed to give effect to the security and confidentiality provisions of the Statistics Act 1975. The core of the LBD dataset is the Longitudinal Business Frame (LBF), which provides longitudinal information on all businesses in the Statistics New Zealand Business Frame since 1999, combined with information from the tax administration system. The LBF population includes all economically significant businesses.[3]

The LBF contains information at both the enterprise level and the plant level. At any point in time, an enterprise will contain one or more plants, and each plant will belong to only one enterprise. Our unit of analysis is the enterprise, although as described below, we use information on plant locations to obtain measures of effective density for each location where the enterprise operates. Plants are assigned a 'permanent business number' (PBN) that identifies them longitudinally. The longitudinal links are established through the application of a number of continuity rules that allow PBNs to be linked even if they change enterprises or tax identifier (Seyb 2003, Statistics New Zealand 2006). The LBF provides monthly snapshots of an enterprise's industry, institutional sector, business type, geographic location, and employee count.[4] For PBNs, there is monthly information on industry, location, and employee count.

[3] A business is economically significant if it a) has annual Goods and Services Tax (GST) turnover of greater than $30,000; or b) has paid employees; or c) is part of an enterprise group; or d) is part of a GST group; or e) has more than $40,000 income reported on tax form IR10; or f) has a positive annual GST turnover and has a geographic unit classified to agriculture or forestry.

[4] Institutional sector distinguishes Producer Enterprise; Financial Intermediaries; General Government; Private not-for-profit serving households; households; and rest of the world.

The LBD is a research database that includes the LBF as well as a range of administrative and survey data that can be linked to the LBF. The primary unit of observation in the LBD is an enterprise observed in a particular year. The current study uses business demographic information from the LBF, linked with financial performance measures (from the Annual Enterprise Survey, and various tax returns, including IR10s), and measures of labour input (working proprietor counts from IR10 forms, and employee counts for PBNs from PAYE (pay-as-you-earn income tax) returns as included in the Linked Employer-Employee Dataset (LEED).

Gross output and factor inputs are measured in current-prices.[5] The primary source used to obtain a value added measure is the Annual Enterprise Survey (AES). The AES is a postal sample survey, supplemented with administrative data from tax sources. We use postal returns from AES to provide annual gross output and factor inputs for each enterprise's financial year. This information is available for around ten percent of enterprises, which are disproportionately larger firms, accounting for around 50 percent of total employment in New Zealand. Where AES information is not available, we derive comparable measures from annual tax returns (IR10s). The methods used for derivation are detailed in Appendix A.

4.1 Production function variables

Gross output is measured as the value of sales of goods and services, less the value of purchases of goods for resale, with an adjustment for changes in the value of stocks of finished goods and goods for resale. Enterprise total employment comprises the count of employees in all of the enterprise's plants, annualised from employee counts as at the 15th of each month, plus working proprietor input, as reported in tax returns. Capital input is measured as the cost of capital services rather than as the stock of capital. There are three components to the cost of capital services: depreciation costs; capital rental and leasing costs; and the user cost of capital. The inclusion of rental and leasing costs (including rates) ensures consistent treatment of capital input for firms that own their capital stock and firms that rent or lease their capital stock. The user cost of capital is calculated as the value of total

5 Changes over time in current price inputs and outputs will reflect both quantity and price changes. The use of double deflation to isolate quantity adjustment over time at the industry level is possible using the Statistics New Zealand PPI input and output indices but only for a selection of one-digit and two-digit industries. Measures of productivity premia for firms within the same industry will reflect both quantity and relative price differences. Spatial price indices are not available for the separate identification of quantity differences.

assets, multiplied by an interest rate equal to the average 90-day bill rate plus 4 percentage points, to approximate the combined cost of interest and depreciation. Intermediate consumption is measured as the value of other inputs used up in the production process, with an adjustment for changes in stocks of raw materials.

4.2 Effective Density

Effective density is calculated for each area unit[6], based on plant level employment, using information on all plants, and is calculated using equation (2), with the distance decay $\alpha=1$. Monthly labour input for each PBN is calculated as the sum of rolling mean employment (RME) plus a share of working proprietor input in the enterprises to which the PBN belongs. RME is the average number of employees on the PBN's monthly PAYE return in the 12 months of the enterprise's financial year, as recorded in the LEED data. PAYE information is not always provided at the PBN level, and in LEED, there is some allocation of PAYE information to PBNs as outlined in Seyb (2003). The annual number of working proprietors in each enterprise is available in the LEED data, based on tax return information. Labour input from working proprietors is allocated to the PBNs within each enterprise in proportion to the PBN's RME. Where an enterprise has only working proprietors, the working proprietor input is allocated equally across all component PBNs. There is a large number of PBNs in each year for which RME is zero. The log of labour input is undefined for these PBNs unless working proprietor information is also incorporated. Using working proprietor information increases the number of plants with usable labour productivity information by 80 to 100 percent, and increases measured aggregate labour input by 13 to 20 percent.[7]

For enterprises that have employing plants in more than one area unit, a separate observation is included for each plant. The enterprise production function variables are repeated across the observations but a separate effective density measure is calculated for each location. All estimation is carried out allowing for

6 An area unit is a geographical area with an average size of around 140 square kilometres and employment of roughly 1,000. In urban areas, the areas are much smaller and the employment counts somewhat higher. For instance, Area Units in the Auckland region are on average around 13 square kilometres and contain employment of about 1,500. In Auckland City, they have an average area of 5.5 square kilometres and employment of 2,500.

7 The increases due to working proprietor inclusion decrease monotonically over time. The contribution to the number of plants (to labour input) are 103% (20%) in 2000, and 79% (13%) in 2006. The impacts are particularly pronounced in single-PBN enterprises that do not belong to an enterprise group. In 2006, the impacts were 101% (24%) and in 2000 they were 142% (37%). There will be some double counting of working proprietors if they also draw PAYE earnings, as they will also appear in the *RME* employee count.

clustering of errors at the enterprise level, to reflect the resulting correlation in errors. The multiple observations are weighted by the proportion of enterprise employment in each location, so that the sum of weights across the separate plant observations is one for each enterprise.[8]

For each year from 1999/2000 to 2005/06 (referred to as 2000 to 2006 respectively for the remainder of the paper), we select enterprises plants that a) are always private-for-profit ; b) are never a household or located overseas; c) have non-missing industry information; and d) are not in the 'Government Administration and Defence' industry.[9] We exclude plants for which location (area unit, territorial authority, or regional council) information is missing, and plants in area units outside territorial authorities (island and inlets). In order to maintain a consistent population that can support analysis while protecting confidentiality, some additional exclusions[10] are applied. Finally, we drop observations where labour input is zero.

Table 2 displays summary statistics for our analysis sample. There are 886,700 enterprise-year observations. Average effective density for the enterprises is 30,248, with a range of 2,298 to 172,863. This range is considerably lower than is observed in Great Britain. The minimum effective density observed in Great Britain in 2002 (29,515) is around the New Zealand mean, and the New Zealand maximum effective density is well below the Great Britain mean of 224,132 (Graham 2006b, p.103). The second and third columns of Table 2 show the rise in effective densities over our study period, reflecting both a general increase in employment and a slight increase in concentration of economic activity. Summary statistics are also provided for the log of effective density and the square of the log. These are the variables that are used in estimation.

The second block of Table 2 summarises gross output and factor inputs. The mean of the log of gross output is 11.68, which corresponds to (geometric)

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8 The approach here differs from that in Graham and Kim (2007), who exclude multi-plant firms from their analysis, though noting the inherent problem of dealing with multi-plant firms - "Even if we had data on the production characteristics at each individual plant, the fact that these form part of a wider corporation weakens the imposition of assumptions about optimization at the plant level" (p274). The inclusion of multi-plant enterprises also provides more generalisable results.

9 Formally, these restrictions refer to a) business type 1-6 (individual proprietorship, partnership, limited liability company, co-operative company, joint venture and consortia, branches of companies incorporated overseas); b) Institutional Sector is never 'household' or 'located overseas' and ANZSIC industry is not Q97 (Households employing staff); c) ANZSIC division M.

10 Specifically, we exclude Area Units in the Chatham Islands, the Middlemore Area Unit in Auckland (521902), and six Auckland Area Units that are tidal, inlets or islands (615900,616001,617102,617702,617903,617604). Tidal areas of Waiheke Island (AU 520804) are grouped with Waiheke Island itself.

average gross output of $118,200. Mean log intermediate consumption and log capital services are 10.64 ($41,800) and 9.92 ($20,300) respectively. Mean log employment is 0.85, which corresponds to 2.3 FTE. Employment is the only pure quantity measure here. Changes over time in output, intermediate consumption and capital services reflect a combination of price changes. Subsequent regression analysis controls for period effects to allow for general price increases. An implication of the use of current-value input and output measures is that measured productivity differences; across time, across industries, or across locations, reflect allocative as well as technical productivity differences. Operating in time periods, industries, or locations where output prices are high relative to input prices is, by this measure, more productive.

Table 2: Summary Statistics

	Pooled		*2000*		*2006*	
	Mean	*Std.dev*	*Mean*	*Std.dev*	*Mean*	*Std.dev*
Effective Density	30,248	(31,107)	27,106	(28,300)	33,289	(33,343)
(range)	[2,298-172,863]		[2,298-150,885]		[2,651-172,863]	
ln(Eff.Dens)	9.87	(0.94)	9.76	(0.93)	9.97	(0.94)
(range)	[7.74-12.06]		[7.74-11.92]		[7.88-12.06]	
ln(Eff.Dens) squared	98.32	(18.81)	96.15	(18.52)	100.35	(19.00)
ln(Gross Output)	11.68	(1.68)	11.48	(1.66)	11.85	(1.69)
ln(Intermed.Cons)	10.64	(1.83)	10.37	(1.81)	10.84	(1.83)
ln(Employment)	0.85	(1.01)	0.85	(0.97)	0.86	(1.06)
ln(Capital Services)	9.92	(1.68)	9.87	(1.61)	10.03	(1.76)
Data sourced from AES	0.06	(0.23)	0.06	(0.23)	0.06	(0.25)
ln(Cap.Serv) squared	101.28	(33.21)	99.99	(31.49)	103.63	(35.23)
ln(Cap.Serv)*ln(Emp)	9.46	(12.57)	9.29	(11.94)	9.74	(13.34)
ln(Cap.Serv)*ln(IntCons)	107.34	(33.30)	103.83	(31.41)	110.67	(34.93)
ln(Cap.Serv)*ln(EffDens)	97.84	(18.82)	96.23	(17.99)	99.87	(19.64)
ln(Emp)*ln(Emp)	1.74	(3.72)	1.65	(3.55)	1.86	(3.93)
ln(Emp)*ln(IntCons)	10.25	(13.92)	9.93	(13.26)	10.60	(14.71)
ln(Emp)*ln(EffDens)	8.53	(10.45)	8.38	(9.97)	8.71	(11.04)
ln(IntCons)*ln(IntCons)	116.65	(40.40)	110.84	(39.05)	120.96	(41.27)
ln(IntCons)*ln(EffDens)	105.20	(21.83)	101.50	(21.95)	108.22	(21.75)
Observations	886,700		133,900		118,100	
Labour share of cost	0.42	(0.23)	0.42	(0.22)	0.42	(0.24)
IntCons share of cost	0.37	(0.22)	0.35	(0.22)	0.38	(0.22)
Capital share of cost	0.21	(0.19)	0.23	(0.21)	0.20	(0.19)
Obs with Labour share>0	788,200		119,000		104,700	

Source: Statistics New Zealand prototype Longitudinal Business Database. Observation counts represent enterprise-year observations and are randomly rounded to the nearest 100, which is greater than is required by Statistics New Zealand's rules for non-disclosure.

Around six percent of observations use data from AES, with the remainder based on IR10 tax forms. Table 2 also presents means of interaction variables that are included in translog production function regressions. These are included to aid in the interpretation of coefficients, rather than having any ready interpretation *per se*.

The final panel shows cost shares for labour, capital and intermediate consumption. Labour costs are measured as total labour earnings from LEED. This includes both wage and salary earnings, and the earnings of the self-employed. In many cases, reported self-employed earnings are zero or negative, leading to potentially negative labour cost shares. The reported cost shares are thus based on a sub-sample of enterprises that excludes those with non-positive labour earnings. In all three years, labour costs account for 42 percent of total costs, intermediate consumption for 35 percent to 38 percent, and capital costs the remaining 20 percent to 23 percent.

5 Results

5.1 Aggregate estimates

Table 3 presents regression estimates of agglomeration elasticities from a Hicks-neutral translog production function specification.[11] The first column shows an agglomeration elasticity of 0.171. This implies that firms in locations with 10 percent higher effective density have productivity that is 1.7 percent higher. This estimate makes no adjustment for enterprise heterogeneity and sorting. Controlling for productivity and density differences across regions and industries reveals that around 70 percent of the cross sectional relationship between effective density and productivity is attributable to observable differences in industry-regional composition. The estimated elasticity is reduced to 0.048, as shown in column (2).[12]

The third column of Table 3 controls more fully for enterprise composition differences, by including enterprise fixed effects. This has the effect of removing the influence of observable and unobservable differences in enterprise productivity and location that are constant over time (including industry). For single plant enterprises, the estimates reflect the relationship between enterprise

[11] Appendix Table 1 shows estimates of production function parameters for the specifications shown in Table 3.

[12] Controlling for industry composition alone reduces the coefficient to 0.041.

productivity and the changing effective density in their location. For multi-plant enterprises, it also reflects the effect of changes in the firm's share of employment in each location. It is plausible that such changes may be made endogenously, with enterprises choosing to increase their presence in areas where their productivity is higher. This form of endogeneity will lead to an upward bias in the estimated elasticity. The impact of controlling for enterprise fixed effects is to reduce the estimated elasticity by over 90 percent; from 0.171 to 0.015. The lower precision of the fixed effects estimates is evident in the size of the standard errors on the fixed effects coefficients. The standard error on the agglomeration elasticity is 0.005, around five times the size of the standard error on the pooled coefficient (0.001) in the first column. Appendix Table 1 shows the other coefficients in the aggregate production function estimation. In contrast to the impact of fixed effects estimation on the agglomeration elasticity standard errors, the standard errors on the other production function coefficients do not change markedly, reflecting greater within-enterprise variability to support identification.

Table 3: Agglomeration Elasticities
Hicks-neutral translog production function specification

	Aggregate production function			*Industry production functions*		
	Pooled *(1)*	*Within Local Industry* *(2)*	*Within Enterprise* *(3)*	*Pooled* *(4)*	*Within Local Industry* *(5)*	*Within Enterprise* *(6)*
	Linear Agglomeration Effects					
ln(EffDens)	0.171**	0.048**	0.015**	0.037**	0.069**	0.010*
	[0.001]	[0.003]	[0.005]	[0.001]	[0.003]	[0.005]
	Quadratic Agglomeration Effects					
ln(EffDens)	0.360**	-0.088*	-0.402**	-0.200**	-0.007	0.184**
	[0.029]	[0.042]	[0.071]	[0.024]	[0.038]	[0.070]
ln(EffDens) squared	-0.009**	0.007**	0.020**	0.012**	0.004*	-0.009*
	[0.001]	[0.002]	[0.003]	[0.001]	[0.002]	[0.003]

Notes: Robust standard errors clustered at the enterprise level. **: significant at 1%; *: significant at 5%. See Appendix Table 1 for full regression estimates for the aggregate production function specifications.

In columns 4 to 6 of Table 3, we show the corresponding estimates of agglomeration elasticities obtained when we relax the constraint that production function parameters are common across industries. The pooled estimates shown in column (4) show an agglomeration elasticity of 0.037. Controlling for the local-industry composition of enterprises leads to a higher estimated elasticity (0.069), implying that, within industries, more productive firms are disproportionately located in lower density areas. It would appear that the pooled estimates *over-estimate* the productivity impact of agglomeration, allaying concerns that composition bias resulting from the sorting of enterprises between locations inflates agglomeration elasticity estimates.

The small difference between the pooled and 'within local industry' estimates using industry-specific production functions suggests that the bias arising from endogenous density may be relatively small.[13] In contrast, imposing a common production function across all industries, as in the upper panel of Figure 1 and the first three columns of Table 3 yields a stark difference between pooled and 'within local industry' estimates, pointing to the invalidity of the assumption of common technologies. Agglomeration elasticities based on aggregate production functions should at a minimum control for heterogeneity across local industries to allow for this mis-specification.

The 'within enterprise' specification shown in column (6) yields a low estimated elasticity of 0.010. We are not able to distinguish whether this reduction is a consequence of the sorting of more productive enterprises into denser areas *within* regions, or of the attenuation bias associated with the use of enterprise fixed effects.

The agglomeration elasticity estimates obtained when we relax the constraint of a linear relationship are shown in the lower panel of Table 3. To aid the interpretation of the coefficients, we plot the implied relationship between density and productivity in Figure 1. The upper panel shows the relationship between effective density and productivity based on an aggregate production function. The three solid curves correspond to the first three columns of Table 3, with the corresponding linear relationships shown by broken lines. The steepest line reflects the pooled estimate, with a corresponding linear coefficient of 0.171. The 'within local industry' relationship is less steep. The 'within enterprise' line shows a downward slope, and thus negative agglomeration elasticities, at lower densities. Both the 'within local industry' and 'within enterprise' profiles show increasing returns to agglomeration.

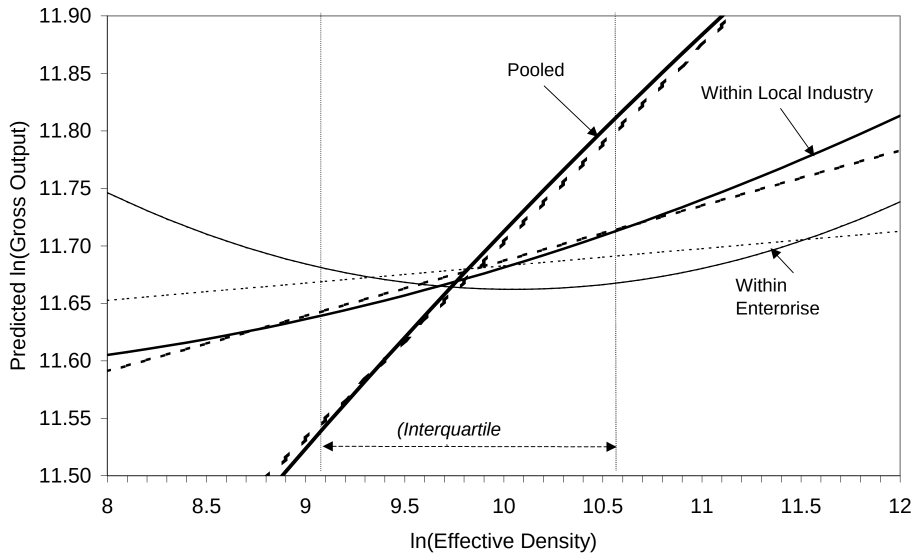
Panel (b) of the figure shows agglomeration elasticities based on industry-specific production functions. Consistent with the linear elasticity estimates in Table 3, the slope of the pooled estimates is slightly lower than the 'within local industry'

[13] It may also be that firms that benefit most from density (rather than firms that have higher productivity *per se*) sort into more dense areas. In this case, the agglomeration elasticity obtained from the 'within local industry' estimates provide a relevant measure of the likely causal impact of changing density.

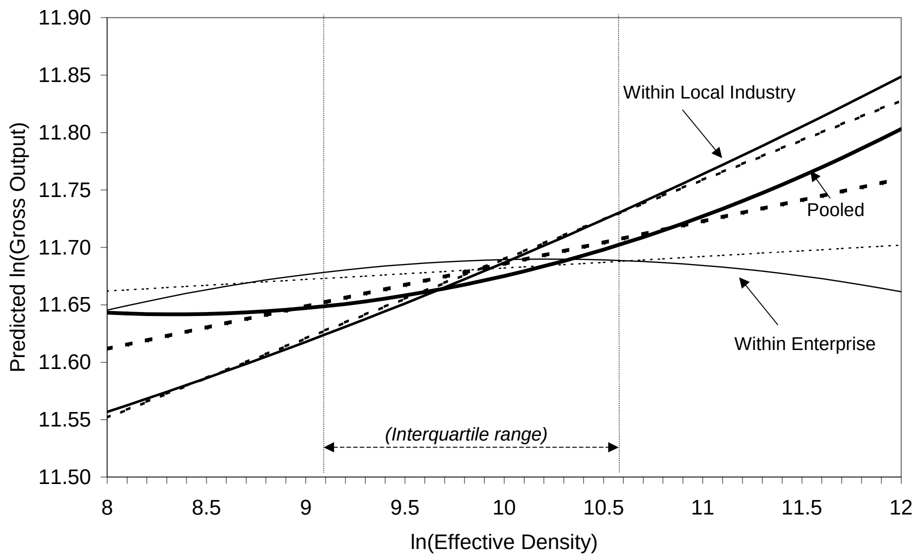
estimates, though relatively similar. The 'within enterprise' estimates are again very flat, and slightly negative at higher densities. The pooled and 'within local industry' estimates show slight increasing returns to agglomeration, though the curves are fairly close to the corresponding linear profiles.[14]

Figure 1: Agglomeration profiles

(a) Aggregate production function



(b) Industry-specific production functions



Note: The productivity-density profiles are those implied by the quadratic coefficients shown in Table 3. Broken lines show the corresponding linear elasticity estimates.

14 Graham 2007 allows for a quadratic relationship using cross-sectional UK data and finds diminishing returns to agglomeration.

The reliability of the estimates depends on the validity of the various assumptions and constraints. First, the assumption that factor choices and effective density is exogenous, conditional on included covariates, can be questioned. We were unable to find satisfactory ways of controlling for possible endogeneity.[15] Second, the assumption that the effect of effective density is Hicks-neutral can also be relaxed. As discussed in section 0, relaxing this assumption does not change the agglomeration elasticity estimates, when evaluated at sample means, but does provide more information on the nature of factor augmentation and price effects.

5.2 Estimates by one-digit industry

Table 4 presents estimates of equation (5) that allow for industry-specific production coefficients for each two-digit industry. Separate agglomeration elasticities are estimated by one-digit industry.[16] The reported coefficients are for a linear effective density specification. The first column of agglomeration elasticities, labelled 'NZTA', are the existing estimates from NZTA (2008), derived from UK agglomeration elasticities. These are shown for UK industry groupings, which do not correspond exactly with New Zealand one-digit groups. Corresponding estimates of New Zealand agglomeration elasticities are positive and significant for all industries except for the *mining and quarrying* group (B), where the estimate is insignificant.

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15 We attempted to use instrumental variables methods to test for and correct for possible endogeneity but could not identify suitable instruments. Lagged levels of inputs and density consistently failed overidentification tests. In the light of this finding, we also examined possible dynamic relationships, estimating a differenced equation with a lagged dependent variable. We tried to instrument for the lagged dependent variable, and also for factor choice and density using suitable lags. We were unable to find suitable lags that passed standard tests of overidentification, making our estimates uninterpretable. The combination of differencing and instrumenting also reduced the number of usable observations by more than 50%. On balance, we believe that controlling for firm-level heterogeneity through the use of enterprise fixed effects leads to more appropriate estimates than are obtained from pooled estimates. However, problems of endogeneity may remain, which we would expect to bias upwards our estimates of agglomeration elasticities. The potential endogeneity also makes the investigation of dynamics problematic.

16 Industry group D (Electricity, Gas and Water) has been omitted to prevent disclosure. Industry groups M (Public Administration and Defence) Q (Personal and other Services) and R (Not elsewhere Classified) have been omitted.

Table 4: Agglomeration elasticities by one-digit industry

	NZ Industry	Number of Ents	UK Industry	NZTA (1)	Industry-specific production functions: Within Industry (2)	Within Local Industry (3)	Within Enterprise (4)
A	Agriculture, Forestry and Fishing	63,200			0.013** [0.003]	0.032** [0.003]	0.041** [0.005]
B/D	Mining & Electricity, Gas & Water	320			0.024 [0.020]	0.035* [0.016]	0.012 [0.009]
C	Manufacturing	20,000	Manufacturing	0.024	0.049** [0.002]	0.061** [0.003]	0.016** [0.005]
E	Construction	34,100	Construction	0.088	0.039** [0.002]	0.056** [0.003]	0.011* [0.005]
F	Wholesale Trade	13,200	Distribution, hotels & catering	0.044	0.072** [0.002]	0.086** [0.003]	0.018** [0.005]
G	Retail Trade	34,200			0.065** [0.002]	0.086** [0.003]	0.027** [0.005]
H	Accom,. Cafes and Restaurants	10,500			0.041** [0.003]	0.056** [0.004]	0.030** [0.005]
I	Transport & Storage	9,800	Transport, storage & communications	0.049	0.041** [0.003]	0.057** [0.004]	0.014** [0.005]
J	Communication Services	2,800			0.053** [0.005]	0.068** [0.006]	0.001 [0.006]
K	Finance and Insurance	3,200	Banking, finance & insurance	0.180	0.076** [0.006]	0.087** [0.006]	-0.006 [0.006]
L	Property and Business Services	56,500	Real estate IT Business services	0.084 0.082 0.167	0.074** [0.002]	0.079** [0.003]	0.000 [0.005]
M	Govt Admin & Defence		Public services	0.292			
N	Education	1,800			0.076** [0.008]	0.076** [0.008]	0.022** [0.008]
O	Health & Community Services	9,900			0.047** [0.005]	0.083** [0.006]	-0.009 [0.006]
P	Cultural and Recreational Services	1,200			0.062** [0.010]	0.053** [0.009]	0.004 [0.010]
	Weighted Average*	250,800		0.127	0.049	0.065	0.019
	All industries	250,800			0.037** [0.001]	0.069** [0.003]	0.010* [0.005]

* Weighted averages are calculated using industry employment shares for the NZTA estimates, and using shares of enterprise-year observations for the other columns.

Comparing the NZTA and pooled estimates for industries that are covered in both columns, the NZTA estimates are generally reassuringly similar – perhaps surprisingly given that the former were based on UK estimates in an ad hoc manner, adjusted to allow for significant differences in densities. Overall, the weighted mean agglomeration elasticity is, however, much smaller for the pooled column, reflecting the inclusion of low-elasticity industry groups that were excluded from the NZTA estimates, and the exclusion of the high-elasticity *public administration & defence* industry from the pooled estimates.

As was the case for the overall estimates in Table 3, controlling for sorting of enterprises across local industries leads to generally higher estimated agglomeration elasticities, with the only exceptions being the relatively small *education* and *cultural and recreational services* industries. The impact of controlling for enterprise fixed effects is to give lower estimates, with the exception of *agriculture, forestry and fishing*. Agglomeration elasticity estimates become insignificant in 6 industries, including the *finance and insurance* industry, which has the largest estimated elasticity in column (3). The reduction in estimated elasticities probably reflects the consequent imprecision of the enterprise fixed effects estimates rather than sorting alone.

On balance, we believe that the 'within local industry' estimates in column (3) provide the best indication of industry-specific agglomeration elasticities. While they are probably biased by the sorting of high productivity firms into areas it is not clear how large the bias is, or even the direction of bias. The fact that controlling for sorting between regions increases estimated elasticities suggests that composition bias may be negative.

Non-linear agglomeration effects

Table 4 summarises agglomeration elasticities under the assumption of a linear relationship between density and productivity, from the 'within local industry' specification. In Figure 2, we show the productivity-density profiles implied by quadratic agglomeration elasticity estimates. For ease of presentation, the industry groups are divided into two sets. The top panel of Figure 2 shows the agglomeration profiles for six industries characterised by high average effective density and high agglomeration elasticities. These are industries with average density greater than 10.2, and include the industries with the five highest 'within local industry' agglomeration elasticities in column (3) of Table 4. The profiles are plotted so that each industry's profile crosses zero at the industry's mean ln(effective density). Mean density and output are also shown in brackets next to the industry's name. Each profile is plotted only for densities between the 10^{th} and 90^{th} percentile of effective density for the industry.

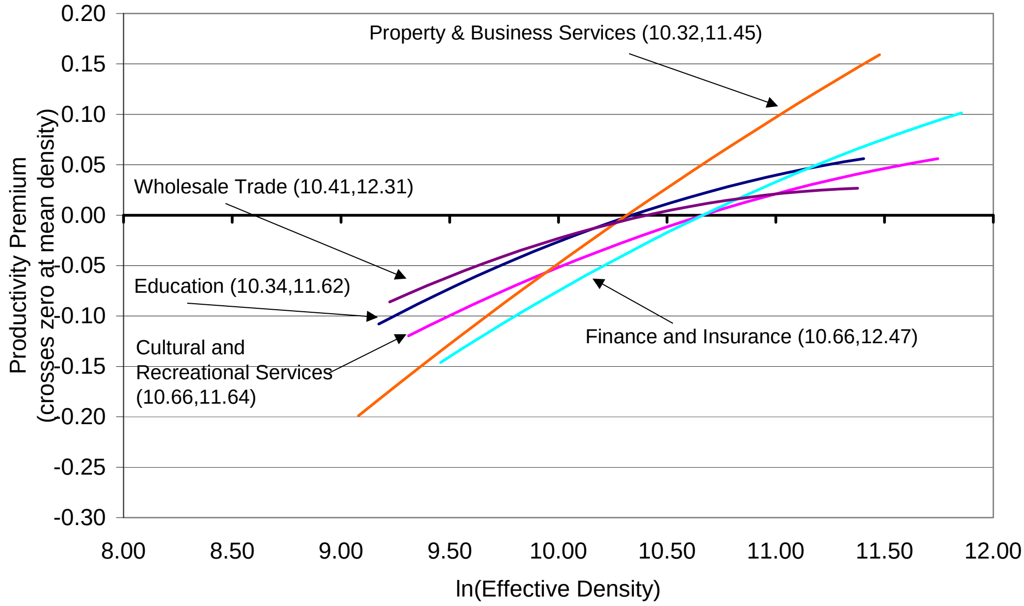
The slopes of these profiles are positive for all industries except *agriculture, forestry and fishing*, and the combined *mining and quarrying, and electricity, gas and water* industries. The profiles show decreasing returns to effective density for all industries. Agglomeration elasticities are shown by the slopes of the profiles. In Figure 3, we plot the agglomeration elasticities that are implied by the Figure 2 profiles. Because of the imposed quadratic functional form, these agglomeration elasticity plots are linear. Because of decreasing returns to agglomeration, all slope downwards.

Relatively high agglomeration elasticities are evident for five industries: *property and business services*, *finance and insurance*, *communication services*, *cultural and recreational services*, and *education*. Evaluated at overall average density of 9.87, the agglomeration elasticities are 0.16, 0.13, 0.12, 0.09, and 0.08 respectively. With the exception of the primary industries, all others show moderate elasticities that are similar to each other, and vary from 0.04 to 0.07 at the overall average density of 9.87.

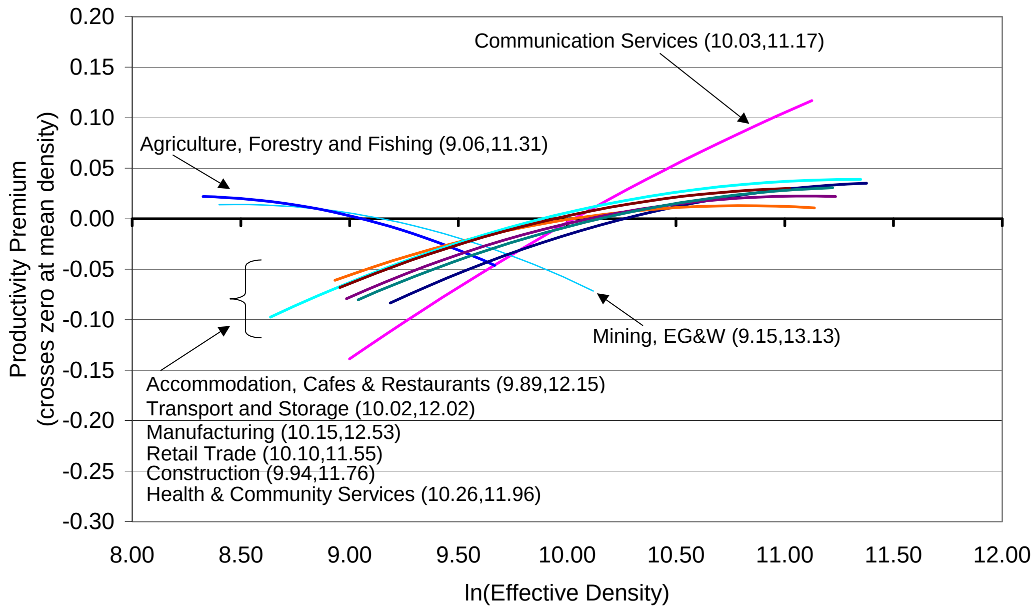
One key feature highlighted by the comparison of Figure 2 and Figure 3 is that, even though productivity is higher in more dense areas, the additional gain from further increases in density is smaller in more dense areas. One implication of these patterns is that the impact of agglomeration on productivity will vary across different regions for two reasons. First, for a given industry structure, agglomeration elasticities will be smaller in denser areas as a result of decreasing returns. Second more dense areas are likely to have a disproportionate share of enterprises that benefit most from agglomeration. Such industries include *property and business services* and *finance and insurance*, the high agglomeration elasticities for which are evident in Figure 3. It is an empirical question which of these factors dominates.

Figure 2: Productivity profiles - industry-specific regressions

High-density Industries



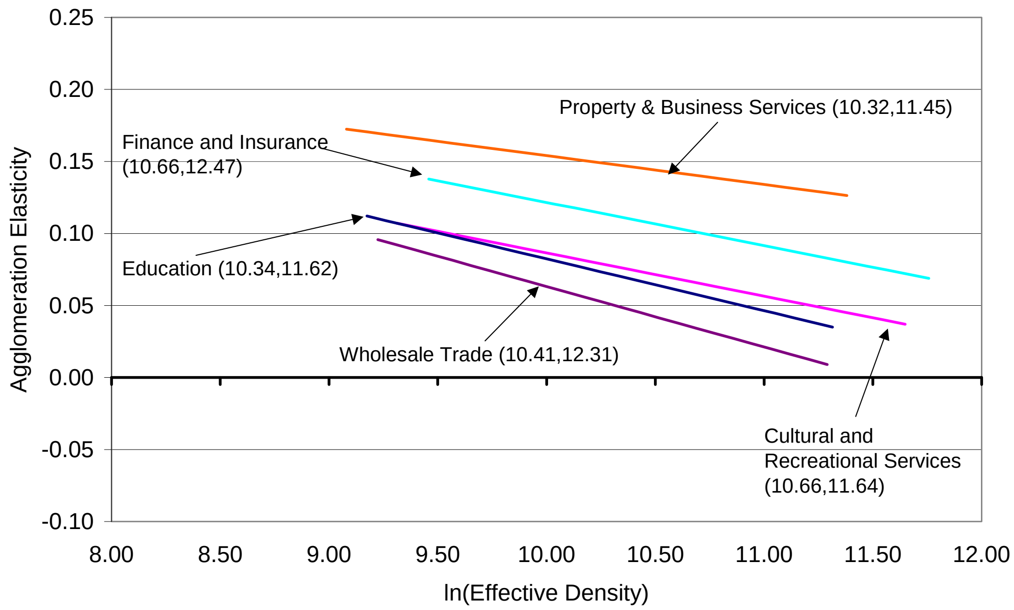
Other Industries



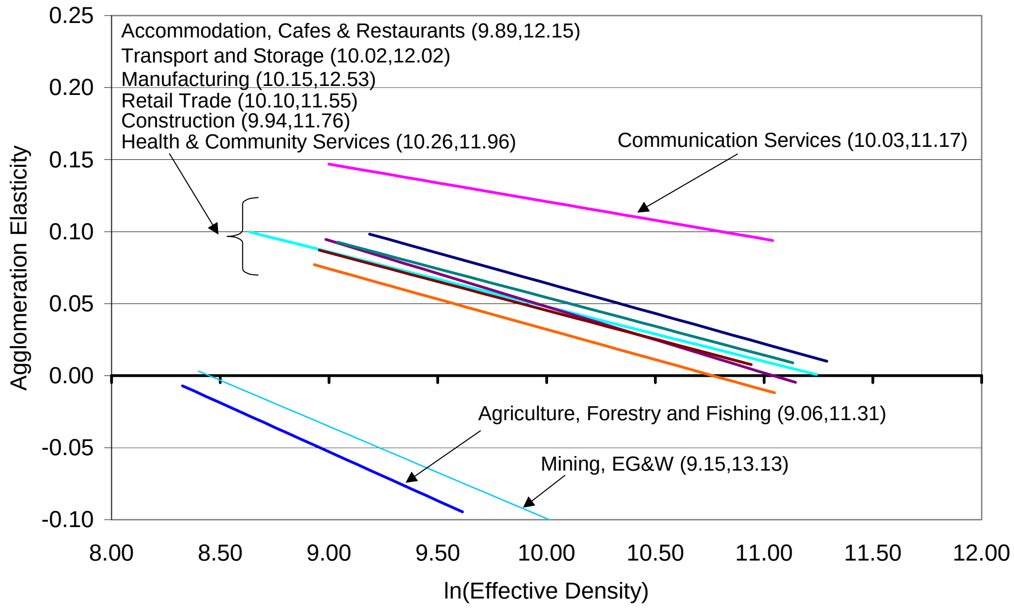
Numbers in brackets show (mean ln(Effective density), mean ln(gross output))

Figure 3: Agglomeration elasticities - industry-specific regressions

High-density Industries



Other Industries



Numbers in brackets show (mean ln(Effective density), mean ln(gross output))

5.3 Estimates by region

In this section, we present estimates of agglomeration elasticities by region, to gauge whether cross-region differences in agglomeration elasticities are dominated by decreasing returns or by high density regions attracting a disproportionate share of industries (or enterprises) that benefit most from agglomeration. We present estimates for each regional council area, with West Coast, Marlborough, Tasman and Nelson combined. For the Auckland region, we also present separate estimates for each of the Territorial Authorities within Auckland.

Table 5 summarises the results. The number of enterprise-year observations is shown in column (1). The mean density of each area is shown in column (2). The estimates in column (3) are obtained by regressing multi-factor productivity on a full set of location dummies and their interactions with ln(Effective density).[17]

Controlling for local industry composition, as shown in column (4), lowers the estimated agglomeration elasticities for high-density regions - all those with ln(Effective density) greater than 9.9 (Canterbury), and raises estimated elasticities for low-density regions. This implies that, within high-density regions, more productive industries sort into higher density areas. If, in addition, there is, within industry sorting of more productive firms into higher density areas, the 'within local industry' estimates for these regions, shown in column (4), will be biased upwards. For low density regions, the opposite pattern holds - more productive industries appear to sort away from the most dense areas.

[17] The separate estimates for the areas within Auckland were obtained by running a separate regression with the Auckland Region dummy replaced by separate dummies for the TAs. The coefficients on other regions were, of course, identical across the two specifications.

Table 5: Agglomeration elasticities – differences across regions

			Industry production function		
	Number of Obs (000)	*ln(Eff Dens)*	*Within Locality*	*Within Local Industry*	*Within Enterprise*
	(1)	*(2)*	*(3)*	*(4)*	*(5)*
Northland Region	41.0	9.07	0.119**	0.177**	0.051
			[0.012]	[0.013]	[0.038]
Auckland Region	223.8	10.98	0.076**	0.056**	-0.033*
			[0.008]	[0.008]	[0.014]
Rodney	22.2	9.93	0.145**	0.088**	-0.009
			[0.027]	[0.029]	[0.053]
North Shore	39.3	10.96	0.023	0.020	-0.093*
			[0.025]	[0.026]	[0.042]
Waitakere	23.5	10.78	0.017	-0.010	-0.068
			[0.036]	[0.037]	[0.064]
Auckland City	87.0	11.44	0.071**	0.061**	-0.027
			[0.009]	[0.010]	[0.016]
Manukau	35.1	10.86	0.099**	0.055	-0.036
			[0.031]	[0.030]	[0.041]
Papakura	6.3	10.48	0.109	-0.006	0.050
			[0.072]	[0.069]	[0.124]
Franklin	10.4	10.03	0.100	-0.016	-0.002
			[0.110]	[0.109]	[0.149]
Waikato Region	102.9	9.68	0.009	0.088**	0.050*
			[0.008]	[0.009]	[0.021]
Bay of Plenty Region	62.7	9.62	0.069**	0.107**	0.00
			[0.012]	[0.013]	[0.028]
Gisborne Region	10.0	9.00	-0.001	0.222**	0.051
			[0.030]	[0.043]	[0.082]
Hawke's Bay Region	35.2	9.44	0.042**	0.103**	0.055
			[0.013]	[0.017]	[0.033]
Taranaki Region	29.7	9.26	-0.130**	0.076**	0.005
			[0.015]	[0.019]	[0.037]
Manawatu-Wanganui Region	55.4	9.40	0.004	0.091**	0.035
			[0.009]	[0.012]	[0.025]
Wellington Region	85.5	10.17	0.085**	0.063**	0.016
			[0.006]	[0.006]	[0.011]
West Coast, Tasman, Nelson, Marl	43.8	9.11	0.068**	0.084**	0.049
			[0.010]	[0.012]	[0.031]
Canterbury Region	122.3	9.91	0.066**	0.048**	0.014
			[0.003]	[0.005]	[0.011]
Otago Region	43.7	8.98	0.041**	0.071**	0.016
			[0.006]	[0.007]	[0.015]
Southland Region	30.7	8.58	-0.042**	0.061**	-0.017
			[0.010]	[0.015]	[0.036]

The standard errors on the estimated agglomeration elasticities for the 'within locality' and 'within local industry' columns range from 0.003 to 0.019 for all but seven of the locations. For the Gisborne region, and for six of the seven territorial authorities in the Auckland region (the exception is Auckland City), the standard errors are higher, ranging from 0.025 to 0.110. These areas have relatively low numbers of enterprise-year observations, and, especially for some of the Auckland TAs, limited variation in effective density, due to the geographic concentration of employment in relatively small areas. For these locations, the estimates shown in Table 5 are an unreliable estimate of the actual elasticity.[18] Perhaps not surprisingly, the 'within enterprise' estimates are imprecise, and none of the locations has elasticity estimates that are significant at the five percent level of significance.

The 'within locality' 'within local industry' estimates in Table 5 are presented graphically in Figure 4, making this pattern more evident. In Figure 4, regions and territorial authorities are ordered from lowest to highest effective density. Mean density is plotted as the upward sloping broken line, plotted against the right-hand axis. The immediate impression from Figure 4 is that the relationship between a region's density and its agglomeration elasticity is not as systematic as was the case for industries. A less systematic pattern may be expected due to the interaction of decreasing returns and industry composition, as noted above. The variability does, however, also reflect the lack of relevant variation in some locations, making it difficult to identify precisely a statistical relationship.

Interpreting the 'within local industry' estimates, we find that the three densest regions, Auckland, Wellington and Canterbury, have similar agglomeration elasticities of 0.056, 0.063, and 0.048 respectively. With the exception of Southland (0.061), all other regions have elasticities of at least 0.07. This is consistent with the decreasing returns to effective density that was evident in the industry-specific estimates in Table 4.

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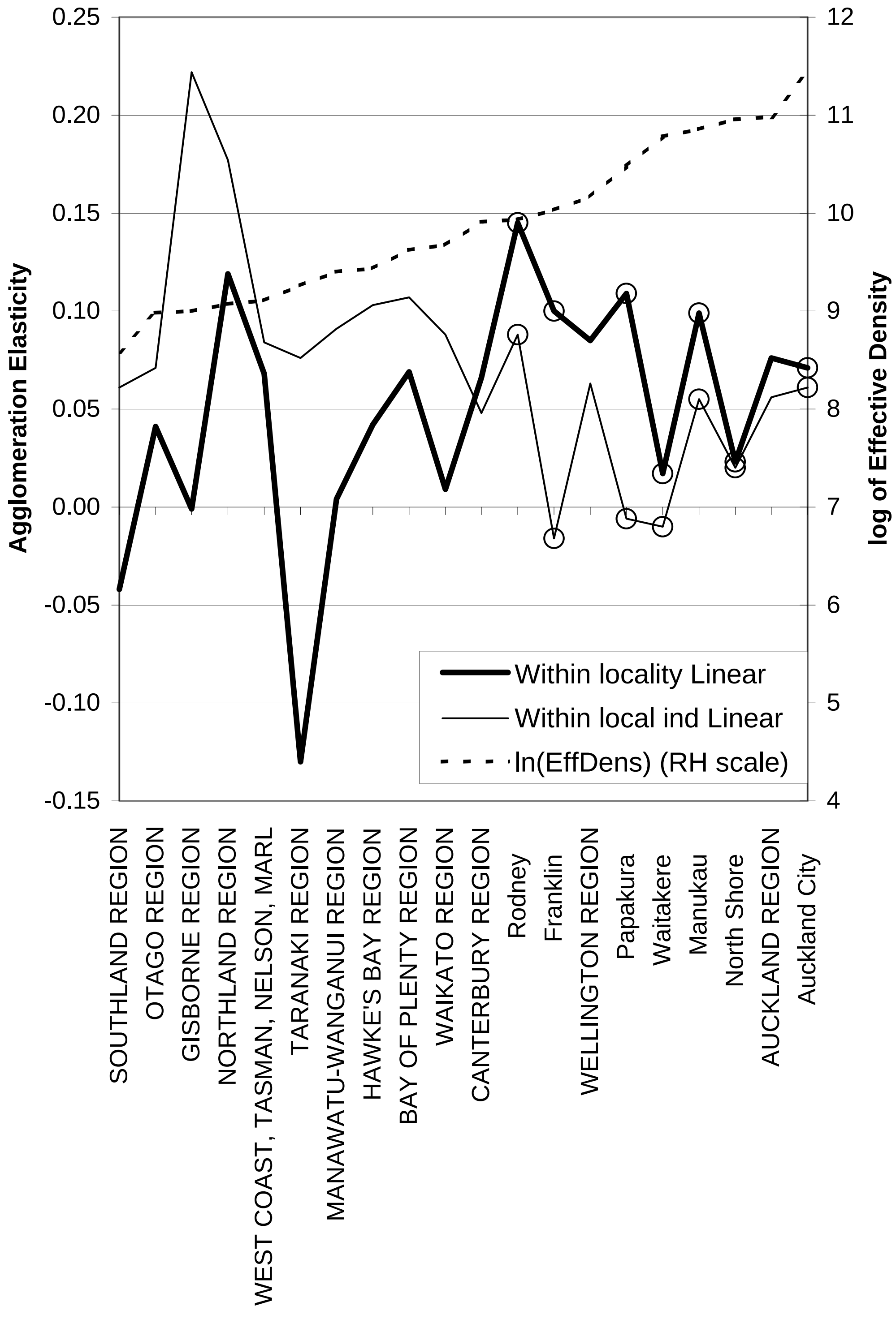
[18] The fragility of the estimates is confirmed by estimating quadratic agglomeration effects (estimates not shown). For most locations, the slope at means is similar to the linear estimates. For the hard-to-identify areas, quadratic profiles are imprecise, with agglomeration elasticities having steeply positive or steeply negative slopes and passing through zero at around mean density.

Figure 4: Agglomeration Elasticities – differences across regions



Note: Territorial authorities within Auckland are indicated by a circle. All other points relate to Regional Council areas.

5.4 Factor augmenting effects and price effects

In this section, we relax the assumption that effective density has a Hicks-neutral effect on productivity, and allow for the interaction of effective density with other factors of production. We estimate an unrestricted version of equation (5) and, using the analytical framework presented in Graham and Kim (2007), calculate a range of derived measures to identify key features of the production function and the role of agglomeration. In particular, Graham and Kim use production theory to decompose the overall agglomeration elasticity into a direct effect, and the contributions that result from agglomeration altering the efficiency of other factors of production, by differentiating equation (5) by *U*:

$$\frac{\partial \log Y_{it}}{\partial U_{it}} = \underbrace{\left(\gamma_u + \gamma_{uu} \log U_{it}\right)}_{\text{Direct Effect}} + \underbrace{\sum_j \gamma_{ju} \log X_{it}^j}_{\substack{\text{Factor-augmenting} \\ \text{effects}}} \tag{6}$$

They also derive expressions for the elasticity of output with respect to each factor of production ($\partial logY_{it}/\partial logX^j_{it}$), and the impact of agglomeration on the demand for each factor:

$$\frac{\partial \log X_{it}^j}{\partial \log U_{it}} = \left(\frac{\partial \log P_{it}^j}{\partial \log X_{it}^j}\right)^{-1} \left(\frac{\partial \log P_{it}^j}{\partial \log U_{it}}\right) \tag{7}$$

where P_{it}^j is the price of input *j*. Agglomeration thus affects the price of each factor, according to its impact on factor efficiency. The effect on factor demand then depends on the factor demand elasticity ($\partial \log P_{it}^j / \partial \log U_{it}$), with a greater change in the amount of a factor demanded when demand is elastic (i.e.: when $\partial \log P_{it}^j / \partial \log X_{it}^j$ is small).[19]

Table 6 summarises the key measures based on an aggregate production function, the estimated parameters of which are presented in Appendix Table 2. All elasticities are calculated at sample means of all variables. We present both pooled and 'within enterprise' (WE) effects estimates, corresponding to the entries in Table 3.

19 See Graham and Kim (2007) for further details.

Table 6: Translog estimates – derived relationships

(A)Scale and agglomeration

	Returns to scale	*Agglomeration elasticity =*	*Labour augmenting*	*+ Capital augmenting*	*+ IntCons augmenting*	*+ Direct effect*
		$(\partial Y/\partial U)$	$(\gamma_{lu}{*}L)$	$(\gamma_{ku}{*}K)$	$(\gamma_{iu}{*}I)$	$(\gamma_u+\gamma_{uu}{*}U)$
Pooled	1.076	0.186	0.030	0.268	-0.979	0.868
WE	1.039	0.012	0.034	0.159	-0.532	0.351

(B) Factor elasticities

		Output elasticities	*Demand elasticities*		
		$\partial Y/\partial X$	$\partial P_X/\partial U$	$\partial X/\partial P_X$	$\partial X/\partial U$
Capital	Pooled	0.129	0.234	-1.321	-0.309
	FE	0.191	0.078	-1.208	-0.094
Labour	Pooled	0.332	0.129	-1.241	-0.160
	FE	0.317	0.121	-1.268	-0.153
Intermediates	Pooled	0.614	-0.126	-1.157	0.146
	FE	0.531	-0.100	-1.201	0.120

The top panel of Table 6 shows the implied returns to scale, and a decomposition of the overall agglomeration elasticity. There is evidence of slightly increasing returns scale in both the pooled (1.076) and 'within enterprise' (1.039) specifications. The agglomeration elasticities for the full translog function, estimated at sample means, are shown in the second column and are similar to those estimated from the more restricted specification in Table 3, with Hicks-neutrality and linearity of agglomeration effects imposed. The pooled estimate of the agglomeration elasticity at means is 0.186 (0.171 in Table 3). When enterprise heterogeneity is controlled for using enterprise fixed effects, the elasticity drops to 0.012 (0.015 in Table 3).

The remaining columns of Table 6 decompose the overall agglomeration elasticity into four additive components: one component for each of the three factors of production, indicating the extent to which agglomeration raises the efficiency of the factor, and one direct effect. For the three factor augmentation columns, a positive estimate indicates that the efficiency of the factor is raised by agglomeration and a negative quantity indicates that the factor is less efficient in areas with high effective density. In both the pooled and 'within enterprise' specifications, effective density is associated with higher efficiency of labour and capital inputs, and lower efficiency of intermediate consumption. Recall that our measures of intermediate consumption and capital are based on dollar values rather than pure quantity indices.

The lower efficiency of intermediate consumption in denser areas may thus reflect higher input prices: the same dollar input adds less to output in denser, high-input-price areas. However, capital inputs, in particular, land, are also more expensive in denser areas, yet the efficiency of capital services charges is higher in denser areas despite the possible price effects. There is a high positive direct effect of agglomeration, indicating that productivity would be higher in denser areas even holding factor inputs and factor efficiency constant. The strength of estimated factor augmentation effects is reduced for capital and intermediate consumption when we control for enterprise fixed effects. This suggests that there is sorting of firms in more dense areas, with denser areas having firms with more efficient capital usage and less efficient intermediate consumption usage at the margin.

The second panel of Table 6 displays the output elasticity of each factor, and three elasticities related to the effect of agglomeration on the demand for each factor. The sum of the factor elasticities equals the returns to scale as shown in the upper panel. The second column of the bottom panel shows the estimated response of factor prices to higher effective density. The patterns confirm the insights from the upper panel. Agglomeration is associated with more efficient labour and capital inputs, and hence higher prices for those factors. The extent to which labour demand is reduced depends on the own-price demand elasticity, which is shown in the third column. Demand is relatively elastic for all three factors, with elasticities ranging from -1.32 to -1.16 in the pooled specification and from –1.27 to –1.20 for the 'within enterprise' specification. The final column shows the factor demand elasticities. The demand for capital and labour are 9 to 15 percent lower in high-density areas ('within enterprise' specification), and the demand for intermediate consumption is raised by 12 percent.

The measures shown in Table 6 can be calculated for each industry, based on industry-specific regressions. Industry-specific patterns are summarised in Table 7 (returns to scale and agglomeration elasticity decomposition) and Table 8 (factor elasticities). Elasticities are calculated at industry-specific means. The caveats expressed above regarding the robustness of the 'within enterprise' estimates of agglomeration elasticities apply *a fortiori* to the less restrictive factor-augmenting specification. However, as is evident in Appendix Table 2, and as was seen in Appendix Table 1 for the Hicks-Neutral specifications, the precision of the production function parameter estimates other than that of the agglomeration elasticity itself is similar in the pooled and 'within enterprise' specifications, giving more confidence that these 'within enterprise' estimates are not greatly affected by attenuation bias.

Table 7: Derived relationships: Scale and Agglomeration from 'within enterprise' specification (by one-digit industry)

	Returns to scale	*Agglomeration elasticity =* $(\partial Y/\partial U)$	*Labour augmenting* $(\square_{lu}*L)$	*+ Capital augmenting* $(\square_{ku}*K)$	*+ IntCons augmenting* $(\square_{iu}*I)$	*+ Direct effect* $(\square_{u}+\square_{uu}*U)$
A Agric, Forest and Fish	1.023	-0.107	0.008	-0.180	0.042	0.022
B Mining & Quarrying	0.997	0.022	-0.180	-1.195	0.409	0.988
C Manufacturing	1.069	-0.012	0.042	0.193	-0.462	0.215
E Construction	1.067	0.038	0.012	0.124	-0.377	0.280
F Wholesale Trade	1.029	0.066	0.033	-0.020	-0.385	0.438
G Retail Trade	1.071	0.037	0.046	0.140	-0.199	0.051
H Accomm, Cafes	1.073	-0.015	0.066	0.171	-0.493	0.241
I Transport & Storage	1.081	0.032	0.017	0.119	-0.348	0.245
J Communication Serv	1.070	-0.026	0.023	0.176	-0.307	0.082
K Finance and Insurance	0.898	-0.028	-0.014	0.278	-0.417	0.126
L Property and Bus Serv	0.980	0.054	0.025	0.162	-0.361	0.228
N Education	1.123	0.065	0.082	-0.223	-0.642	0.848
O Health & Comm Serv	1.050	0.022	0.005	-0.087	0.010	0.094
P Cultural and Recr Serv	1.095	-0.014	0.004	0.134	-0.259	0.108
All Industries	1.039	0.012	0.034	0.159	-0.532	0.351

The variation in agglomeration elasticities across industries is relatively small; ranging from –0.107 in *agriculture*, to 0.066 for *wholesale trade*. There is much greater variation, however, in the contributions of different components. For instance, the direct effect of agglomeration ranges from 0.022 for *agriculture*, to 0.848 for *education*, and the contribution of intermediate consumption augmentation ranges from –0.642 in education to 0.042 in *agriculture* (discounting estimates from the small *mining* industry). Some of this variation in component contributions may be a consequence of imprecise estimation[20] but for most industries, the decomposition provides interpretable patterns. We discount the decompositions for the relatively small *mining* and *education* industries.

The three industries with the highest estimated agglomeration elasticities in Table 7 (*wholesale trade*, e*ducation*, and *property and business services*) also had relatively large agglomeration elasticities in Table 4. In all three cases, there is a relatively large positive direct effect of agglomeration, offset by a negative contribution from

[20] For instance, the relatively small *education* industry (around 6,000 observations on 1,800 enterprises) and *mining* industry (1,300 observations on 310 enterprises) have the largest positive contributions from a direct agglomeration effect (0.848 and 0.988 respectively) but also large negative contributions from capital augmentation (-0.223 and –1.195).

intermediate consumption input being less efficient in more dense areas. With the exceptions of *finance and insurance* and *mining*[21], labour efficiency is raised in all industries, although the effect contributes relatively little compared with the direct effects and intermediates augmentation, ranging from 0.004 to 0.082. In nine out of the fourteen industries, the capital efficiency is higher in denser areas, with a minimum contribution of 0.119.

Table 8 shows the implications of the patterns of factor augmentation on factor demands, and also the factor output elasticities for each industry. Output elasticities range from 0.220 (*agriculture*) to 0.461 (*education*) for labour, from 0.099 (*construction*) to 0.283 (*retail trade)* for capital, and from 0.420 (*retail trade*) to 0.635 (*manufacturing*) for intermediate consumption. The fourth column of Table 8 shows that most industries follow the general pattern of agglomeration raising the demand for intermediates and reducing demand for labour and capital inputs, with the reduction in labour demand being more pronounced. Other than *mining*, all industries have own-price elasticities of demand for capital, labour, and intermediates between –1.4 and –1.1, implying elastic factor demand. The patterns of factor augmentation that give rise to the factor price responses to agglomeration, as shown in the second column, thus translate fairly directly to factor demands.

[21] The 'within enterprise' estimates for each of these industries are imprecise due to relatively small numbers of enterprises and because geographic concentration results in limited variation in effective density.

Table 8: Derived relationships: factor elasticities from 'within enterprise' specification (by one-digit industry)

	Output Elasticities	*Demand Elasticities*		
	$\partial Y/\partial X$	$\partial P_x/\partial U$	$\partial X/\partial P_x$	$\partial X/\partial U$
	Labour			
A Agriculture, Forestry and Fishing	0.220	0.056	-1.377	-0.077
B Mining & Quarrying	0.329	-0.184	-1.926	0.354
C Manufacturing	0.292	0.096	-1.273	-0.122
E Construction	0.244	0.079	-1.360	-0.107
F Wholesale Trade	0.378	0.081	-1.270	-0.102
G Retail Trade	0.368	0.080	-1.250	-0.100
H Accommodation, Cafes and Restaurants	0.287	0.145	-1.342	-0.195
I Transport & Storage	0.275	0.069	-1.271	-0.088
J Communication Services	0.285	0.140	-1.210	-0.169
K Finance and Insurance	0.295	-0.019	-1.152	0.022
L Property and Business Services	0.338	0.100	-1.252	-0.125
N Education	0.461	0.164	-1.335	-0.219
O Health & Community Services	0.405	0.015	-1.232	-0.019
P Cultural and Recreational Services	0.323	0.022	-1.248	-0.028
All Industries	**0.317**	**0.121**	**-1.268**	**-0.153**
	Capital			
A Agriculture, Forestry and Fishing	0.232	-0.072	-1.178	0.085
B Mining & Quarrying	0.144	-0.545	-2.044	1.114
C Manufacturing	0.142	0.124	-1.169	-0.144
E Construction	0.099	0.142	-1.152	-0.164
F Wholesale Trade	0.202	-0.001	-1.175	0.001
G Retail Trade	0.283	0.018	-1.199	-0.022
H Accommodation, Cafes and Restaurants	0.215	0.055	-1.294	-0.072
I Transport & Storage	0.165	0.073	-1.195	-0.087
J Communication Services	0.174	0.076	-1.142	-0.086
K Finance and Insurance	0.175	0.185	-1.169	-0.217
L Property and Business Services	0.218	0.057	-1.231	-0.070
N Education	0.207	-0.101	-1.144	0.115
O Health & Community Services	0.209	-0.040	-1.218	0.049
P Cultural and Recreational Services	0.180	0.082	-1.182	-0.097
All Industries	**0.191**	**0.078**	**-1.208**	**-0.094**
	Intermediates			
A Agriculture, Forestry and Fishing	0.572	0.008	-1.170	-0.009
B Mining & Quarrying	0.524	0.256	-1.423	-0.365
C Manufacturing	0.635	-0.072	-1.200	0.086
E Construction	0.724	-0.046	-1.134	0.052
F Wholesale Trade	0.450	-0.069	-1.241	0.085
G Retail Trade	0.420	-0.079	-1.222	0.097
H Accommodation, Cafes and Restaurants	0.571	-0.094	-1.305	0.123
I Transport & Storage	0.641	-0.048	-1.139	0.055
J Communication Services	0.611	-0.088	-1.123	0.099
K Finance and Insurance	0.428	-0.061	-1.167	0.071
L Property and Business Services	0.424	-0.106	-1.212	0.129
N Education	0.455	-0.122	-1.224	0.149
O Health & Community Services	0.436	0.005	-1.189	-0.006
P Cultural and Recreational Services	0.593	-0.037	-1.133	0.042
All Industries	**0.531**	**-0.100**	**-1.201**	**0.120**

6 Summary and discussion

The paper presents the first set of agglomeration elasticity estimates directly estimated from New Zealand microdata. The pooled cross-sectional patterns of elasticities by industry are fairly similar to the existing estimates based on UK data, as are currently used in the NZTA Economic Evaluation Manual (NZTA 2008).

We estimate an aggregate pooled cross-sectional agglomeration elasticity of 0.171. There is considerable variation in the size of estimated industry-specific agglomeration elasticities. The largest estimates are for the *finance & insurance* (0.076), *education* (0.076), *property & business services* (0.074), *wholesale trade* (0.072), and *retail trade* (0.065) industries. The smallest estimate is for the *agriculture, forestry & fishing* industry (0.013).

These cross-sectional estimates may overstate the true impact of agglomeration on productivity, as a result of the sorting of high-productivity firms into high-density areas. If the estimated agglomeration effects reflect sorting rather than a causal effect, increases in density as may result from investments in transport infrastructure will not necessarily result in net increases in production.

We would prefer to rely on estimates that exclude the impact of firm heterogeneity and sorting and to this end we present panel estimates of agglomeration elasticities that control to some extent for these influences. We present 'within local industry' estimates that control for sorting across regions and industries, and 'within enterprise' estimates that also control for sorting within locations. The 'within local industry' estimates are generally similar, though slightly larger, than the cross-sectional estimates. In contrast, the 'within enterprise' estimates are generally much smaller than the corresponding pooled cross-sectional estimates, consistent with the presence of sorting. Unfortunately, as a result of various statistical features of the data, discussed in the paper, the 'within enterprise' estimates may understate the true causal effect of agglomeration on productivity. We thus rely on the 'within local industry' estimates as providing the most reliable indication of agglomeration elasticities.

Overall, allowing for industry differences in technology (production functions), the 'within local industry' specification yields an agglomeration elasticity of 0.069. This varies across industries, from industry-specific estimates ranging from 0.032 (*agriculture, forestry and fishing*) to 0.087 (*finance and insurance*). Other high-elasticity industries are *wholesale trade* (0.086), *retail trade* (0.086) and *health and community services* (0.083). There is evidence of decreasing returns to agglomeration within all industries.

Agglomeration elasticities also vary across regions, from a low of 0.048 in Canterbury to a high of 0.177 in Northland.[22] High density regions of Canterbury, Wellington (0.063) and Auckland (0.056) have lower agglomeration elasticities than less dense regions, consistent with decreasing returns to agglomeration. We are unable to obtain reliable estimates for territorial authorities within Auckland, with the exception of Auckland City (0.061).

We find that agglomeration generally increases the productivity of labour and capital inputs, though the contributions of agglomeration through these channels is smaller than the direct (factor-neutral) effect.

7 Future directions

The current paper represents a significant advance in our knowledge of the relationship between agglomeration and productivity in New Zealand. The analyses do, however, highlight a number of issues that could usefully be investigated in future research.

1) *Analysis of localisation effects*: The estimates in the current paper capture only the effects of overall effective density. It is plausible that, for at least some industries, it is the density of own-industry employment that is most relevant for their productivity. The analysis could be extended by estimating the elasticity of productivity with respect to own-industry as well as overall density, adding an extra regression term: $\beta_U \ln(\text{EffDens}) + \beta_O \ln(\text{OwnEffDens}/\text{EffDens})$.

2) *More flexible measurement of density*: First, The assumption of a constant distance decay of 1.0 could be relaxed, to estimate the geographic extent of agglomeration effects and detect differences in this across industries. Second, the assumption of a quadratic effect of effective density on productivity could be relaxed to detect more general patterns of non-linearity.

22 The estimated elasticity for Gisborne is higher (0.222) but is not statistically significant.

3) *Dynamics of agglomeration effects*: More analysis of the temporal extent of agglomeration effects could be undertaken. The current paper has focused on the concurrent relationship between effective density and productivity. However, the benefits of density may accrue over time, in which case fixed effects estimates will understate the true impact.

4) *Alternative treatment of heterogeneity*: Our attempts to control for enterprise heterogeneity using the 'within enterprise' specification were beset by problems of attenuation bias and lack of precision. An alternative means of controlling for heterogeneity and sorting within as well as between locations is offered by the control-function approach (Olley and Pakes 1996, Levinsohn and Petrin 2003, Ackerberg et al. 2006). Re-estimating production functions and agglomeration elasticities using these methods may provide more reliable estimates.

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Appendix A: Comparability between different data sources: AES and IR10

Records for enterprises with postal AES records contain derived measures of gross output and intermediate consumption. For enterprises with IR10 records but no AES records, these quantities have to be derived from reported items.

Capital services charges: For both data sources, we impute a capital service charge for firms that rent or lease some of their capital inputs, and count transfer this imputed amount from intermediate consumption to capital services. Rental leasing and rates costs are reported separately on the IR10 form but not in AES. We express IR10 rental, leasing and rates costs as a ratio to a subset of expenses that are measured consistently across the two data sets. We then impute AES rental and leasing as the predictions from a group logit of that ratio as a function of depreciation costs, asset values separately for vehicles, plant and machinery, furniture and fittings, and land and buildings, all measured as a proportion of commonly identified expenses, and year effects.

Purchases of goods for resale: The AES measure of gross output deducts purchases of goods for resale from gross sales. An examination of industry-by industry differences in reported sales amounts for firms with both AES and IR10 records suggests that in some industries, many firms report resale purchases as part of intermediate consumption. We calculate, for each two-digit industry and year, the ratio of AES total resale purchases to the sum of intermediate consumption and resale purchases. We then apply this ratio to IR10 intermediate consumption to obtain imputed resale purchases. We adjust IR10 gross output and intermediate consumption by subtracting imputed resale purchases from both.

Interest paid: For general finance and insurance industries, AES treats interest paid as a deduction from gross output. IR10 records are treated in the same way.

Road user charges: These should not be included in intermediate consumption but are not separately reported on IR10 forms. A proportion of IR10 intermediate consumption is removed, based on the proportion of AES intermediate consumption accounted for by (separately reported) road user charges.

8 Appendix Tables

Appendix Table 1: Hicks-neutral aggregate translog production function: linear and quadratic agglomeration effects

	Linear agglomeration effects			*Quadratic agglomeration effects*		
	Pooled	*Within Local Industry*	*Within Enterprise*	*Pooled*	*Within Local Industry*	*Within Enterprise*
ln(EffDens)	0.171**	0.048**	0.015**	0.360**	-0.088*	-0.402**
	[0.001]	[0.003]	[0.005]	[0.029]	[0.042]	[0.071]
ln(EffDens) squared				-0.009**	0.007**	0.020**
				[0.001]	[0.002]	[0.003]
ln(Capital)	-0.147**	-0.227**	0.220**	-0.149**	-0.227**	0.220**
	[0.011]	[0.011]	[0.014]	[0.011]	[0.011]	[0.014]
ln(Labour)	1.330**	1.313**	1.136**	1.332**	1.312**	1.136**
	[0.021]	[0.020]	[0.026]	[0.021]	[0.020]	[0.026]
ln(Intermediates)	0.117**	0.166**	0.175**	0.116**	0.167**	0.175**
	[0.012]	[0.012]	[0.015]	[0.012]	[0.012]	[0.015]
ln(Cap)^2	0.030**	0.041**	0.026**	0.030**	0.041**	0.026**
	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]
ln(Cap)*ln(Lab)	-0.009**	-0.025**	-0.005**	-0.010**	-0.025**	-0.005**
	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]
ln(Cap)*ln(Int)	-0.028**	-0.034**	-0.050**	-0.028**	-0.034**	-0.050**
	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]
ln(Lab)^2	0.059**	0.050**	0.065**	0.059**	0.050**	0.065**
	[0.002]	[0.001]	[0.002]	[0.002]	[0.001]	[0.002]
ln(Lab)*ln(Int)	-0.093**	-0.081**	-0.082**	-0.094**	-0.081**	-0.082**
	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]	[0.002]
ln(Int)^2	0.040**	0.041**	0.043**	0.040**	0.041**	0.043**
	[0.000]	[0.000]	[0.001]	[0.000]	[0.000]	[0.001]
Dummy for AES observation	0.068**	0.008	0.059**	0.068**	0.008	0.060**
	[0.005]	[0.005]	[0.009]	[0.005]	[0.005]	[0.009]
Year dummies	Y	Y	Y	Y	Y	
Local Industry dummies		Y			Y	
Enterprise dummies			Y			Y
Observations	1041300	1041300	1041300	1041300	1041300	1041300
Number of Enterprises	886700	886700	886700	886700	886700	886700
R-squared	0.80	0.82	0.95	0.8	0.82	0.95

Appendix Table 2: Translog coefficient estimates –fully interacting density effects

	Pooled	*Within enterprise*
α_K	-0.345**	0.086**
	[0.018]	[0.022]
α_L	0.891**	0.677**
	[0.032]	[0.034]
α_I	0.997**	0.678**
	[0.018]	[0.022]
α_U	0.769**	-0.379**
	[0.034]	[0.089]
$\gamma_{UU}/2$	0.005**	0.037**
	[0.001]	[0.004]
$\gamma_{KK}/2$	0.030**	0.027**
	[0.001]	[0.001]
γ_{KL}	-0.006**	-0.004*
	[0.002]	[0.002]
γ_{KI}	-0.036**	-0.055**
	[0.001]	[0.001]
γ_{KU}	0.027**	0.016**
	[0.001]	[0.002]
$\gamma_{LL}/2$	0.054**	0.061**
	[0.002]	[0.002]
γ_{LI}	-0.088**	-0.077**
	[0.002]	[0.002]
γ_{LU}	0.035**	0.040**
	[0.002]	[0.003]
$\gamma_{II}/2$	0.045**	0.045**
	[0.000]	[0.001]
γ_{IU}	-0.092**	-0.050**
	[0.001]	[0.002]
AES observation	0.102**	0.060**
	[0.005]	[0.008]
Year dummies	Yes	Yes
Constant	-1.155**	5.089**
	[0.245]	[0.494]
Observations	886700	886700
Number of enterprises		250800
R-squared	0.80	0.52

Notes: Robust standard errors clustered at the enterprise level. **: significant at 1%; *: significant at 5%. R-squared for the Fixed Effect column is calculated for within-enterprise variation

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