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Agglomeration Elasticities and Firm Heterogeneity

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Abstract

This paper estimates the relationship between agglomeration and multi factor productivity at the one digit industry level and by region using longitudinal firm level data for New Zealand. A key focus of the paper is on methods to represent firm level heterogeneity and non-random sorting of firms. The panel structure of the data allows us to control for it at the level of local industries or enterprises. We obtain a cross-sectional agglomeration elasticity of 0.171, which falls by 70% when we use local industry controls, and by 90% when we impose enterprise fixed effects. Using industry specific production functions, we find that the "within local industry" estimates are similar, though slightly larger than the cross sectional estimates (~0.070), suggesting negative sorting between areas, combined with positive sorting within areas. The within-enterprise estimates yield a small elasticity of 0.010. Our results indicate that the imposition of a common production technology across all industries is not a valid assumption. While cross-sectional estimates may overstate the true impact of agglomeration on productivity in the presence of positive bias from sorting, the within enterprise approach (which is increasingly common in the literature) can suffer from identification problems due to the highly persistent nature of agglomeration variables and 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.

Keywords: Agglomeration; urban density; productivity
JEL Classifications: L25, R12, R3

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 Melo et al [1], Duranton and Puga [2] and Rosenthal and Strange [3].

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

The article 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 thick labour markets, ease of linkages to input and output markets, and knowledge spillovers arising from proximity to others in the same industry (Marshall [4]). Each of these potential sources is consistent with agglomeration effects – the observed positive relationship between agglomeration and productivity. The existence of such a positive relationship is thus uninformative about the underlying nature of agglomeration economies. The problem of identification extends also to microeconomic theory. Duranton and Puga [2] 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 [3], continues to struggle in identifying the sources of agglomeration.

Many studies have, however, quantified the strength of the relationship between economic productivity and the concentration of activity. An influential study by Ciccone and Hall [5] estimates an elasticity of total factor productivity to employment density of 0.04 across US states. Graham [6] 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. [1] find a median estimate of 0.041.

There are a small number of empirical studies that estimate the strength of agglomeration effects on productivity in New Zealand. Williamson et al [7] report an elasticity of around 0.03 between employment density and average earnings in Auckland using data from the 2001 Census. Williamson et al [8] 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 [9] 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 difference form. These estimates control for 3-digit industry composition, but not for capital intensity of firms.

The current paper 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.

[1] Note that the two estimates are not directly comparable because of differences in specification and evaluation. Williamson *et al* [7] reports estimates from an equation of Income = $a+b*\log_{10}(\text{Density})$. Williamson *et al* [8] estimates $\ln(\text{Income}) = a+b*\ln(\text{Density})$

Another key concern in this paper is with methods to represent firm level heterogeneity and non-random sorting of firms. The panel structure of the data allows us to controls for firm-level heterogeneity in distinct ways, and we show how the different assumptions underpinning the model affect the magnitude of the agglomeration estimates.

3 Methods

Agglomeration effects are characterised as the productive impact of employment in surrounding areas on a firm's production technology. Local employment density is treated as an input into a firm's production function:

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

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. Employment is measured as total employment, capturing general agglomeration effects, without providing particular insights into the strength of localisation economies.

Employment density is a commonly used proxy for agglomeration. A more general measure is presented in Graham [6], 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.

Using the summary measure U_i as defined above in equation (2), Graham and Kim [10] incorporate effective density as a factor-augmenting input to production in a value-added production function, approximated by a translog form (Christensen et al. [11]):

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

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 Hicks-neutrality, so that $f_i\left(\{D_{dit}\},\{X_{it}^j\}\right)=g\left(U_i\right)h\left(\{X_{it}^j\}\right)$. Graham [12] estimates a restricted form of equation (3), with $\gamma_{ju}=0\ \forall j$, reflecting this assumption. The added assumption of homogeneity (as in Graham [13]) 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). 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 Hicks-neutral form of equation (3), augmented with an appropriate error structure:

$$\begin{aligned}\log Y_{it} &= \alpha_0+\gamma_u\log U_{it}+\frac{1}{2}\gamma_{uu}\left(\log U_{it}\right)^2\\&\quad+\sum_{j=1}^{J}\alpha_i\log X_{it}^j+\frac{1}{2}\sum_{h=1}^{H}\sum_{j=1}^{J}\gamma_{hj}\log X_{it}^h\log X_{it}^j+e_{it}\qquad(4)\\e_{it}&=\lambda_i+\tau_t+\varepsilon_{it}\end{aligned}$$

The initial regression estimates in Table 2 are based on linear rather than quadratic agglomeration effects (γ_{uu}=0) with the production function parameters 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 stacked 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.

The assumed error structure also varies across our specifications, to gauge the impact of alternative controls for firm heteregeneity. 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 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 removes the influence of higher productivity firms sorting into higher-density regions. The agglomeration elasticity estimate is still biased by 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 [14]; Olley and Pakes [15]), though we do not pursue these methods in the current article.

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 [14]).

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. Access to the data used in this study was provided by Statistics NZ in accordance with security and confidentiality provisions of the Statistics Act 1975 and the Tax Administration Act 1994 . The results in this paper have been confidentialised to protect individual businesses from identification. See Maré and Graham [16] for the full disclaimer. 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.2

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 [17], Statistics New Zealand [18]). The LBF provides monthly snapshots of an enterprise's industry, institutional sector, business type, geographic location, and employee count.[3] For PBNs, there is monthly information on industry, location, and employee count.

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

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2 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.

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

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.[4] 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, which has three components: 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 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.

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[4] 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.

4.2 Effective Density

Effective density is calculated for each area unit[5], 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[6]) plus a share of working proprietor input in the enterprises to which the PBN belongs. 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 [17]. 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 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

5 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.

6 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.

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.

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 1 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 [19], p.103). The second and third columns of Table 1 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 1 summarises gross output and factor inputs. The mean of the log of gross output is 11.68, which corresponds to (geometric) 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

8 The approach here differs from that in Graham and Kim [10], 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.

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. Around six percent of observations use data from AES, with the remainder based on IR10 tax forms.

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 2 presents regression estimates of agglomeration elasticities from a Hicks-neutral translog production function specification. 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).[11]

The third column of Table 2 controls more fully for enterprise composition differences, by including enterprise fixed effects. This has the effect of

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

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 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.

In columns 4 to 6 of Table 2, we show the corresponding estimates of agglomeration elasticities obtained by relaxing 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). This finding is consistent with more productive firms within industries being disproportionately located in lower density areas. Alternatively, the finding may reflect - for at least some industries - positive stronger sorting within areas than between areas; yielding higher estimated elasticities. Productive firms choose denser areas within regions, but are more randomly spread across regions. Whatever the source of difference, the small size of 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.[12] In contrast,

[12] 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.

imposing a common production function across all industries, as in the upper panel of Figure 1 and the first three columns of Table 2 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 2. 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 2, 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 2, the slope of the pooled estimates is slightly lower than the 'within local industry' 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.[13]

The reliability of the estimates depends on the validity of the various assumptions and constraints. First, the assumption that factor choices and effective

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[13] Graham [20] allows for a quadratic relationship using cross-sectional UK data and finds diminishing returns to agglomeration.

density is exogenous, conditional on included covariates, can be questioned. We were unable to find satisfactory ways of controlling for possible endogeneity.[14] Second, the assumption that the effect of effective density is Hicks-neutral can also be relaxed. Relaxing this assumption does not change the agglomeration elasticity estimates, when evaluated at sample means, but can potentially provide more information on the nature of factor augmentation and price effects.[15]

5.2 Estimates by one-digit industry

Table 3 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.

As was the case for the overall estimates in Table 2, controlling for sorting of enterprises across local industries leads to generally higher estimated agglomeration elasticities. The only exceptions are 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 (2). The reduction in estimated elasticities probably reflects the consequent imprecision of the enterprise fixed effects estimates rather than sorting alone.

On balance, the 'within local industry' estimates in column (2) appear to provide the best indication of industry-specific agglomeration elasticities. While they may still be biased by the sorting of high productivity firms into and within areas it is not clear how large the bias is, or even the direction of bias.

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14 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.

15 Maré and Graham [16] provides estimates of factor augmenting agglomeration effects.

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.

Non-linear agglomeration effects

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 (2) of Table 3. 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 10th and 90th 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.

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 4 summarises the results. The number of enterprise-year observations is shown in column (1) and the mean density of each area 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.

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

[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.

estimates shown in Table 4 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 4 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 3.

6 Summary and Discussion

This article demonstrates the impact on estimated agglomeration elasticities of alternative controls for firm heterogeneity, and shows the heterogeneity of agglomeration elasticities that exists across industries and regions. It also presents the first set of agglomeration elasticity estimates directly estimated from New Zealand microdata.

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*

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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.

(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 present panel estimates of agglomeration elasticities that control to some extent for the influence of firm heterogeneity and sorting. Specifically, 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 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 issues that are discussed above, 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, 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 w*holesale 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.[19] 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).

[19] The estimated elasticity for Gisborne is higher (0.222) but is not statistically significant.

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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 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.

Table 1: 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)
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.

Table 2: Agglomeration Elasticities
Hicks-neutral translog production function specification

	Aggregate production function			*Industry production functions*		
	Pooled	*Within Local Industry*	*Within Enterprise*	*Pooled*	*Within Local Industry*	*Within Enterprise*
	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(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.

Table 3: Agglomeration elasticities by one-digit industry

	NZ Industry	*Number of Ents*	*Industry-specific production functions* *Within Industry* *(1)*	*Within Local Industry* *(2)*	*Within Enterprise* *(3)*
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	0.049** [0.002]	0.061** [0.003]	0.016** [0.005]
E	Construction	34,100	0.039** [0.002]	0.056** [0.003]	0.011* [0.005]
F	Wholesale Trade	13,200	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	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	0.076** [0.006]	0.087** [0.006]	-0.006 [0.006]
L	Property and Business Services	56,500	0.074** [0.002]	0.079** [0.003]	0.000 [0.005]
M	Govt Admin & Defence				
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	0.049	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.

Table 4: Agglomeration elasticities – differences across regions

			Industry production function		
	Number of Obs (000) (1)	*ln(Eff Dens)* (2)	*Within Locality* (3)	*Within Local Industry* (4)	*Within Enterprise* (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]

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	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

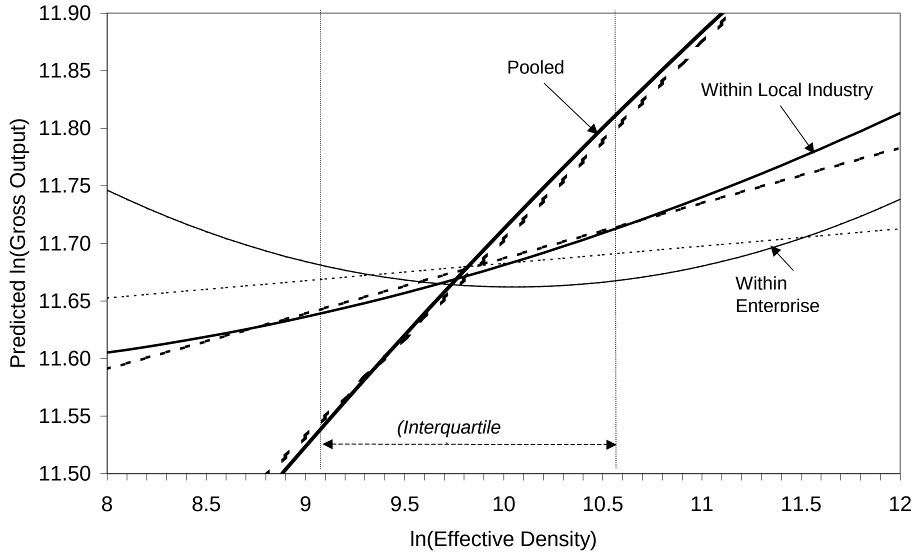
Appendix Table 2: Translog coefficient estimates –fully interacting density effects

	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

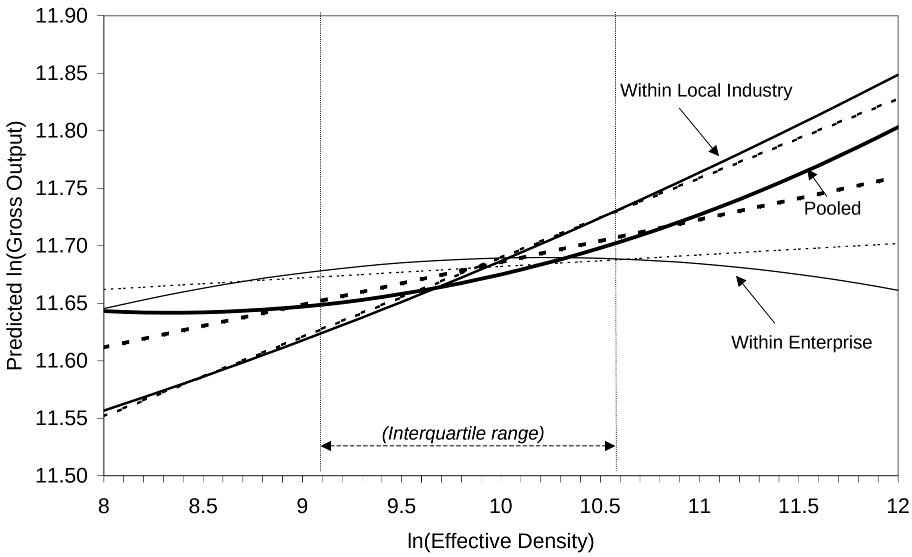
Notes: Robust standard errors clustered at the enterprise level. **: significant at 1%; *: significant at 5%. R-squared for the Fixed Effect column is calculated for within-enterprise variation

Figure 1: Agglomeration profiles

(a) Aggregate production function



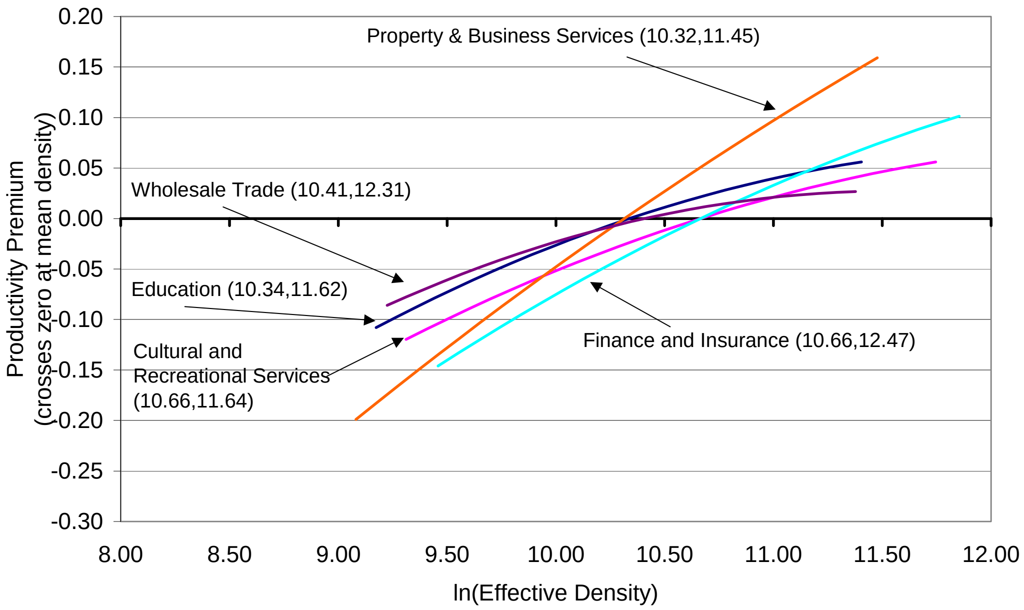
(b) Industry-specific production functions



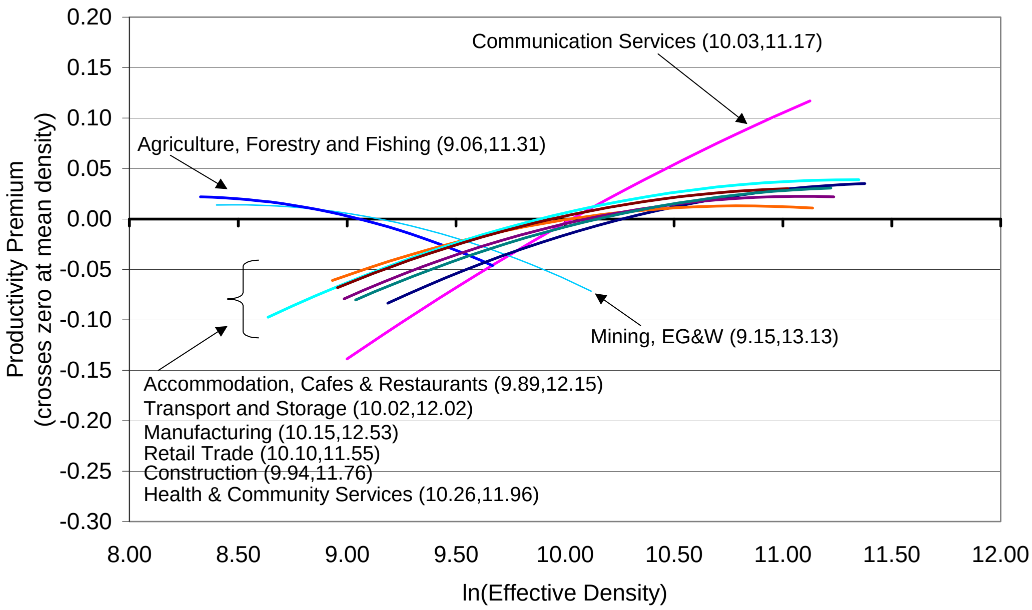
Note: The productivity-density profiles are those implied by the quadratic coefficients shown in Table 2. Broken lines show the corresponding linear elasticity estimates.

Figure 2: Productivity profiles - industry-specific regressions

High-density Industries



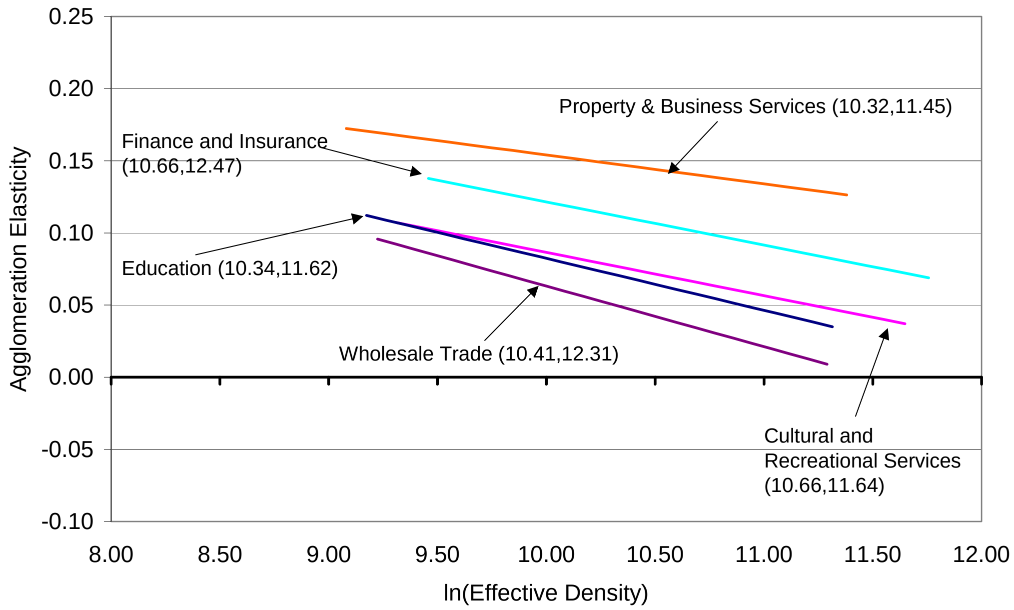
Other Industries



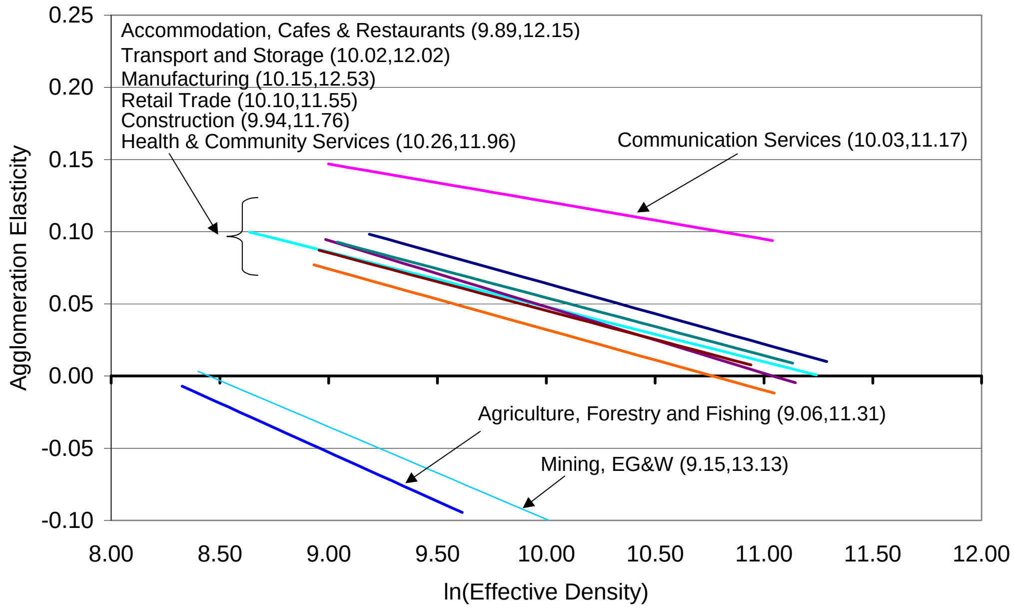
Numbers in brackets show (mean ln(Effective density), mean ln(gross output))

Figure 3: Agglomeration elasticities - industry-specific regressions

High-density Industries

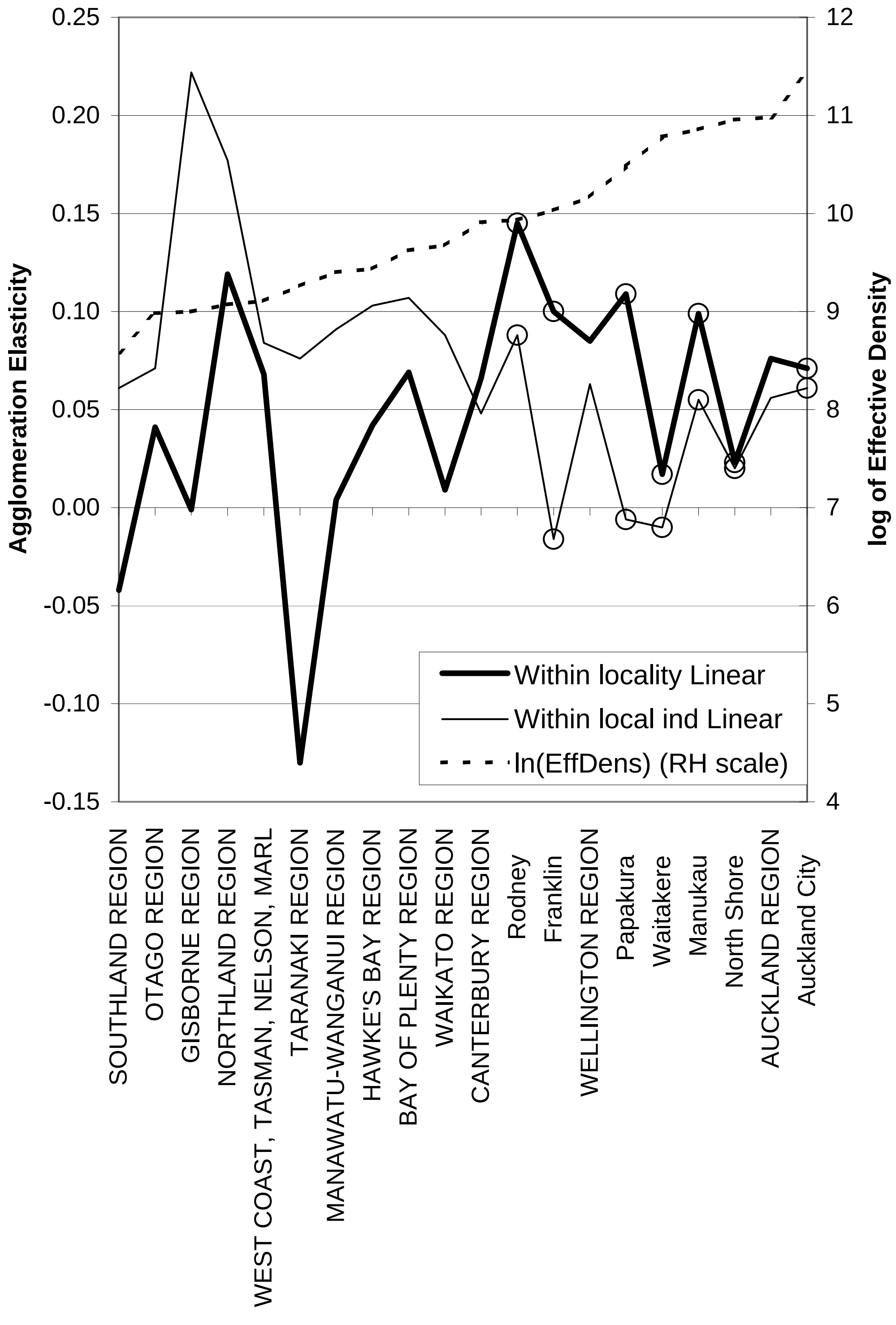


Other Industries



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

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.

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