

ECONOMIC GEOGRAPHY AND WAGES

Mary Amiti and Lisa Cameron*

Abstract—This paper estimates the agglomeration benefits that arise from vertical linkages between firms. We identify the agglomeration benefits off the spatial variation in firms' nominal wages. Using unusually detailed intermediate input data, we take account of the location of input suppliers to estimate cost linkages; and the location of demand from final consumers and other firms to estimate demand linkages. The results show that the externalities that arise from demand and cost linkages are quantitatively important and highly localized. An increase in either cost or demand linkages from the 10th to the 90th percentile increases wages by more than 20%.

I. Introduction

MANUFACTURING wages vary significantly across regions within countries. For example, in Indonesia's weaving mills industry the average wage paid by a firm at the 90th percentile of the wage distribution in 1996 was more than twice as high as that paid at the 10th percentile (after adjusting for skill differentials). These firms were 518 km apart on the island of Java. Similar patterns are observed for other industries. The existence of such large wage differentials raises the question as to why firms do not relocate to low-wage regions and arbitrage these differences away. The reasons we explore in this paper are related to the potential agglomeration benefits they might enjoy from being close to other firms.

Three main sources of externalities arising from geographical agglomerations have been identified by Marshall (1920)—they are (a) input/output linkages;¹ (b) labor pooling; and (c) knowledge spillovers. The role of input/output linkages in driving agglomeration of industries and hence wage inequalities has recently been formalized and developed in the international trade and economic geography literature by Krugman and Venables (1995) and Fujita, Krugman, and Venables (1999). The theory posits that firms benefit from being close to a large supply of intermediate input producers due to savings on transport costs, and from access to a large variety of differentiated inputs, reducing total costs, increasing profits, and thus attracting more firms.² This gives rise to a cost linkage or supply access effect. Similarly, firms benefit from being close to the

markets for their output due to increased demand, giving rise to a demand linkage or market access effect, which also increases profits. Of course, firms in neighboring regions can also benefit from these agglomerations in the form of lower prices for inputs and higher demand for their goods.

We use this theoretic framework to estimate the benefits of agglomeration arising from input/output linkages, with firm-level data for Indonesia. We identify the agglomeration benefits off the spatial variation in firm-level nominal wages.³ By utilizing an unusually detailed data set, we can construct a measure of cost linkages or supply access based on firms' self-reported inputs and the location of firms that supply the relevant inputs; and a measure of demand linkage or market access based on the location of final demand and demand from other firms. With this information we estimate the size of these pecuniary externalities and how far they spread across space. We use three waves of Indonesia's manufacturing census, which is a complete enumeration of all firms with twenty or more employees—1983, 1991, and 1996—to examine how geographical links between firms change over a long period of rapid growth.

Estimating the benefits of different sources of agglomeration and how far these benefits spread is of particular importance for regional policy development. Governments around the world spend large sums of money in the pursuit of decentralization. This is true in developed countries such as in the European Union, where large amounts of public expenditure are devoted to developing the poorer southern regions. It is also true in developing countries such as Indonesia where decentralization is currently a major political and public policy issue. The concentration of industry on Java has fed into preexisting sentiments of pro-Java bias, which have fostered movements for greater decentralization. The Indonesian government has been actively pursuing decentralization in an attempt to spread the benefits of industrialization to the other (outer) islands—with limited success. Our study gives an indication of how large the benefits of agglomeration arising from vertical linkages are. It is the spatial linkages that determine the extent to which the benefits of development spread across space. An understanding of the way in which they operate and how far they spread is crucial when considering policies that seek to influence regional development.

Indonesia's geography, public policy, and political history also make it an interesting laboratory in which to examine the theory. Although its 200 million people are spread over 900 islands and an east-west distance of 5,500 km, there is

firms—this would be the case if the upstream industry were oligopolistic

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* International Monetary Fund and CEPR; and University of Melbourne, respectively.

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¹ See Hirschman (1958).

² More intense competition in the upstream industry could also lead to lower intermediate input prices and hence more benefits to downstream

FIGURE 1.—GEOGRAPHIC DISTRIBUTION OF FORMAL-SECTOR MANUFACTURING COMPANIES



... are positively corre-
... of these papers use aggre-
... manufacturing or at the two-digit
... of them focus on input/output
... Redding and Venables (2004) do
... , but their data are highly aggre-
... level, and they do not have data on
... between firms. Instead, they rely on
... from an international trade gravity equa-
... for access to intermediate inputs.

In contrast to these papers, we use firm-level data to
... the interfirm linkages. Our disaggregated approach
... based on which inputs firms use and hence is likely to
... more accurately capture vertical linkages between firms. By
... using firm-level data we can take into account industry fixed
... effects and firm-level controls in our estimation. More
... aggregated studies run the risk that their effects may be
... driven by industry composition or the average size of firms,
... both of which might be related to agglomeration economies.
... hence it is important to partial them out in the empirical

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... the manufacturing sector in a location that matters, but the
... mix of firms. That is, after controlling for the total number
... of firms in each location, we still find that the variables
... measuring the proximity to suppliers and the market (that is,
... supplier and market access) continue to be the more impor-
... tant determinants of wages.
... Like this study, Dumais, Ellison, and Glaeser (2002) use
... firm-level data (for the United States) to estimate the impor-
... tance of all three sources of agglomeration—input/out-
... put linkages, labor pooling, and technological externalities—on the effects of employment growth (rather than
... wages). However, their study ignores the spatial links be-
... tween firms. All of their measures only take account of
... proximity of other firms within the same metropolitan area
... and ignore distance to neighboring areas. This might explain
... their small and sometimes insignificant coefficient on

vertical linkages—they find that labor pooling is the most important source of agglomeration. In contrast, our study takes into account that firms purchase inputs and sell output to other districts within Indonesia and to the rest of the world.⁴ Although we find that the effects are highly localized, they certainly cross district borders.

The existing small body of work on the concentration of industry in Indonesia, although informative, has not specifically examined cost and demand linkages as a source of agglomeration and has largely neglected an examination of the spatial aspects of such linkages. Henderson and Kuncoro (1996) examine firms' location decisions and find that firms strongly prefer locations where there are mature firms in related industries.

Section II develops the formal model. Section III provides background information on Indonesia and details of the data sources. Section IV presents the results and section V concludes.

II. Theory

We derive our estimating equation from an international trade and economic geography model developed by Krugman and Venables (1995) and extended in Fujita et al. (1999). It is a model in which vertical linkages between upstream and downstream firms create forces leading to industrial agglomeration. Firms are assumed to compete in a monopolistically competitive environment, where differentiated inputs enter the production function symmetrically and differentiated final goods enter the consumer's utility symmetrically.

A. Supply

The production function for a firm v in industry i in the manufacturing sector, located in district k , is given by

$$(L_k^{iv})^{\alpha^i} (K_k^{iv})^{\beta^i} \prod_u (C_k^u)^{\mu^{iu}} F^i b^i X_k^{iv}, \quad \alpha^i + \beta^i + \sum_u \mu^{iu} = 1, \quad (1)$$

with all location-specific variables denoted by subscripts and industry-specific variables with superscripts. The production technology consists of a variable cost, b^i , and a small fixed cost of setting up a plant, F , to produce a variety v .⁵ The fixed cost gives rise to increasing returns to scale technology; and the small size of F ensures that the number of varieties produced is large enough to make oligopolistic

interactions negligible. To produce output, x_k^{iv} , requires L_k^{iv} of labor and K_k^{iv} of capital,⁶ and varieties of intermediate inputs, supplied by each industry u , with

$$C_k^u = \left[\sum_{l=1}^K \sum_{v=1}^{N_k^u} (c_{lk}^{uv}/t_{lk}^u)^{\frac{\sigma^u-1}{\sigma^u}} \right]^{\frac{\sigma^u}{\sigma^u-1}}, \quad (2)$$

where c_{lk}^{uv} is the quantity of a variety v input demanded from upstream industry u produced in district l . The number of varieties produced by industry u

industry

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close to lots of upstream firms also reduces the price index due to savings on transport costs. This has a direct effect on producer prices of final goods.

Allowing free entry and exit of firms into each industry gives the level of output each firm must produce to just cover fixed costs, and hence make zero profits,

$$x_k^{iv} \bar{x}^i \frac{F^i(\sigma^i - 1)}{b^i}. \quad (6)$$

B. Aggregate Demand

To calculate total demand for industry i goods produced in district k we sum across demand in all districts l ,

$$c_k^i = \sum_{l=1}^K c_{kl}^i = (p_k^i)^{-\sigma^i} \sum_{l=1}^K (t_{kl}^i)^{1-\sigma^i} E_l^i (P_l^i)^{\sigma^i-1}, \quad (7)$$

where $E_l^i = s^i Y_l + \sum_d \mu^{di} N_l^d p_l^d x_l^d$. Demand for industry i goods comes from consumers and from downstream firms. Consumers allocate a constant share, $s^i Y_l$, of income to industry i ,⁸ and the price index is analogous to equation (5) with $u = i$. Transport costs on final goods are modeled analogously to those on intermediate inputs [as in equation (3)]. Each downstream firm spends a proportion u^{di} of its total revenue on intermediate inputs produced by industry i . Demand for intermediate inputs from downstream firms is derived using Shephard's lemma on the price index (as shown in Dixit & Stiglitz, 1977).

Substituting prices, expenditure, and transport costs [equations (4) and (3)] into the aggregate demand function [equation (7)], setting demand equals supply in the product market, imposing the zero profit level of output [equation (6)], substituting for the intermediate input price index [equation (5)], and rearranging gives the zero profit wage, which is the maximum wage a firm in industry i can afford to pay,

$$(w_k^{iv})^{\alpha^i} \left((\bar{x}^i)^{\frac{1}{\sigma^i}} b^i \theta^i \right)^{-1} r_k^{-\beta^i} \prod_u \left\{ \sum_{l=1}^k \sum_{v=1}^{N_k^u} (p_l^{uv})^{1-\sigma^u} e_k^{-\delta_{1d_{kl}}} \right\}^{\frac{\mu^i}{\sigma^i-1}} \sum_{l=1}^K \left\{ e^{-\delta_{2d_{kl}}} \left(s^i Y_l + \sum_d \mu^{di} N_l^d p_l^d x_l^d \right) (P_l^i)^{\sigma^i-1} \right\}^{\frac{1}{\sigma^i}}. \quad (8)$$

This is the main equation we are interested in. It embodies utility and profit maximization conditions, product market equilibrium, and free entry and exit. The expression with the first set of braces represents cost linkages or supplier access (SA), which the theory suggests has a positive effect on wages—the closer a firm is to its input suppliers, the lower its total cost and the higher the zero profit wage. The

coefficient on the distance parameter, δ_1 , indicates how quickly the externalities arising from proximity to input suppliers diffuse across space. A positive coefficient indicates that firms in close proximity benefit more than those farther away. The higher this coefficient, the more localized the externalities. The second line in equation (8) represents demand linkages or market access (MA), which has a positive effect on wages—the closer a firm is to its market, which comprises consumers and other firms that purchase its output, the more profitable it is and hence the higher its zero profit wage. Similarly, the coefficient on distance, δ_2 , indicates how far these benefits extend across space.

Our basic estimating equation, after taking logs of equation (8), becomes

$$\ln w_k^{iv} = \gamma_0 + \gamma_1 \ln(SA_k^i(e^{\delta_{1d_{kl}}})) + \gamma_2 \ln(MA_k^i(e^{\delta_2})) \quad (9)$$

of this sort in some of the specifications. The industry wage differentials may also be driven by differences in the market and supply access of different industries located in the same district. These differences will persist if there are frictions in labor mobility across industries, for example, as a result of industry-specific skill acquisition. The market access and supply access variables vary by five-digit industry and district.

Third, the theory assumes that labor is completely immobile across locations, giving rise to location-specific wages. Clearly this is not the case across districts within Indonesia. Provided that there are some frictions in labor mobility between locations, then the relationships in equation (9) will hold. This seems realistic in the context of Indonesia. Ties to the land are strong, and migrating to an industrial center may mean leaving one's own ethnic group and for that reason may be unattractive. Hence, not everyone is willing or able to migrate to the labor markets in industrial centers.¹¹

Fourth, other sources of agglomeration such as technological spillovers and labor pooling could give rise to higher wages. We construct variables to capture these effects and include them as additional regressors.

III. Data and Measurement

Our analysis uses firm-level data. The geographic unit of analysis is the *kabupaten*. Indonesia has a five-tiered geographic system—national, provinces, districts (*kabupaten*), subdistricts (*kecamatan*), and villages (*desa*).¹² A map showing the geographic distribution of manufacturing output in 1996 by district is presented in figure 1. There is little formal-sector manufacturing in the eastern islands (Nusa Tenggara Timur, East Timor, Maluku, and Irian Jaya), so we drop these regions from our initial sample (and they are not shown on the map). Sulawesi has slightly more in the way of manufacturing and we leave it in because it is a large, important land mass. The figure shows that manufacturing is concentrated largely around Java's urban centers, with some activity in Sumatra, and to a lesser extent Kalimantan. Our sample consists of 210 districts, 88 of which are on the

island of Java. These cover an area of 1,375,369 square kilometers, roughly the total land area of Germany, France, and Spain together, and an east-west distance greater than that from London to Istanbul. As can be seen from figure 1, there is considerable variability in terms of manufacturing activity within relatively small geographic areas. Much of this variability would be lost if we were to conduct the analysis at a more aggregate level.

A. Sources

Our main data source is the Manufacturing Survey of Large and Medium-Sized Firms (Survei Industri, SI). This survey is an annual census of all manufacturing firms in Indonesia with twenty or more employees ($N = 22,997$ in 1996). The SI data capture the formal manufacturing sector; the survey collects an unusually rich array of firm-level data, which includes information on firm output, imports, exports, wages, employment by skill level, and foreign ownership.

Most importantly for this study, the SI questionnaire also asks each firm to list all of their individual intermediate inputs and the amount spent on each in rupiah. Although this information is not routinely prepared, it was coded by the Indonesian statistical agency (Badan Pusat Statistik, BPS) and made available to us for the year 1998. For all other years, the only available information on inputs is the total expenditure on domestic inputs and imported inputs. We aggregate the 1998 data within five-digit industry categories to provide us with a 307 manufacturing input/output table, and assume that the mix of inputs used by industries does not change over our sample period. Combining the input codes with the location codes, we are able to link each firm to all potential suppliers in Indonesia and construct the supplier access variable.¹³ Similarly in reverse, we can identify the location of firms that are potential purchasers of an industry's output and so construct the market access variables. The 1998 data also list raw materials used by firms, but data at the district level on raw material production are not readily available. The omission of such information would constitute a potentially serious omitted vari-

construct the regional income data needed for the calculation of the final demand component of the market access variable. These data are also produced by BPS (BPS, 1995, 1998, 2000a). The earliest year for which such data are available is 1983. Oil revenues in Indonesia accrue almost entirely to the central government, so it is important to net them out when seeking to construct a measure of regional income. Non-oil GRDP figures are published from 1993. For years prior to 1993, we predict district oil revenues from available concurrent provincial figures and subtract this from the GRDP (including oil) data. Final demand shares from input-output tables published in BPS (1992, 1997) are applied to the income to construct final consumer demand at the five-digit industry level.¹⁴

We construct a measure of skilled labor from the 1995 Intercensal Survey. It is a large household survey ($N = 216,945$) that is conducted at ten yearly intervals midway between census years. We use information on the educational attainment of the population to control for differences in skill levels across districts.

BPS (2000b) provides information on land utilization in Indonesia. From this we construct a variable for the percentage of the district's potentially arable land that is not covered with housing and another for the percentage of district land area that is swamp. We use these to proxy for the cost of immobile factors of production and location amenity.

Finally, distances between districts were calculated using ArcView's geographic information system (GIS) technology with a district-level map of Indonesia. We construct pairwise measures of the shortest distance between the geographic center of each location. We thus end up with 210 distance variables (in kilometers). The distances range from a minimum of 6.2 km between North Jakarta and Central Jakarta to a maximum of 3,304 km from Aceh Besar in the northwestern tip of Sumatra to Sangihe Talaud in the far northeast of North Sulawesi.

B. Measurement

The dependent variable—the average firm wage—is constructed by dividing each firm's annual wage bill (in rupiah) by the average number of workers employed over that twelve-month period. We then convert this to a daily wage assuming a six-day working week. These data produce a wage distribution similar to that for formal-sector workers in the most commonly used source of Indonesian wage data, the Labor Force Survey (*Sakernas*).¹⁵ The supplier access variable is calculated from firms' self-reported value of output in rupiah; and the market access variable is calcu-

lated from firm's self-reported total expenditure on intermediate inputs.

Supplier access. The supplier access effect comes through the price indices of intermediate inputs, P_k^u , in equation (5). Individual input price data are unavailable so we approximate the cost linkages as follows:

$$SA_k^i = \sum_l^K \left[\left(\sum_u^U a^{ui} \phi_l^u \right) e^{-\delta_1 \cdot d_{kl}} \right], \quad (10)$$

$$\text{where } \phi_l^u = \frac{X_l^u}{X^u} = \frac{1}{X^u} \sum_{v=1}^{N_l} X_l^{uv} P_l^{uv}.$$

This is essentially an inverse proxy of the price index in equation (5). It measures the proximity of firms to their potential suppliers. The term ϕ_l^u is the total value of intermediate inputs produced by industry u in district l , X_l^u , divided by the total produced in Indonesia, X^u . We know where in Indonesia these inputs are produced; however, we do not know exactly from which location these inputs are purchased, so our measure represents potential suppliers rather than actual suppliers. Although we do not have individual prices, the cost linkages are still well represented in equation (10) since this "price index" is lower, the higher the share of intermediate inputs that are produced in close proximity. The share of intermediate inputs are weighted by the share of industry u in the total cost of industry i inputs, a^{ui} .

Market access. The market access variable is given by

$$MA_k^i = \sum_{l=1}^K \left[\left(\frac{s^i Y_l - \sum_d^D a^{di} I_l^d}{TD^i} \right) e^{-\delta_2 \cdot d_{kl}} \right]. \quad (11)$$

The inner bracketed term sums demand across all downstream firms and consumers in location l that demand industry i goods. Total demand from downstream firms is defined as the total expenditure of downstream firms in district l on intermediate inputs, I_l^d , times the share of downstream firms' intermediate input expenditure that is spent on industry i goods, a^{di} [which equals $\mu^{di} N_l^d p_l^d x_l^d$ in equation (8)]. This, scaled by total demand in Indonesia by firms and consumers, TD^i , is distance adjusted (in the same

TABLE 1.—SUMMARY STATISTICS

	Indonesia				Java				Outer Islands			
	Mean	Std	Min	Max	Mean	Std	Min	Max	Mean	Std	Min	Max
Wage	7,905.53	6,226.97	920.85	51,877.92	7,893.89	6,245.25	928.81	51,877.92	7,968.18	6,128.72	920.85	50,399.16
Supplier access	0.05	0.08	0	1	0.05	0.08	0	1	0.02	0.04	0	0
Market access	0.02	0.04	0	1	0.02	0.04	0	1	0.01	0.02	0	0
Imports	0.10	0.26	0	1	0.11	0.25	0	1	0.09	0.26	0	1
Exports	0.17	0.34	0	1	0.14	0.32	0	1	0.30	0.42	0	1
Size	206.21	594.75	12	23,516	205.28	613.45	12	23,516	211.22	481.90	14	5,184
Foreign ownership	0.05	0.19	0	1	0.05	0.19	0	1	0.06	0	0	1
Govt ownership	0.01	0.12	0	1	0.01	0.11	0	1	0.03	0.15	0	1
Female participation	0.37	0.30	0	1	0.37	0.30	0	1	0.40	0.31	0	1
High school education	0.31	0.27	0	1	0.29	0.26	0	1	0.39	0.28	0	1
Tertiary education	0.03	0.06	0	0.93	0.03	0.06	0	0.93	0.03	0.06	0	0.81
Population skill level	0.36	0.13	0.09	0.62	0.36	0.14	0.09	0.62	0.35	0.12	0.12	0.56
Labor pooling	-0.03	0.04	-0.39	0.00	-0.03	0.04	-0.36	0.00	-0.03	0.04	-0.39	0
Spillovers	50.66	95.24	1	393	56.79	101.68	1	393	17.67	31	1	128
Competition	0.01	0.07	0	1	0.0145	0.0662	0	1				
No. of firms in 1986	338.05	299.88	0	1,143	374.24	305.30	2	1,143	143.29	165	0	450
Coast	0.67	0.47	0	1	0.62	0.48	0	1	0.91	0	0	1
Swamp	0.03	0.04	0	0.60	0.02	0.04	0	0.14	0.05	0.07	0	0.60
Land	0.59	0.20	0	0.96	0.56	0.20	0.06	0.96	0.73	0.12	0	0.96
Skill	0.36	0.13	0	0.62	0.36	0.14	0.09	0.62	0.35	0.12	0	0.56
Port	132.20	158.57	0	944.18	97.27	97.86	0	350.90	320.23	258.88	0	944.18
# industries		172				170				128		
# <i>kabupatens</i>		177				87				90		
N		13,472				11,361				2,111		

imported. We then try an alternative specification that is more closely aligned with the theory. In this specification we model the rest of the world (ROW) as being in one geographic location, and then distance to the ROW varies across Indonesia only via a “distance to port” component, which we define as being distance to the closest port, d_p . That is, the market access term becomes

$$MA_k^i = \sum_{l=1}^K \left[\left(\frac{s^i Y_l \sum_d a^{di} I_l^d}{TD^i} \right) e^{-\delta_2 \cdot d_{kl}} + \gamma_x \cdot exshare \cdot e^{-\delta_x d_{kp}} \right], \quad (12)$$

where *exshare* is the percentage of the firm’s output that is exported. We allow exports to have a different effect on wages than domestic demand via γ_x and we estimate the parameter on distance to the nearest port (δ_x).¹⁶ For the supply access variables we treat imported inputs as a separate industry—on the basis of quality differences between imported and domestic inputs. This requires a separate term for all imported inputs, thus adding the share of imported inputs, exponentially weighted by the distance to the closest port as an explanatory variable. We find that the coefficients on domestic supplier and market access are not affected by this alternative treatment of trade, so we then proceed with the simpler specification.

¹⁶ In this specification the domestic demand term is deflated by $(1 - exshare)$ so it represents the share of total (international and domestic) demand that comes from each *kabupaten*.

Labor pooling. To examine the effects of labor pooling, we follow Dumais, Ellison, and Glaeser (2002) and construct an index that captures the similarity of firm f in district k ’s labor requirements to the requirements of other firms in the same district. The index is calculated as

$$LP_k^f = - \sum_s \left(L^{fs} \sum_{j \neq i} \frac{E_k^j}{E_k^f} L^{js} \right)^2, \quad (13)$$

where L^{fs} is the fraction of firm f ’s labor force that has education level s , E_k^f is the number of workers in firm f , and E_k is the total number of workers in district k . The index thus compares the educational composition of firm f ’s workforce with the education composition of other firms in the same district. The education categories are no education, primary education, lower secondary school, upper secondary school, and tertiary educated. The index is a sum of squared deviations measure. The higher the value of the index, the better the match between the firm’s education composition and that of surrounding firms. The maximum value of 0 indicates a perfect match.¹⁷ A pooled market for specialized worker skills benefits workers and firms. Krugman (1991) shows that it is more profitable for firms to locate where there is a pooled market for skills despite competition from other firms for workers because the benefits of a more efficient labor force outweigh the competition effects. Hence, we hypothesize that the index will have a positive effect on wages.

¹⁷ We calculated this measure at the provincial and *kabupaten* level. The provincial-level variable gave a better fit.

Technological and knowledge spillovers. We measure the effect of technology spillovers by proximity to other firms within the same five-digit category; that is, the number of firms in the same industry in every district, distance

TABLE 2.—BASIC SPECIFICATION

	Indonesia (1)	Java (2)	Outer Islands (3)	Java (4)	Java Alternative Trade (5)
<i>Supply access</i> - γ_1 :	0.0556 (0.0191)	0.1031 (0.0239)	0.0159 (0.0098)	0.0994 (0.0233)	0.1201 (0.0198)
Distance, km/100 - δ_1	1.7899 (0.7069)	0.9962 (0.2329)	3.0841 (2.4139)	1.0654 (0.2636)	0.9061 (0.1877)
<i>Market access</i> - γ_2 :	0.1071 (0.028)	0.2224 (0.0395)	0.0022 (0.0194)	0.2215 (0.0389)	0.2022 (0.0342)
Distance, km/100 - δ_2	2.8104 (1.2288)	2.7127 (0.4206)	5.4849 (49.3683)	2.6943 (0.4108)	2.7820 (0.4863)
Exports	0.3348 (0.0587)	0.2561 (0.0417)	0.4611 (0.0649)	0.2559 (0.0417)	0.3805 (0.0848)
Distance to port, km - δ_X					0.5581 (0.1141)
Imports	0.4059 (0.0869)	0.38 (0.0942)	0.3151 (0.0723)	0.3806 (0.0942)	0.5265 (0.1015)
Distance to port, km - δ_M					0.4478 (0.5909)
<i>Region dummies:</i>					
Sumatra	0.3414 (0.0679)		0.0801 (0.0688)		
Kalimantan	0.5191 (0.0955)		0.2356 (0.0939)		
Sulawesi	0.2682 (0.0966)		-0.2134 (0.0838)		
Jakarta	0.1124 (0.0316)	-0.0337 (0.0309)		-0.0316 (0.0312)	-0.0322 (0.0312)
<i>Industry dummies:</i>					
Wood/Furniture	0.1207 (0.0390)	0.2297 (0.0327)	0.1918 (0.098)	0.2282 (0.0329)	0.2104 (0.0365)
Paper/Printing	0.3681 (0.0300)	0.3643 (0.0248)	0.5494 (0.0933)	0.3636 (0.0250)	0.3634 (0.0231)
Chemicals/Plastics	0.3052 (0.0721)	0.3273 (0.0711)	0.3942 (0.106)	0.3270 (0.0712)	0.3200 (0.0684)
Nonmetallic minerals	0.1874 (0.0367)	0.2266 (0.0312)	0.3351 (0.0824)	0.2258 (0.0313)	0.2267 (0.0277)
Metals	0.5573 (0.1126)	0.5047 (0.1114)	0.5397 (0.1419)	0.5044 (0.1114)	0.5173 (0.1086)
Machinery and components	0.3847 (0.0487)	0.3563 (0.0398)	0.6174 (0.1094)	0.3557 (0.0401)	0.3471 (0.0332)
Other	0.0437 (0.0509)	0.0447 (0.0503)	0.2501 (0.0827)	0.0444 (0.0505)	0.0405 (0.0468)
Constant	8.9272 (0.0648)	9.3125 (0.0627)	8.3897 (0.1307)	9.3082 (0.0625)	9.2800 (0.0602)
Linkage variables coverage	Indonesia	Indonesia	Indonesia	Java	Java
RSS	3,736.3	2,926.7	571.9	2,927.8	2,912.9
R-squared	0.29	0.33	0.35	0.33	0.33
N	13,472	11,361	2,111	11,361	11,361

Standard errors in parentheses.

results for Indonesia as a whole [column (1)] show that demand and cost linkages have a positive and strongly significant effect, as predicted by the theory. Both the coefficients on distance (δ) and the coefficients on the distance-adjusted supply and market access variables (γ) are significant. These variables explain 29% of the variation in log wages. Column (2) presents the results for Java. The coefficients here are also positive and significant, and the γ 's are larger, suggesting that the agglomeration externalities are quantitatively more important in Java than in Indonesia as a whole. The results show that a distance-adjusted increase of 10% in supplier access increases wages by 1.03%, and a 10% increase in market access allows firms to increase wages by 2.2%.

The parameters on distance, δ , indicate how quickly the market and supply access spillovers decay with distance. If $\delta = 0$, then an increase in the externality in one district has the same effect on wages in all districts in Indonesia, regardless of how far they are from the source. If $\delta = \infty$, then an increase in the externality in location l will have no effect on wages in district k ($k \neq l$)—all effects are completely localized, which means that firms benefit from demand and supply only within their own district. To examine how far the benefits of market access and supply access spread, we use Keller's (2002) approach and calculate at what distance from the district are 90% of the effects of the district's externality dissipated. This involves finding the D^* that satisfies $0.1 = e^{-\delta D^*}$. The results from column (2)

indicate that both effects are highly localized with only 10% of the market access benefit spreading beyond 85 km; and the supplier access benefit spreading a little farther with 10% of the benefit going beyond 231 km.

Column (3) presents the results for the Outer Islands. In sharp contrast to Java, all of the market access and supply access parameters are statistically insignificant for the Outer Islands. The Outer Islands are much more sparsely populated and much less industrialized than Java. In 1996 there were only 4,339 formal-sector manufacturing firms in the outer regions (or 0.003 firms per square kilometer) compared with 18,506 (0.145 per square kilometer) in Java, and many of these were involved in the processing of natural products like wood and rubber.

The linkage terms in the first three columns include links to firms on all islands. In column (4) of table 2 we reestimate the equation for Java but now exclude links to the Outer Islands. The results show that linkages to the Outer Islands do not generate agglomeration externalities for firms on Java—the coefficients in columns (2) and (4) are almost identical. These results underpin the difficulty the Indonesian government has experienced in trying to move industry to the outer regions. Not only is the very small number of firms in these regions a concern, the Outer Islands are so far from Java so as to not benefit from the existence of the Javanese markets and suppliers.²³

The coefficients on the percentage of output exported and the percentage of inputs imported are positively signed and significant in all of the specifications, confirming that the more internationally focused firms pay higher wages. To check that these results are not sensitive to the way trade is included, we reestimate column (4) with the alternative treatment of international trade (described above) and report the results in the final column. Prior to 1985, Indonesian government regulation forced all international shipping through one of four ports—Tanjung Priok (Jakarta) and Surabaya in Java, Belawan in North Sumatra, and Ujungpandang in Sulawesi. Since 1985, investment in port infrastructure has remained centered on these four ports and they continue to be the most important gateways for international freight. We include imports as a separate term, adjusted by distance to the nearest of these ports; and we include exports inside the market access term, also adjusted by distance to the nearest port. Both the exports and imports terms remain significant. It is difficult to interpret the coefficient on distance as a spread of externalities given that the distances are only to the port and not to the trading partner, but the statistically significant estimate of δ_X at 0.55 shows that exporting firms benefit from being close to a port. The distance coefficient on imports, δ_M , is 0.44 but insignificant, suggesting that access to imports is unaffected by a firm's location within Java. Note that these firms do not necessarily import the goods themselves, they may buy imported inputs from an importing agent, and hence being close to a port may be less vital.

The estimates of the domestic supply and market access parameters are almost completely unchanged by the new treatment of trade—the coefficient on supply access is slightly higher and the one on market access slightly lower, but both fall well within the 95% confidence interval of the column (4) estimates. Both the import and export terms remain significant. Given that this more complicated alternative specification does not affect the market and supply access parameters, subsequent estimations will use the simpler specification.

Note that the Jakarta dummy is insignificant in columns (2) and (4). Thus, having controlled for the market and supplier access that Jakarta provides, there are no additional benefits from being in the nation's capital. Below we restrict our attention to more closely characterizing the linkages on Java (excluding linkages to the Outer Islands). Although business regulation across Java during our period of study was fairly uniform (see Brodjonegoro, 2004), we continue to control for Jakarta in case there are additional benefits derived from locating in the nation's capital.

C. Additional Controls

Table 3 examines whether the results for Java are robust to the addition of further controls.

Other sources of agglomeration. In column (2) of table 3, we add variables that attempt to capture the other forces of agglomeration: labor pooling and technological spillovers. The labor-pooling index is strongly significant and positive, suggesting that firms benefit from the presence of other firms that use a similar mix of skills and as a result will be more productive and pay higher wages. To capture technological spillovers we include the number of firms in the firm's own five-digit industry. This is calculated for each district and then distance weighted in the same way as the market and supply access variables. It is negatively signed and significant, indicating that proximity to other firms in the same industry reduces the zero-profit wage. It may be that the benefits of spillovers are offset by competition effects, even though we have controlled for competition by also including the market share variable—the firm's share of Java-wide same five-digit industry output—which has a positive and significant coefficient as hypothesized. Alternatively, spillovers may arise through other channels not captured by this variable; for example, technological spillovers could be transferred through the supply chains and so are in fact picked up by 3.9(in) could five7e controlle.2(contr46fTJcle.2(c

and so column (3) of table 3 presents the results with three-digit industry dummies. The coefficients on the linkage terms only change very slightly.²⁴ The spillover variable is now insignificant, so we drop this variable from subsequent specifications.

Industry wage differentials are known to exist for a number of reasons that are not in the theoretical model and

TABLE 4.—SENSITIVITY TESTS

	Comparison Col (6) Table 3 (1)	Small GDP <i>Kabupaten</i> (2)	Drop Own <i>Kabupaten</i> (3)	Lagging 5 Years (4)	Dropping if Own Industry Input Use (5)
<i>Supply access</i> - γ_1 :	0.0930 (0.0193)	0.0927 (0.0210)	0.0742 (0.017)	0.1035 (0.0165)	0.0938 (0.0209)
Distance, km/100 - δ_1	0.8771 (0.1703)	0.8107 (0.1664)	0.9553 (0.1979)	1.1053 (0.2198)	0.8318 (0.1665)
<i>Market access</i> - γ_2 :	0.1450 (0.0329)	0.1658 (0.0357)	0.1462 (0.0317)	0.1284 (0.0316)	0.1535 (0.0349)
Distance, km/100 - δ_2	2.1368 (0.5575)	2.3208 (0.5553)	2.0183 (0.4454)	2.0511 (0.5937)	2.1193 (0.5923)
Exports	0.1568 (0.0217)	0.1468 (0.0236)	0.1581 (0.0215)	0.1643 (0.0229)	0.1697 (0.0214)
Imports	0.1837 (0.0608)	0.1380 (0.0807)	0.1799 (0.0593)	0.1758 (0.0603)	0.1547 (0.0685)
Labor pooling (province)	0.2639 (0.0374)	0.1996 (0.0486)	0.2642 (0.0368)	0.2676 (0.0368)	0.2808 (0.0398)
Competition	0.5084 (0.1291)	0.4434 (0.1707)	0.6419 (0.1363)	0.7252 (0.1318)	0.5850 (0.1477)
Industry	3-digit	3-digit	3-digit	3-digit	3-digit
RSS	2,311.9	1,501.7	2,322.9	2,299.0	2,027.8
R-squared	0.472	0.499	0.469	0.472	0.469
N	11,361	7,317	11,359	11,310	10,152

Standard errors in parentheses.

these controls increases the adjusted R^2 from 0.37 (with the three-digit dummies) to 0.47. All of the additional controls are strongly statistically significant and are signed as expected. For example, a 1 percentage point increase in the percentage of workers who are female decreases average firm wages by 0.32%. The coefficients on the market and supply access variables remain statistically significant and are slightly smaller in magnitude.

Location-specific effects. A potential concern with our estimates is that we may be picking up a relationship that is being driven by a third omitted variable that is correlated with both wages and the linkage variables. For example, it may be that firms are attracted to districts which have good existing infrastructure such as roads, telecommunications, and a skilled workforce or which are attractive to live in, and that wages are bid up in these areas. We have already controlled for the skill level of the population; now we add controls for exogenous amenity. Previous studies have used variables reflecting the weather of locations; following Roback (1982), average temperature, humidity, and wind speed are typically used. These variables do not adequately capture differences in exogenous amenity in Java which are almost invariably hot and humid.²⁵ Instead, to capture exogenous amenity we have included a dummy variable for whether the district is on the coast, the distance to the closest major port, and the percentage of the district's area that is swamp land. We also include a measure of the percentage of potentially arable land that is not housing as

²⁵ Bandung is an exception to this. Its maximum temperatures hover around the mid-20's (Celsius), compared to the low 30s for most other locations. In the sensitivity analysis we experiment with dropping Bandung, and the results are not sensitive to its exclusion.

an inverse proxy of the price of immobile factors and hence expect this variable to have a positive effect on wages. All these variables are at the district level.

Column (5) controls for exogenous amenity in one important further way. We include the total number of formal-sector manufacturing firms in each district as an explanatory variable. This variable reflects the attractiveness of a district to firms (including preexisting infrastructure), so we would expect it to be positively signed. To reduce the possibility of this variable being correlated with the error term, we lag it ten years.²⁶ This takes us back to the early stages of Java's rapid industrialization. The number of formal-sector firms almost doubled in Java between 1986 and 1996 (from 10,159 to 18,506).

All of the additional variables are signed as expected, but only being on the coast and the number of firms in 1986 are statistically significant. The ten-year lagged number of firms is an important determinant of wages, but the extent of a district's industrialization is not driving our supply and market access results. The coefficients on the linkage terms remain significant and the point estimates remain similar in magnitude. Column (6) presents our preferred specification. It drops the insignificant location-specific variables.

D. Sensitivity Tests

Table 4 presents the results of a number of sensitivity tests to explore the possibility of endogeneity arising from reverse causality. That is, we are concerned that the location of firms, and hence the patterns of supply and market access may be determined by wages, rather than the reverse. First,

²⁶ The results are similar if we use the contemporaneous number of firms.

following the approach of Hanson (2005) and Keller (2002) we reestimate the equation with the full set of controls but dropping districts that individually constitute more than 2% of Indonesia's GDP. This drops the main industrial centers of Jakarta, Surabaya, and Bandung. Wages in these large centers of economic activity are the most likely to determine location patterns both within these centers and in neighboring districts. Hence the sensitivity of the results to dropping these observations gives us an indication of the extent of any endogeneity bias in our results. Dropping these cities also reduces the possibility of simultaneity bias arising from natural geographic features in these locations that may explain agglomeration—for example, Jakarta and Surabaya's natural harbors and Bandung's elevated position.

Second, in a similar vein, we drop the own-district component of the market and supplier access variables. If the linkage terms were a function of wages, then this is more likely to be the case for own-district effects.

Third, we lag both the linkage variables five years. This reduces the possible correlation between the error term and these variables. However, to the extent that these variables are correlated over time, any endogeneity that exists will persist.

Finally, we drop observations on industries in which more than 20% of inputs come from within their own five-digit industry. This reduces the scope for reverse causality coming through the supply access variable and also ensures that the variable is indeed picking up vertical linkages rather than horizontal spillovers.

The estimates of all four market access and supply access parameters (γ_1 , γ_2 , δ_1 , δ_2) are robust to all of these sensitivity tests. The coefficients remain significant. The point estimates in many cases are almost exactly the same, and where they differ they lie well within the 95th percentile confidence interval of the original estimates.

E. Interpretation of Magnitudes

Column (6) of table 3 is our preferred specification. Market and supply access have a significant positive effect on wages of similar magnitude: an increase in supply access of 10% increases wages by 0.9%, and an increase in market access of 10% increases wages by 1.5%. Most of this benefit dissipates over a short distance: only 10% of the benefit of market access spreads farther than 108 km and only 10% of the benefit of supply access spreads beyond 262 km. Another way of examining the magnitude of the effects is to analyze the effect of reducing distance between all districts, which would represent a fall in transport costs. For example, suppose all districts were 20% closer to each other than they are now. Our results indicate that the resulting improved supplier access would lead to an average increase in wages of 1.7% and a maximum of 7.2%; and the improved market access would lead to an average increase of 2.9%, with a maximum of 13.1%.

To examine the relative magnitude of the different sources of agglomeration, we consider how an increase in each variable from the 10th to the 90th percentile affects wages. We find that market

access has the largest average effect on wages of 26.6%; then supplier access with an average of 21.8%; and labor pooling the smallest effect of 11.9%. Similarly, increasing each variable by either an average of 10 percentiles, 20 percentiles, or 25 percentiles shows the linkage variables to have the largest effect. For example, the results from increasing variables by an average of 25 percentiles are as follows: market access increases wages by 9.6%; supplier access by 8.4%; and labor pooling by 3.1%.²⁷ This contrasts with Dumais, Ellison, and Glaeser (2002) that find labor pooling to have the largest effect in the United States. Labor pooling may be less important in a developing country because skills are not as differentiated as in a developed country. Also, as noted above, their estimates of the agglomeration externalities arising from vertical linkages may be understated due to the examination of only those linkages that exist within a firm's own metropolitan area.

F. Changes Over Time

We compare results for 1983 and 1991 with 1996 in table 5.²⁸ Summary statistics are presented in table A1. Some of the control variables are not available in the earlier years, so we also present results for 1996 with a smaller, comparable set of regressors. The supply access estimates are significant in all years and stable across time. The market access parameters are stable from 1991 to 1996. However, the coefficient γ_2 is a bit smaller in 1983 (0.14 compared with 0.19 in 1996 and 1991), which suggests that market access has become more important over time. The point estimate on δ_2 is much higher in 1983 than in the later years (decreasing from 4.97 in 1983 to 2.98 in 1991 and further to 2.6 in 1996). This suggests that the market access externality may have become less localized over time. In contrast, the supply access externality appears to have become more localized over time, with δ_1 increasing from 0.7 in 1983 to 0.9 in 1996.

As transport infrastructure and telecommunications improvements take place, one might expect that externalities arising from agglomeration benefits would spread over longer distances. However, as technologies become more advanced and products become more sophisticated, the need for face-to-face communication becomes more important, making externalities even more localized. These two offsetting effects may explain why the spread of the supply access externality has fallen over time while the market access effect may have become more diffused. Given that a large

²⁷ These results are calculated by averaging the effect of an increase from the 25th to the 50th percentile and from the 50th to the 75th percentile. This is consistent with the elasticities. A 10% increase in labor pooling results in a 0.09% increase in wages, which is significantly smaller than the market and supply access effects.

²⁸ We did not estimate the equations in time differences because our main variables of interest do not vary greatly over time, and so taking differences is likely to leave one with considerable measurement error. Furthermore, we would also be constrained to only including firms that existed in both periods, which could result in sample selection bias. Also, important firm-level controls such as the skill composition of the workforce were available only for 1996 and so could not be included in a time-differenced equation.

TABLE 5.—COMPARISONS ACROSS YEARS

	1996	1991	1983
<i>Supply access</i> - γ_1 :	0.0985 (0.0241)	0.1178 (0.0298)	0.1029 (0.0445)
Distance - δ_1	0.9208 (0.2022)	0.8348 (0.3176)	0.7198 (0.4214)
<i>Market access</i> - γ_2 :	0.1944 (0.0384)	0.1906 (0.0416)	0.1435 (0.0497)
Distance - δ_2	2.6115 (0.4782)	2.9833 (0.9343)	4.9731 (2.4137)
Exports	0.1527 (0.0312)	0.0758 (0.0466)	
Imports	0.2409 (0.0825)	0.1722 (0.0487)	0.0892 (0.0464)
Market share	0.7611 (0.1445)	1.0658 (0.1643)	0.3613 (0.1295)
Jakarta	0.0166 (0.0303)	0.1048 (0.0312)	0.1498 (0.0532)
Firm size	0.0067 (0.0023)	0.0073 (0.0030)	0.0259 (0.0068)
Foreign ownership	0.4308 (0.0652)	0.6605 (0.1353)	1.2450 (0.0873)
Government ownership	0.4419 (0.0611)	0.4724 (0.0621)	0.5358 (0.0587)
# firms lagged 10 years*	0.0110 (0.0037)	0 (0.0001)	0.0201 (0.0067)
Coast	-0.0015 (0.0154)	0.0153 (0.0270)	-0.0012 (0.0325)
Industry	3-digit	3-digit	3-digit
RSS	2,708.6	2,263.7	1,185.2
R-squared	0.382	0.380	0.425
N	11,361	7,927	3,857

For 1983 we used the first available year of SI data, which is 1976. Standard errors in parentheses.

part of the market access component comprises final demand from consumers, where face-to-face contact between producers and consumers is not so important, the fall in transport costs may dominate the effect.²⁹

The stability of the results across time is significant in two senses. First, in terms of the robustness of our results, the variables for 1991 and 1983 were constructed from a completely separate set of data and produce similar estimates. Second, in a substantive sense, even though Indonesia experienced dramatic change between 1983 and 1996 in terms of improvements in infrastructure, the effects of supplier access remained largely unchanged, with some increase in the market access effect. This is consistent with findings of studies such as Dumais, Ellison, and Glaeser (2002) which show that although there is a large amount of individual entry and exit of firms over time, the overall patterns of agglomeration are persistent.

V. Conclusions

This paper examines the benefits of agglomeration arising from vertical linkages between firms. Using firm-level data for Indonesia from 1996, 1991, and 1983, we show that

²⁹ These findings are consistent with the international trade and distance literature. For example, Berthelon and Freund (2003) find that the effect of distance on international trade has not changed for 75% of industries but has become more important for 25% of industries, suggesting that these industries trade less with more distant countries than they did twenty years ago.

firms benefit greatly from proximity to a large supply of inputs and good market access. Firms with the best supply or market access can afford to pay more than 20% higher wages than those with the poorest access. Labor pooling is less quantitatively important and we were unable to identify any positive effects from technology spillovers. These results are robust to controlling for more standard explanations of wage variation such as skill levels and firm size, and infrastructure variables. The results are also robust to a set of sensitivity tests designed to test the extent of endogeneity of the market access and supply access variables.

Further, we found that the benefits of vertical linkages are highly localized. Firms do benefit from vertical linkages, but not if they are located in the periphery. Only 10% of the market access benefit spreads beyond 108 km, and only 10% of the supply access benefit spreads beyond 262 km. We show that firms located in Indonesia's Outer Islands are too far away to benefit from the agglomeration of industries on the main island of Java.

The large agglomeration benefits arising from vertical linkages combined with the high localization of the benefits can explain why firms are reluctant to relocate to low-wage areas. These results also underscore the difficulty governments around the world have in generating economic growth in far-flung regions—where the citizens are often the poorest and benefit the least from economic growth. Although our results are based on Indonesian data, they clearly have more general implications. Large regional inequalities are a worldwide phenomenon and governments continue to spend large sums of money to try to attract firms to poorer regions. Given the size of the estimated agglomeration externalities, our results suggest that overcoming the attraction of existing agglomerations is likely to continue to be a difficult task.

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APPENDIX

TABLE A1.—SUMMARY STATISTICS FOR 1991 AND 1983

	Java - 1991				Java - 1983			
	Mean	Std	Min	Max	Mean	Std	Min	Max
Wage	4,339.46	4,010.37	549.70	36,368.39	1,700.42	1,527.10	167.81	10,588.57
Supplier access	0.05	0.08	0	1	0.05	0.08	0	1
Market access	0.02	0.04	0	0.94	0.01	0.04	0	1
Imports	0.15	0.30	0	1	0.24	0.35	0	1
Exports	0.11	0.29	0	1				
Jakarta	0.23	0.42	0	1	0.27	0.44	0	1
Size	193.92	512.23	20	14,830	129.71	281.30	10	5,338
Foreign ownership	0.03	0.15	0	1	0.03	0.14	0	1
Govt ownership	0.02	0.14	0	1	0.03	0.17	0	1
No. of firms in 1986	264.77	267.24	0	869	303.75	274.48	4	869
Coast	0.55	0.50	0	1	0.44	0.50	0	1
Swamp	0.02	0.03	0	0.14	0.03	0.04	0	0.14
# industries		157				140		
# kabupaten		83				75		
N		7,927				3,857		

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