

# Where Do Firms Locate? Testing Competing Models of Agglomeration

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## Abstract

Since firms' location decisions tend to be the focal point of economic models of agglomeration, distinguishing the causes of agglomeration requires identifying the important elements of those decisions. Firms value proximity to customers in pecuniary externality models, proximity to specialized inputs in natural advantage models, and proximity to other firms as sources of positive externalities in production externality models. Special cases of production externalities are localization and urbanization externalities, which are benefits generated by proximity to similar and different firms, respectively. Comparative statics involving land rents, productivity, and local employment patterns distinguish each model from the others, revealing which local feature is most valuable to firms in different industries. County level data for the fabricated metals, food, industrial machinery, miscellaneous manufacturing, printing, and stone, clay and glass industries is consistent with the pecuniary externality model. Data for the chemicals, electronics, instruments, furniture, paper, petroleum, primary metals, and transportation equipment industries is consistent with the natural advantages model. Data for the apparel and textiles industries is consistent with the urbanization externality variety of production externality models. Data for the lumber and rubber industries is not consistent with any of the models. There is no evidence that localization externalities play a primary role in firms' location decisions.

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# 1 Introduction

Three classes of models dominate discussions about the important elements of firms' location decisions and the causes of agglomeration in general. *Pecuniary externalities* are the source of agglomeration in the “new economic geography” models.<sup>1</sup> These models are characterized by consumers with preferences for diversity in consumption, monopolistically competitive firms producing differentiated products, increasing returns to scale at the firm level, and transportation costs. In these models, locations with high demand for a good attract producers of that good. Additional producers require additional employees, who in turn generate even higher demand for all goods at that location, making it even more attractive to other producers. In addition, consumers like to live in places with lots of producers because they have to import fewer goods, so more variety is available at lower prices. *Production externality* models are based on the idea that firms' production possibilities depend on the actions of other firms at the same location, via, for example, knowledge spillovers.<sup>2</sup> If firms benefit from proximity to other firms engaged in similar activities, they are said to enjoy *localization externalities*. If firms benefit from diversity in production or from the total amount of economic activity around them, then they are said to enjoy *urbanization externalities*. In either case, firms want to locate where other firms are. Finally, *natural advantage* models are based on the idea that different locations are endowed with different features which make them more attractive to different types of producers.<sup>3</sup> Producers who value a particular feature, such as proximity to a body of water or soil amenable to grape production, will concentrate at locations with more of that feature.

Each theory has intuitively appealing features: Pecuniary externality models emphasize the desire of firms to be close to their customers and vice versa, natural advantage models highlight that firms prefer to be near their inputs, and production externality models focus on the benefits to firms of proximity to other firms that are sources of positive externalities in production. All of these factors may play a role when firms decide where to operate. However, it is not clear how important each factor is, or in which circumstances one local characteristic is more valuable than the others. This is important because the welfare and policy implications of the models differ. In this paper, I focus on identifying which of these models best explains the location decisions of firms in different industries.

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<sup>1</sup>See, for example, Krugman (1991a), Krugman (1991b), Fujita and Krugman (1995), and Fujita, Krugman, and Venables (1999).

<sup>2</sup>See, for example, Berliant, Peng, and Wang (2002), Fujita and Ogawa (1982), Henderson (1974), Henderson (1977), Henderson (1988), and Jacobs (1969).

<sup>3</sup>See, for example, Berliant and Konishi (2000), Ellison and Glaeser (1999), Kim (1995), and Kim (1999).

To identify each model in the data, I first focus on the relationship between residential land rents and technical change, where technical change is anything that causes firms' production functions to shift. I show that the effect of technical change on residential land rents distinguishes models with pecuniary externalities from those with production externalities or natural advantages. In models with pecuniary externalities, technical change causes changes in the number of firms operating in a region, the quantity of output each firm produces, and the price each firm sets for its output, but has no effect on either wages or the level of employment in a region. Thus, it has no effect on demand for land or residential land rents in that region. However, in models with either production externalities or natural advantages, technical change leads to changes in wages, which in turn causes changes in demand for land and thus residential land rents.

Next, I show that the effect on residential land rents of changes in the local distribution of employment across industries distinguishes production externality models from both pecuniary externality models and natural advantage models. Consider the two special cases of production externalities discussed above, localization externalities and urbanization externalities. If firms in an industry enjoy localization externalities, then the production possibilities of a firm depend on how specialized is local employment in the firm's industry. Alternatively, if firms in an industry benefit from urbanization externalities, then a firm's production possibilities depend on how diversified is local employment. In either case, firms' production possibilities depend on the overall distribution of local employment across industries. Thus, the marginal product of labor and wages can vary with the local employment distribution. Demand for land and thus residential land rents must then depend on the local employment distribution as well. However, in models with pecuniary externalities and models with natural advantages, there is no connection between residential land rents and the local distribution of employment across industries. The comparative statics that distinguish the models are summarized in Table 1.

The main empirical results are the following. For sixteen of the eighteen industries analyzed, one of the three models captures the most important element of the location decisions of firms in that industry. For the food, printing and publishing, stone, clay, and glass, fabricated metals, industrial machinery and equipment, and miscellaneous manufacturing industries, the data are consistent with the predictions of the pecuniary externalities model. For these industries, proximity to customers or output markets is the overriding factor in firms' location decisions. For the paper, chemicals, petroleum and coal products, primary metals, electronic and other electric equipment, transportation equipment, instruments, and furniture and fixtures industries, the data are consistent with the predictions of the natural advantages model. Firms in these industries place the most emphasis on proximity to specialized inputs when making their location decisions. For the textiles and apparel industries, the

data are consistent with the urbanization externality variety of the production externality model. Proximity to other, diverse firms as sources of positive externalities is the most important element of firms' location decisions in these industries. Finally, the data for the lumber and wood products and rubber and plastics industries is not consistent with the predictions of any of the models. For firms in these industries, either two or more factors are of nearly equal importance, firms in different subindustries place emphasis on different factors when making location decisions, or none of the three models discussed in this paper adequately captures the important element in these firms' location decisions.

This paper improves on the literature in several ways.<sup>4</sup> First, I construct a test that simultaneously distinguishes between pecuniary externality models, natural advantage models, and the two varieties of production externality models, localization and urbanization. The two closest predecessors to this paper, Kim (1995) and Rosenthal and Strange (2001), address at most three of the four models. Kim (1995) distinguishes between localization externality models, pecuniary externality models, and natural advantage models for the U.S. manufacturing sector as a whole. Rosenthal and Strange (2001) explore how well natural advantages, transportation costs, and three different types of localization externalities explain industry localization patterns.<sup>5</sup> However, neither considers the role urbanization externalities may play or identifies which model best explains the location decisions of firms in individual industries. In other related literature, Ellison and Glaeser (1999) and Kim (1999) find that natural advantages explain a significant fraction of industry localization and location patterns, respectively, but leave determining how much of the remainder other factors explain to future work. Davis and Weinstein (1996), Davis and Weinstein (1998), Davis and Weinstein (1999), and Hanson and Xiang (2002) investigate whether natural advantage models or pecuniary externality models best explain trade patterns for different industries, but do not allow production externalities to play a role in their explanation. Dinlersoz (2002) finds evidence consistent with both pecuniary externality and production externality models in different industries, but does not consider whether the evidence is also consistent with natural advantage models. Holmes (2002) examines whether pecuniary externality or production externality models best explain the locations of sales offices, but cannot distinguish the influence of production externalities from that of natural advantages.

Second, I distinguish each model using comparative statics that involve a novel set of variables, residential land rents, industry productivity, and local industry employ-

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<sup>4</sup>Hanson (2001) provides a good review of the empirical literature on agglomeration.

<sup>5</sup>Localization is the extent to which an industry is concentrated in a few locations, rather than dispersed across many locations. Kim (1995) measures localization using an index of localization developed by Hoover (1936). Ellison and Glaeser (1999) and Rosenthal and Strange (2001) measure localization using the Ellison-Glaeser index of localization, developed by Ellison and Glaeser (1997).

ment shares, that are testable using easily available data. Similar comparative statics involving wages, rather than land rents, would also distinguish among the models, but data on wages by industry by location are often censored.

Third, the comparative statics are derived directly from economic models. The comparative statics explored by Henderson (1999) and Rosenthal and Strange (2002) in quantifying the benefits and geographic reach of localization and urbanization externalities, as well as those explored by Ellison and Glaeser (1999), Kim (1995), and Rosenthal and Strange (2001) are intuitive, but it is not clear if they are supported by theory. For example, Ellison and Glaeser (1999), Kim (1995), and Rosenthal and Strange (2001) infer the causes of agglomeration from the determinants of industry localization. However, it is easy to construct an example in which industries are perfectly localized regardless of the type of production externality from which they benefit (see Proposition 3 in Section 3). Thus, it is not clear what the determinants of localization actually reveal.

I begin by describing the different models. For tractability, I describe each model separately, rather than combining them into a single framework. I present models of pecuniary externalities, production externalities, and natural advantages in sections 2, 3, and 4 of this paper, respectively, and show the comparative statics results that identify each model. In Section 5, I construct an econometric model to distinguish between the theories based on the comparative statics. In section 6, I present the results. I conclude in section 7. The appendices contain all proofs, derivations, and data sources.

## 2 A Pecuniary Externality Model

In this section, I present the model of an economy with pecuniary externalities introduced by Krugman (1991b). To facilitate comparison of this model with the other two, I make one modification to Krugman's (1991b) original specification. I replace the population of immobile farmers, who produce a costlessly traded and homogeneous agricultural good, with a population of immobile landlords, who are endowed with residential land. Consumers then consume residential land instead of the agricultural good. Helpman (1998) constructs a similar model that generates similar results.

There are two regions in the economy. Let  $s = 1, 2$  denote region. The three types of goods in the economy are labor, land, and manufactured goods. There is a continuum of types of manufactured goods. Let  $(\mathcal{J}, \Omega, \eta)$  be the atomless measure space of potential manufactured goods, where  $\mathcal{J} = [0, \infty)$ ,  $\Omega$  is the  $\sigma$ -algebra of all Lebesgue measurable subsets of  $\mathcal{J}$ , and  $\eta$  is Lebesgue measure. Let  $j \in \mathcal{J}$  specify a type of manufactured good. Not all manufactured goods will actually be produced in equilibrium. Without loss of generality, we can name the manufactured goods so that

only goods  $j \in [0, J]$  are actually produced in equilibrium, where  $J$  is endogenous.

There is a fixed unit continuum of consumers in the economy. There are two types of consumers in the economy, workers and landlords. Let  $\mu$  be the fraction of consumers who are workers. All workers are identical and freely mobile. Each worker is endowed with one unit of labor, which she supplies inelastically, and no land. Let  $1 - \mu$  be the fraction of consumers who are landlords. All landlords are identical and immobile. Landlords are evenly distributed across the two regions. Each landlord owns one unit of land. Let  $l \in \mathbf{R}_+$  denote the quantity of residential land consumed and let  $m(j)$  denote the quantity of manufactured good  $j$  consumed. Let  $m : \mathcal{J} \rightarrow \mathbf{R}_+$  be measurable, with  $m(j) = 0$  for all  $j > J$ .<sup>6</sup> All workers and landlords have the same utility function,

$$U(m, l) = M^\mu l^{1-\mu},$$

where  $M$  is a manufactures aggregate,

$$M = \left[ \int_{\mathcal{J}} m(j)^{\frac{\sigma-1}{\sigma}} d\eta(j) \right]^{\frac{\sigma}{\sigma-1}},$$

where  $\sigma > 1$ . Let  $N_s \in [0, 1]$  denote the fraction of workers who live in region  $s$ .

Manufacturing firms produce differentiated products. Each firm produces a single type of good, and each type of good is produced by a single firm, so  $j$  denotes both the type of good and its producer. Firms are freely mobile and are monopolistically competitive. To produce  $q(j)$  units of manufactured good  $j$ , a firm needs  $\alpha + \beta q(j)$  units of labor. Firms use no land. Let  $p(j)$  denote the price a firm receives for manufactured good  $j$  and let  $w_s$  be the price of labor in region  $s$ . A firm producing good  $j$  in region  $s$  makes profits

$$\pi_s(j) = p(j)q(j) - w_s(\alpha + \beta q(j)).$$

Since firms are monopolistically competitive, they choose the profit-maximizing price for their product. The quantity they sell,  $q(j)$ , depends on the price of good  $j$ . Furthermore, manufactured goods are costly to transport. If one unit of manufactured good is shipped from one region to another, then only  $\tau$  units arrive, where  $0 < \tau < 1$ . Finally, let  $\mathcal{J}_s \subset [0, J]$  be the set of manufactured goods produced in region  $s$ , where  $\mathcal{J}_1 \cap \mathcal{J}_2 = \emptyset$  and  $\mathcal{J}_1 \cup \mathcal{J}_2 = [0, J]$ . Let  $J_s = \eta(\mathcal{J}_s)$ , so  $J_1 + J_2 = J$ .

Throughout the following definitions, let  $i = W, L$  identify workers and landlords, respectively. An *allocation* is a list

$$\left( \{l_s^W, l_s^L, m_s^W, m_s^L, N_s, \mathcal{J}_s\}_{s=1,2}, q \right),$$

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<sup>6</sup>All statements concerning measurability are with respect to the appropriate subspace of Lebesgue measurable subsets of the real line.

where  $l_s^i \in \mathbf{R}_+$ ,  $m_s^i : \mathcal{J} \rightarrow \mathbf{R}_+$  is measurable with  $m_s^i(j) = 0$  for all  $j > J$ ,  $N_s \in \mathbf{R}_+$ , and  $q : \mathcal{J} \rightarrow \mathbf{R}_+$  is measurable with  $q(j) = 0$  for all  $j > J$ . An allocation is *interior* if  $N_1 > 0$  and  $N_2 > 0$ . An allocation is *feasible* if for all  $s$ ,

$$\frac{1-\mu}{2}l_s^L + N_s\mu l_s^W = \frac{1-\mu}{2}; \quad (1)$$

for almost all  $j \in \mathcal{J}_1$ ,

$$\frac{1-\mu}{2}m_1^L(j) + N_1\mu m_1^W(j) + \frac{\frac{1-\mu}{2}m_2^L(j) + N_2\mu m_2^W(j)}{\tau} = q(j); \quad (2)$$

for almost all  $j \in \mathcal{J}_2$ ,

$$\frac{\frac{1-\mu}{2}m_1^L(j) + N_1\mu m_1^W(j)}{\tau} + \frac{1-\mu}{2}m_2^L(j) + N_2\mu m_2^W(j) = q(j); \quad (3)$$

for all  $s$ ,

$$\int_{\mathcal{J}_s} \alpha + \beta q(j) d\eta(j) = N_s\mu, \quad (4)$$

and

$$N_1 + N_2 = 1. \quad (5)$$

Equation (1) is material balance in residential land in each region. Equations (2) and (3) are material balance in manufactured goods produced in regions 1 and 2, respectively. Equation (4) is material balance in labor in each region. Equation (5) states that the number of workers in each region adds up to the total population of workers in the economy.

Let  $I_D$  be the indicator function of the measurable set  $D \subset \mathbf{R}$ , so that  $I_D(x) = 1$  if  $x \in D$  and  $I_D(x) = 0$  if  $x \notin D$ . Let  $r_s$  denote the price of residential land in each region. An *interior equilibrium* is a feasible and interior allocation,

$$\left( \{l_s^{*W}, l_s^{*L}, m_s^{*W}, m_s^{*L}, N_s^*, \mathcal{J}_s^*\}_{s=1,2}, q^* \right),$$

and prices  $(p^*, w_1^*, w_2^*, r_1^*, r_2^*)$ , where  $p^* : \mathcal{J} \rightarrow \mathbf{R}_+$  is measurable with  $p^*(j) = 0$  for  $j > J$ , and  $(w_1^*, w_2^*, r_1^*, r_2^*) \in \mathbf{R}_+^4$ , such that for all  $s$ ,

$$U(l_s^{*W}, m_s^{*W}) \geq U(l_s^W, m_s^W) \quad (6)$$

for all  $(l_s^W, m_s^W) \in \mathbf{R}_+^2$  such that

$$r_s^* l_s^W + \int_{\mathcal{J}} \left( I_{\mathcal{J}_s}(j) p^*(j) m_s^W(j) + I_{\mathcal{J}_{s'}}(j) \frac{p^*(j)}{\tau} m_s^W(j) \right) dj = w_s^*;$$

for all  $s, s'$ ,

$$U(l_s^{*W}, m_s^{*W}) = U(l_{s'}^{*W}, m_{s'}^{*W}); \quad (7)$$

for all  $j$ ,

$$p^*(j)q^*(j) - w_s^*(\alpha + \beta q^*(j)) \geq p(j)q(j) - w_s^*(\alpha + \beta q^M(j)); \quad (8)$$

for all  $j$ ,

$$p^*(j)q^*(j) - w_s^*(\alpha + \beta q^*(j)) = 0; \quad (9)$$

and for all  $s$ ,

$$U(l_s^{*L}, m_s^{*L}) \geq U(l_s^L, m_s^L) \quad (10)$$

for all  $(l_s^L, m_s^L) \in \mathbf{R}_+^2$  such that

$$r_s^* l_s^{*L} + \int_{\mathcal{J}} \left( I_{\mathcal{J}_s}(j) p^*(j) m_s^L(j) + I_{\mathcal{J}_{s'}}(j) \frac{p^*(j)}{\tau} m_s^L(j) \right) dj = r_s^*.$$

Equation (6) states that all workers maximize utility subject to their budget constraint. As in Krugman's (1991b) model, the iceberg form of the transportation cost implies that when consumers in one region purchase manufactured goods produced by a firm in the other region, they pay  $\tau^{-1}$  times the firms' profit-maximizing price. Consumers located in the same region as the firm from which they purchase goods simply pay the firm's profit-maximizing price. Equation (7) is the free mobility condition; workers enjoy the same utility regardless of the region they live in. Equation (8) states that all manufacturing firms are choosing the profit-maximizing price for their product. Equation (9) is the free entry condition; manufacturing firms will enter the industry until all firms earn zero profits. Equation (10) states that landlords in both regions maximize utility subject to their budget constraint.

The main result of this section is Proposition 2, which states that equilibrium residential land rents are invariant to changes in firms' fixed and marginal costs. I preface this result with Proposition 1, which states that an interior equilibrium exists for all possible values of the parameters. Proposition 1 ensures that Proposition 2 is not vacuous.

A lemma will be useful when stating Propositions 1 and 2. Lemma 1 states that the equilibrium share of workers in region 1, equilibrium wages, and equilibrium land rents are zeros of a system of equations,  $f = [f_1 \ f_2 \ f_3 \ f_4]^T$ , which is defined as follows:

$$\begin{aligned} f_1 &= \frac{w_1}{(r_1)^{1-\mu} \hat{G}_1^\mu} - \frac{1}{(r_2)^{1-\mu} \hat{G}_2^\mu}, \\ f_2 &= \frac{N_1 w_1}{r_1} - \frac{1}{2}, \\ f_3 &= \frac{1 - N_1}{r_2} - \frac{1}{2}, \text{ and} \end{aligned}$$

$$f_4 = \frac{\frac{1-\mu}{2}r_1 + N_1w_1}{(w_1)^\sigma \hat{G}_1^{1-\sigma}} + \frac{\frac{1-\mu}{2}r_2 + (1-N_1)}{\tau \left(\frac{w_1}{\tau}\right)^\sigma \hat{G}_2^{1-\sigma}} - 1,$$

where

$$\begin{aligned}\hat{G}_1 &= [N_1(w_1)^{1-\sigma} + (1-N_1)(1/\tau)^{1-\sigma}]^{\frac{1}{1-\sigma}}, \\ \hat{G}_2 &= [N_1(w_1/\tau)^{1-\sigma} + (1-N_1)]^{\frac{1}{1-\sigma}}.\end{aligned}$$

**Lemma 1** *Normalize  $w_2^* = 1$ . Then  $(N_1^*, w_1^*, r_1^*, r_2^*) \in f^{-1}(0)$ .*

*Proof* All proofs are in the appendices.

Using Lemma 1, it is easy to show that at least one interior equilibrium exists, regardless of the parameter values. Specifically, the symmetric equilibrium, in which half of the population of workers lives in each region and wages and land rents are the same in both regions, always exists. For some values of the parameters, there may be other equilibria, but the symmetric equilibrium always exists. Let  $\Phi = \mathbf{R}_+^2 \times (0, 1)^2 \times (1, \infty)$  be the exogenous parameter space.

**Proposition 1** *For any  $(\alpha, \beta, \mu, \tau, \sigma) \in \Phi$ , there exists an interior equilibrium.*

What is technical change in this model? Intuitively, positive technical change, or an improvement in productivity, allows firms to produce a the same amount of output with fewer inputs. Recall that a firm producing  $q(j)$  units of good  $j$  requires  $\alpha + \beta q(j)$  units of labor. It is easy to see, then, that positive technical change must manifest itself through either a lower fixed labor requirement, a lower marginal labor requirement, or both. Thus, technical change is a change in  $\alpha$ , a change in  $\beta$ , or both.

**Proposition 2** *If zero is a regular value of  $f$ , then technical change has no effect on residential land rents, i.e. for  $s = 1, 2$ ,*

$$\frac{\partial r_s^*}{\partial \alpha} = \frac{\partial r_s^*}{\partial \beta} = 0.$$

The intuition is the following (see Lemmas 5 and 6 in Appendix A). Suppose technical change leads to a decrease in the fixed labor requirement. Lower fixed costs allow more firms to operate, but each firm produces less output. These two effects offset each other, so that there is no change in either regional employment or real wages. Thus, there is no change in the demand for land and no change in residential land prices when productivity changes. Next, suppose technical change leads to a decrease in the marginal labor requirement. In this case, each firm produces more output, but, since the quantity of labor required to produce each additional unit

has decreased, there is no change in employment at each firm. The number of firms operating in each region is unrelated to the marginal labor requirement, so there is no change in either regional employment or wages. It follows that there is no change in either demand for land or the price of land. Overall, residential land prices respond to neither changes in firms' fixed labor requirements nor changes in firms' marginal labor requirements.

The invariance result stated in Proposition 2 distinguishes the pecuniary externalities model from both the production externality model and natural advantage model, which are discussed in the next two sections. The source of this invariance result is the industrial organization of the pecuniary externalities model. In this model, firms are monopolistically competitive, the number of firms actively producing goods is endogenous, and the number of goods available to consumers is endogenous. In the other two models, firms will be perfectly competitive, the number of firms will be fixed, and the number of goods will be fixed. As a result, changes in productivity affect the economy through different channels. In the pecuniary externality model, changes in fixed costs cause entry and exit of firms and so cause changes in the variety of products available to consumers. Changes in marginal costs lead to changes in the quantity of output firms produce and in the markup of price over cost. So, consumers benefit from improvements in productivity either through availability of a greater variety of goods or through lower prices of existing goods. Changes in productivity are not, however, reflected in changes in wages. On the other hand, we will see that since firms are perfectly competitive in the other two models, changes in productivity generate changes in both output and input prices. Changes in wages are then passed on to landlords in the form of changes in land rents. In a sense, perfect competition in the production externality and natural advantage models implies that productivity changes in local industries are at least partially capitalized into local land rents.

### 3 A Production Externality Model

In this section, I present a model of an economy in which firms benefit from production externalities, or spillovers. This model is based on the model of localization externalities described by Henderson (1988). The model described below differs from Henderson's (1988) model in that the number of locations in this model is exogenous and the specification of the externality in this model is generalized to allow both localization externalities and urbanization externalities as special cases. In Henderson's (1988) model, the number of locations is endogenous and only localization externalities are considered.

There are two regions in the economy, identified by  $s = 1, 2$ . There are two manufactured goods in the economy,  $X$  and  $Y$ , as well as land, labor, and raw materials.

Manufactured goods are costlessly transported between regions. Raw materials are immobile.

The economy is populated by a fixed unit continuum of freely mobile workers. Each worker is endowed with one unit of labor, which she supplies inelastically. Let  $x$ ,  $y$  and  $l$  denote quantities of goods  $X$ ,  $Y$ , and residential land consumed, respectively. All workers have the same utility function

$$U(x, y, l) = x^a y^b l^{1-a-b},$$

where  $0 < a, b < 1$ . Let  $p_X$ ,  $p_Y$ ,  $w_s$ , and  $r_s$  be the prices of good  $X$ , good  $Y$ , labor in region  $s$ , and residential land in region  $s$ , respectively. A worker living in region  $s$  faces the budget constraint  $p_X x + p_Y y + r_s l \leq w_s$ . If a worker living in region  $s$  maximizes her utility subject to her budget constraint in region  $s$ , then  $V(p_X, p_Y, w_s, r_s)$  is her corresponding indirect utility. Workers choose the location that offers them the highest indirect utility. Let  $N_s \in [0, 1]$  be the share of workers living in region  $s$ .

An absentee landlord owns all the land and raw materials in the economy and supplies them inelastically. To keep things simple, the landlord consumes only good  $Y$  and supplies no labor. Let  $\bar{L}$  and  $\bar{\Gamma}$  be the quantities of residential land and raw materials, respectively, available in each region. Let  $\rho_s$  be the price of raw materials in region  $s$ . Let  $y^L$  be the landlord's consumption of good  $Y$ .

There are fixed unit continua of identical  $X$  producers and identical  $Y$  producers. Production of each type good is perfectly competitive. For  $j = X, Y$ , let  $q_{js}$  be the quantity of  $j$  produced by a firm in region  $s$ , and let  $\lambda_{js}$  and  $\gamma_{js}$  be the quantities of labor and raw materials used by a firm producing  $j$  in region  $s$ . Let  $\Lambda_{js}$  be the share of workers employed in industry  $j$  in region  $s$ . All producers have the same production function,

$$q_{js} = \xi_j G_j(\Lambda_{Xs}, \Lambda_{Ys})(\lambda_{js})^\alpha (\gamma_{js})^{1-\alpha},$$

where  $\alpha \in (0, 1)$ ,  $\xi_j \in \mathbf{R}_+$  is an exogenous Hicks-neutral shift factor and  $G_{js}$  is a Hicks-neutral shift factor that depends on the local employment structure. For all  $j, s$ , let  $G_j : \mathbf{R}_+^2 \rightarrow \mathbf{R}_+$  be  $\mathcal{C}^2$ . Each firm perceives that  $G_j(\Lambda_{Xs}, \Lambda_{Ys})$  is determined exogenously.

This specification of  $G_j$  includes models of localization externalities and urbanization externalities as special cases. First, a firm enjoys localization externalities if its production possibilities depend on how specialized its location is in its industry. I measure regional specialization in industry  $j$  by the share of regional employment in industry  $j$ .

**Definition 1** Firms in industry  $j$  enjoy *localization externalities* if

$$G_j(\Lambda_{Xs}, \Lambda_{Ys}) \equiv G_j \left( \frac{\Lambda_{js}}{\Lambda_{Xs} + \Lambda_{Ys}} \right),$$

with  $G'_j > 0$ .

Alternatively, a firm enjoys urbanization externalities if its production possibilities depend on how diversified is its location. I measure regional diversity with a Herfindahl index of employment concentration (Henderson (1995)). The larger the value of the index, the more regional employment is concentrated in a single industry, so the less diversified is the region.

**Definition 2** Firms in industry  $j$  enjoy *urbanization externalities* if

$$G_j(\Lambda_{Xs}, \Lambda_{Ys}) \equiv G_j \left( \sum_j \left( \frac{\Lambda_{js}}{\Lambda_{Xs} + \Lambda_{Ys}} \right)^2 \right),$$

with  $G'_j < 0$ .

Let  $Q_{js}$  be aggregate production of good  $j$  in region  $s$  and let  $\Gamma_{js}$  be the aggregate quantity of raw materials employed in production of  $j$  in region  $s$ . For  $j = X, Y$ , since production functions are homogeneous of degree one in own inputs, firms can be aggregated by industry and region. The  $j$ -industry production function in region  $s$  is

$$Q_{js} = \xi_j G_j(\Lambda_{Xs}, \Lambda_{Ys}) (\Lambda_{js})^\alpha (\Gamma_{js})^{1-\alpha},$$

Since firms' production functions are homogenous of degree one in own inputs, the number of firms in each region is indeterminate. For simplicity then, I identify only aggregate inputs and outputs. To simplify notation, let  $G_{js} \equiv G_j(\Lambda_{Xs}, \Lambda_{Ys})$ .

An *allocation* is a list

$$(\{N_s, x_s, y_s, l_s, Q_{Xs}, Q_{Ys}, \Lambda_{Xs}, \Lambda_{Ys}, \Gamma_{Xs}, \Gamma_{Ys}\}_{s=1,2}, y^L) \in \mathbf{R}_+^{21}.$$

An allocation is *interior* if  $N_1 > 0$  and  $N_2 > 0$ . An allocation is *feasible* if

$$\text{for } s = 1, 2, N_s l_s = \bar{L}, \quad (11)$$

$$\text{for } s = 1, 2, \Lambda_{Xs} + \Lambda_{Ys} = N_s, \quad (12)$$

$$N_1 + N_2 = 1, \quad (13)$$

$$\text{for } s = 1, 2, \Gamma_{Xs} + \Gamma_{Ys} = \bar{\Gamma}, \quad (14)$$

$$\text{for } s = 1, 2, j = X, Y, \xi_j G_{js} (\Lambda_{js})^\alpha (\Gamma_{js})^{1-\alpha} = Q_{js}, \quad (15)$$

$$N_1 x_1 + N_2 x_2 = Q_{X1} + Q_{X2}, \quad (16)$$

$$N_1 y_1 + N_2 y_2 + y^L = Q_{Y1} + Q_{Y2}. \quad (17)$$

Equations (11) are material balance in residential land. Equations (12) are material balance in local labor. Equation (13) is material balance in population. Equations (14) are material balance in raw materials. Equations (15) state that output can be produced with the specified inputs. Equations (16) and (17) are material balance in goods  $X$  and  $Y$ .

An *interior equilibrium* is a feasible and interior allocation

$$(\{N_s^*, x_s^*, y_s^*, l_s^*, Q_{Xs}^*, Q_{Ys}^*, \Lambda_{Xs}^*, \Lambda_{Ys}^*, \Gamma_{Xs}^*, \Gamma_{Ys}^*\}_{s=1,2}, y^{*L}) \in \mathbf{R}_+^{21}.$$

and prices

$$(w_1^*, w_2^*, r_1^*, r_2^*, p_X^*, p_Y^*, \rho_1^*, \rho_2^*) \in \mathbf{R}_+^8$$

such that for  $s = 1, 2$ ,

$$U(x_s^*, y_s^*, l_s^*) \geq U(x_s, y_s, l_s) \quad (18)$$

for all  $(x_s, y_s, l_s) \in \mathbf{R}_+^3$  such that

$$p_X^* x_s + p_Y^* y_s + r_s^* l_s = w_s^*,$$

$$V(p_X^*, p_Y^*, w_1^*, r_1^*) = V(p_X^*, p_Y^*, w_2^*, r_2^*), \quad (19)$$

for  $j = X, Y$  and  $s = 1, 2$ ,

$$p_j^* Q_{js}^* - w_s^* \Lambda_{js}^* - \rho_s^* \Gamma_{js}^* \geq p_j^* Q_{js} - w_s^* \Lambda_{js} - \rho_s^* \Gamma_{js} \quad (20)$$

for all  $(Q_{js}, \Lambda_{js}, \Gamma_{js}) \in \mathbf{R}_+^3$  such that

$$Q_{js} = \xi_j G_{js} (\Lambda_{js})^\alpha (\Gamma_{js})^{1-\alpha},$$

and

$$y^{*L} = \bar{L}(r_1^* + r_2^*) + \bar{\Gamma}(\rho_1^* + \rho_2^*). \quad (21)$$

Equation (18) states that all consumers are maximizing utility subject to their budget constraints. Equation (19) is the free mobility condition; workers enjoy the same level of utility regardless of where they live. Equation (20) states that all producers are maximizing profits. Equation (21) requires the landlord to exhaust all of her income.

Equilibria can be classified as one of three types, according to how localized are industries and how specialized are regions. Loosely, industry localization is the extent to which an industry is concentrated in a small number of regions, rather than spread out over many locations. Regional specialization is the extent to which productive activity in a region is concentrated in a small number of industries, rather than spread out over many industries. In a *perfectly localized/specialized equilibrium*, a single industry operates in each region. For example, if almost all  $X$  producers locate in region 1 and almost all  $Y$  producers locate in region 2, then both industries are perfectly

localized and both regions are perfectly specialized. In a *diversified equilibrium*, both industries operate in both regions, so a positive measure of both  $X$  and  $Y$  industries are in both regions. In an *imperfectly localized/specialized equilibrium*, two industries operate in one region and a single industry operates in the other region. For example, if all  $X$  producers and a positive measure of  $Y$  producers are in region 1 and only the remainder of the  $Y$  producers are in region 2, then the  $X$  industry is perfectly localized in region 1, region 2 is perfectly specialized in  $Y$  production, the  $Y$  industry is somewhat diversified across regions, and region 1 is somewhat diversified across industries.

The main results of this section are Proposition 3, Proposition 4, Lemma 3, and Lemma 4. Proposition 3 states that a perfectly localized/specialized equilibrium always exists. I present this result to show that perfect localization implies little about the type of production externality firms in an industry benefit from. For brevity and for generality, the other results are stated in the context of diversified equilibria. Proposition 4 states that land rents are positively related to productivity change. Lemmas 3 and 4 state the relationship between land rents and the local share of employment in an industry when firms benefit from localization externalities and urbanization externalities, respectively. It is easy to show that these results are valid for all three types of equilibria. LaFountain (2001) discusses the conditions under which equilibria (not necessarily interior) exist, so these statements are not vacuous.

**Proposition 3** *A perfectly localized/specialized interior equilibrium exists.*

This result implies that no matter what type of production externality firms benefit from, an equilibrium exists in which industries are perfectly localized, i.e. each industry is concentrated at a single location. Notably, industries may be perfectly localized in equilibrium even if one or both industries benefit from urbanization externalities. Thus, by itself, localization does not reveal what type of production externality, if any, firms benefit from.

The following lemma will be useful when stating Proposition 4. Lemma 2 states that the (diversified) equilibrium quantities of labor and raw materials employed in each industry and each region are zeros of the system of equations  $g = [g_1 \ g_2 \ g_3 \ g_4 \ g_5]^T$ , where

$$\begin{aligned}
g_1 &= \frac{G_{X1} (\Gamma_{X1}/\Lambda_{X1})^{(1-\alpha)(a+b)}}{(\Lambda_{X1} + \Lambda_{Y1})^{1-a-b}} - \frac{G_{X2} (\Gamma_{X2}/\Lambda_{X2})^{(1-\alpha)(a+b)}}{(1 - \Lambda_{X1} - \Lambda_{Y1})^{1-a-b}}, \\
g_2 &= \frac{G_{X2}}{G_{X1}} \left( \frac{\Gamma_{X2}/\Lambda_{X2}}{\Gamma_{X1}/\Lambda_{X1}} \right)^{1-\alpha} - \frac{G_{Y2}}{G_{Y1}} \left( \frac{(\bar{\Gamma} - \Gamma_{X2})/(1 - \Lambda_{X1} - \Lambda_{Y1} - \Lambda_{X2})}{(\bar{\Gamma} - \Gamma_{X1})/\Lambda_{Y1}} \right)^{1-\alpha}, \\
g_3 &= G_{X1} \frac{\Lambda_{X1}}{\Gamma_{X1}} - G_{Y1} \frac{\Lambda_{Y1}}{\bar{\Gamma} - \Gamma_{X1}},
\end{aligned}$$

$$g_4 = G_{X2} \frac{\Lambda_{X2}}{\Gamma_{X2}} - G_{Y2} \frac{(1 - \Lambda_{X1} - \Lambda_{Y1} - \Lambda_{X2})}{\bar{\Gamma} - \Gamma_{X2}}, \text{ and}$$

$$g_5 = \sum_{s=1,2} a G_{Xs} (\Lambda_{Xs} + \Lambda_{Ys}) \left( \frac{\Gamma_{Xs}}{\Lambda_{Xs}} \right)^{1-\alpha} - G_{Xs} (\Lambda_{Xs})^\alpha (\Gamma_{Xs})^{1-\alpha}.$$

Lemma 2 also identifies equilibrium land rents as functions of these variables.

**Lemma 2** *Let  $p_X$  be the numeraire. If the equilibrium is diversified, then for all  $(a, b, \alpha) \in (0, 1)^3$ ,  $(\Lambda_{X1}^*, \Lambda_{Y1}^*, \Lambda_{X2}^*, \Gamma_{X1}^*, \Gamma_{X2}^*) \in g^{-1}(0)$ . Furthermore,*

$$r_1^* = \frac{1 - a - b}{\bar{L}} (\Lambda_{X1}^* + \Lambda_{Y1}^*) \alpha \xi_X G_{X1} \left( \frac{\Gamma_{X1}^*}{\Lambda_{X1}^*} \right)^{1-\alpha} \text{ and}$$

$$r_2^* = \frac{1 - a - b}{\bar{L}} (\Lambda_{X2}^* + \Lambda_{Y2}^*) \alpha \xi_X G_{X2} \left( \frac{\Gamma_{X2}^*}{\Lambda_{X2}^*} \right)^{1-\alpha}.$$

As in the pecuniary externalities model, technical change is anything that causes firms' production functions to shift. In this model, however, the local employment structure can cause firms' production structure to shift as well, through the function  $G_j$ . We have to be careful to identify technical change as anything that causes the production function to shift, other than local inputs. Technical change in industry  $j$ , then, is a change in the Hicks-neutral productivity parameter  $\xi_j$ .

**Proposition 4** *If zero is a regular value of  $g$ , then land rents in regions where  $X$  producers operate are positively related to technical change in  $X$  production, i.e. for  $s = 1, 2$ ,*

$$\frac{\partial r_s^*}{\partial \xi_X} > 0.$$

The intuition behind this result is that when productivity in the  $X$  industry increases, good  $X$  becomes less expensive relative to good  $Y$ , increasing demand for  $X$ . The increase in productivity allows  $X$  producers to meet the additional demand for  $X$  without increasing their labor and raw materials inputs. At the same time, increasing productivity in the  $X$  industry increases the marginal productivity of labor employed in the  $X$  industry, and thus real wages. Since land is a normal good, demand for land increases, causing residential land rents to rise as well.

It will be useful to highlight the relationship between land rents and regional specialization in equilibrium. Proposition 3 tells us that once the distribution of local inputs in region 1 is determined, land rents are determined as follows:

$$r_1^* = \frac{1 - a - b}{\bar{L}} (\Lambda_{X1}^* + \Lambda_{Y1}^*) \alpha \xi_X G_{X1} \left( \frac{\Gamma_{X1}^*}{\Lambda_{X1}^*} \right)^{1-\alpha}. \quad (22)$$

Thus, land rents depend on the local employment structure via the function  $G_X$ . It follows that if firms producing good  $X$  enjoy localization externalities, then

$$G_{X1} = G_X \left( \frac{\Lambda_{X1}^*}{\Lambda_{X1}^* + \Lambda_{Y1}^*} \right),$$

where  $G'_X > 0$ . This implies that, all else being equal, the more specialized is region 1 in  $X$  production, the higher are residential land rents.

**Lemma 3** *If  $X$  producers benefit from localization externalities, then residential land rents in regions where  $X$  producers operate are positively related to the share of local employment in the  $X$  industry.*

On the other hand, if firms producing good  $X$  benefit from urbanization externalities, then

$$G_{X1} = G_X \left( \sum_{j=X,Y} \left( \frac{\Lambda_{j1}^*}{\Lambda_{X1}^* + \Lambda_{Y1}^*} \right)^2 \right),$$

where  $G'_X < 0$ . In this case, the relationship between specialization and land rents is slightly more complicated. If the share of local employment in the  $X$  industry is less than one half, then residential land rents are positively related to the share of local employment in the  $X$  industry. If more than half of local employment is in the  $X$  industry, then land rents are negatively related to the share of local employment in the  $X$  industry.

**Lemma 4** *Let  $X$  producers benefit from urbanization externalities. If the share of local employment in the  $X$  industry is less than one-half, then land rents in regions where  $X$  producers operate are positively related to the share of local employment in the  $X$  industry. If the share of local employment in the  $X$  industry is greater than one-half, then land rents in regions where  $X$  producers operate are negatively related to the share of local employment in the  $X$  industry.*

Showing that Proposition 4 and Lemmas 3 and 4 hold for perfectly and imperfectly localized/specialized equilibria simply requires a slightly different definition of  $g$  in Lemma 2.

## 4 A Natural Advantages Model

The final model I present is one in which different regions are endowed with different characteristics and firms' production possibilities are location-specific. Thus, firms in different industries may find it advantageous to locate in different regions. This

model of natural advantages is most closely related to the specific factors model of international trade (Jones (1971)). However, this model does not include residential land consumption and wages cannot differ across regions.

There are two regions in the economy, identified by  $s = 1, 2$ . There are two manufactured goods in the economy,  $X$  and  $Y$ , as well as land, labor, and raw materials. Manufactured goods are costlessly transported between regions.

The economy is populated by a fixed unit continuum of freely mobile workers. Each worker is endowed with one unit of labor, which she supplies inelastically. Let  $x$ ,  $y$  and  $l$  denote quantities of goods  $X$ ,  $Y$ , and residential land consumed, respectively. All consumers have the same utility function

$$U(x, y, l) = x^a y^b l^{1-a-b},$$

where  $0 < a, b < 1$ . Let  $p_X$ ,  $p_Y$ ,  $w_s$ , and  $r_s$  be the prices of good  $X$ , good  $Y$ , labor in region  $s$ , and residential land in region  $s$ , respectively. A worker living in region  $s$  faces budget constraint  $p_X x + p_Y y + r_s l \leq w_s$ . If a worker in region  $s$  maximizes her utility subject to her budget constraint in region  $s$ , then  $V(p_X, p_Y, w_s, r_s)$  is her corresponding indirect utility. Workers choose the location that offers them the highest indirect utility. Let  $N_s \in [0, 1]$  be the fraction of consumers living in region  $s$ .

An absentee landlord owns all the land in the economy and all the raw materials, and supplies both inelastically. To keep things simple, the landlord consumes only good  $Y$  and supplies no labor. Let  $\bar{L} \in \mathbf{R}_+$  be the quantity of residential land available in each region. Let  $\bar{\Gamma}_X \in \mathbf{R}_+$  and  $\bar{\Gamma}_Y \in \mathbf{R}_+$  be the quantity of raw materials used in the production of  $X$  and  $Y$ . For simplicity, assume that raw materials used in  $X$  production are only available in region 1 and raw materials used in  $Y$  production are available only in region 2. Raw materials cannot be transported between regions. Let  $\rho_j$  be the price of raw materials used in the production of good  $j$ . Let  $y^L$  be the landlord's consumption of good  $Y$ .

There are fixed unit continua of identical  $X$  producers and identical  $Y$  producers. Production of each type good is perfectly competitive. Let  $q_{js}$  be the quantity of  $j = X, Y$  produced by a firm in region  $s$  and let  $\lambda_{js}$  and  $\gamma_{js}$  be the quantities of labor and raw materials, respectively, used by a firm producing  $j$  in region  $s$ . All firms producing good  $j$  have production function

$$q_{js} = \xi_j (\lambda_{js})^\alpha (\gamma_{js})^{1-\alpha},$$

where  $\xi_j \in \mathbf{R}_+$  and  $0 < \alpha < 1$ .

Since raw materials needed to produce  $X$  are only available in region 1, all firms producing positive quantities of  $X$  must locate in region 1, and similarly, all firms producing  $Y$  must locate in region 2. Without loss of generality, we can assume that

almost every firm producing  $X$  locates in region 1, and almost every firm producing  $Y$  locates in region 2. Thus, we can drop the location subscript on firms' inputs and outputs. Let  $Q_j$ ,  $\Lambda_j$ , and  $\Gamma_j$  be the aggregate quantities of output, labor input, and raw materials input, respectively, in the  $j$  industry. Since production functions are homogeneous of degree one, the  $j$ -industry production function is

$$Q_j = \xi_j(\Lambda_j)^\alpha(\Gamma_j)^{1-\alpha}.$$

An *allocation* is a list

$$(N_1, N_2, x_1, x_2, y_1, y_2, l_1, l_2, Q_X, Q_Y, \Lambda_X, \Lambda_Y, \Gamma_X, \Gamma_Y, y^L) \in \mathbf{R}_+^{15}.$$

An allocation is *interior* if  $N_1 > 0$  and  $N_2 > 0$ . An allocation is *feasible* if,

$$\text{for } s = 1, 2, N_s l_s = \bar{L}, \quad (23)$$

$$\Lambda_X = N_1, \quad (24)$$

$$\Lambda_Y = N_2, \quad (25)$$

$$N_1 + N_2 = 1, \quad (26)$$

$$\text{for } j = X, Y, \Gamma_j = \bar{\Gamma}_j, \quad (27)$$

$$\text{for } j = X, Y, \xi_j(\Lambda_j)^\alpha(\Gamma_j)^{1-\alpha} = Q_j, \quad (28)$$

$$N_1 x_1 + N_2 x_2 = Q_X, \quad (29)$$

$$N_1 y_1 + N_2 y_2 + y^L = Q_Y. \quad (30)$$

Equations (23) are material balance in residential land. Equations (24) and (25) are material balance in local labor. Equation (26) is material balance in population. Equations (27) are material balance in raw materials. Equations (28) state that output can be produced with the specified inputs. Equations (29) and (30) are material balance in goods  $X$  and  $Y$ .

An *interior equilibrium* is a feasible and interior allocation

$$(N_1^*, N_2^*, x_1^*, x_2^*, y_1^*, y_2^*, l_1^*, l_2^*, Q_X^*, Q_Y^*, \Lambda_X^*, \Lambda_Y^*, \Gamma_X^*, \Gamma_Y^*, y^{*L}) \in \mathbf{R}_+^{15}.$$

and prices

$$(w_1^*, w_2^*, r_1^*, r_2^*, \rho_X^*, \rho_Y^*, p_X^*, p_Y^*) \in \mathbf{R}_+^8$$

such that for all  $s$ ,

$$U(x_s^*, y_s^*, l_s^*) \geq U(x_s, y_s, l_s) \quad (31)$$

for all  $(x_s, y_s, l_s) \in \mathbf{R}_+^3$  such that

$$p_X^* x_s + p_Y^* y_s + r_s^* l_s = w_s^*,$$

$$V(p_X^*, p_Y^*, w_1^*, r_1^*) = V(p_X^*, p_Y^*, w_2^*, r_2^*), \quad (32)$$

for all  $j$  and for all  $s$ ,

$$p_j^* Q_j^* - w_s^* \Lambda_j^* - \rho_s^* \Gamma_j^* \geq p_j^* Q_j - w_s^* \lambda_j^T - \rho_s^* \Gamma_j \quad (33)$$

for all  $(Q_j, \Lambda_j, \Gamma_j) \in \mathbf{R}_+^3$  such that

$$Q_j = \xi_j (\Lambda_j)^\alpha (\Gamma_j)^{1-\alpha},$$

and

$$y^{*L} = \bar{L}(r_1^* + r_2^*) + \rho_X^* \bar{\Gamma}_X + \rho_Y^* \bar{\Gamma}_Y. \quad (34)$$

Equation (31) states that all consumers are maximizing utility subject to their budget constraints. Equation (32) is the free mobility condition; workers enjoy the same level of utility regardless of where they live. Equation (33) states that all producers are maximizing profits. Equation (34) requires the landlord to exhaust all of her income.

Proposition 6, which states that residential land rents are positively related to changes in productivity, is the main result of this section. The preceding result, Proposition 5, states that an interior equilibrium exists for all values of the parameters. Let  $\Phi = (0, 1)^3 \times \mathbf{R}_+^2$  be the exogenous parameter space.

**Proposition 5** *For any value of  $(a, b, \alpha, \xi_X, \xi_Y) \in \Phi$ , there exists an interior equilibrium where the equilibrium share of employment in region 1 is*

$$N_1^* = \frac{1}{1 + \left(\frac{a\alpha}{1-\alpha}\right)^{a+b}}$$

and equilibrium residential land rents in region 1 are

$$r_1^* = \frac{1-a-b}{\bar{L}} \alpha \xi_X (\bar{\Gamma}_X)^{1-\alpha} (N_1^*)^\alpha.$$

**Proposition 6** *Residential land rents in the region where  $X$  producers operate are positively related to productivity in the  $X$  industry,*

$$\frac{\partial r_1^*}{\partial \xi_X} > 0.$$

The intuition is similar to that in the production externality model. When  $\xi_X$  increases, the marginal productivity of labor in region 1 increases, and thus wages in region 1 increase. Since land is a normal good, demand for residential land increases, driving up residential land rents. At the same time, the good  $Y$  becomes relatively more expensive, so factor payments in region 2 must increase in order to maintain the zero profit condition for firms in region 2.

## 5 A Test of the Models' Predictions

Each model described above focuses on a single influence on firms location decisions. Pecuniary externality models emphasize proximity to customers, production externality models emphasize proximity to sources of positive externalities in production, and natural advantage models emphasize proximity to specialized inputs. The purpose of this paper is determine the predominant influence on firms behavior in order to shed light on the predominant source of agglomeration. It follows from Proposition 2 that if the location decisions of firms in an industry are best described by the pecuniary externality model, then residential land rents in regions where that industry operates will be unrelated to productivity in that industry. On the other hand, Propositions 4 and 6 suggest that if the location decisions of firms in an industry are consistent with either production externality or natural advantage models, then residential land rents in regions where that industry operates will be positively related to productivity in that industry. Furthermore, if firms in an industry benefit from production externalities, then Lemmas 3 and 4 imply that residential land rents in regions where those industries operate will depend on the share of local employment in that industry. They will not if firms' behavior is more consistent with that described by either pecuniary externality or natural advantage models.

To determine which model best describes firms' location decisions, I estimate the following fixed effects model for each manufacturing industry  $j$ , where  $j$  is defined by the 1987 Standard Industrial Classification (SIC) at the two-digit level:

$$\ln(RENT_{st}) = \alpha_s + \beta X_{st} + \delta PROD_t + \gamma SHARE_{st} + \epsilon_{st}, \quad (35)$$

where  $RENT_{st}$  is the residential land rent in region  $s$  in year  $t$ ,  $\alpha_s$  is the region fixed effect,  $X_{st}$  is a vector of region control variables,  $PROD_t$  is the productivity of industry  $j$  in year  $t$ ,  $SHARE_{st}$  is the share of manufacturing employment in industry  $j$  in region  $s$  in year  $t$  and  $\epsilon_{st}$  is an i.i.d. disturbance. The signs of the coefficients  $\delta$  and  $\gamma$  reveal the model with which the data are consistent. If  $\delta = 0$  and  $\gamma = 0$ , then the data for industry  $j$  are consistent with pecuniary externality models, indicating that proximity to customers or output markets is the most important element of firms' location decisions. If  $\delta > 0$  and  $\gamma = 0$ , then the data for industry  $j$  are consistent with natural advantage models, indicating that proximity to inputs is the most important element of firms' location decisions. If  $\delta > 0$  and  $\gamma \neq 0$ , then the data for industry  $j$  are consistent with production externalities, indicating that proximity to other firms' that are sources of positive externalities is the most important element in firms' location decisions. If  $\delta > 0$  and  $\gamma < 0$ , then the data for industry  $j$  are consistent with urbanization externalities, and firms want to be in diverse environments. If  $\delta > 0$  and  $\gamma > 0$ , then the data for industry  $j$  are consistent with both localization and urbanization externalities, and we cannot determine whether firms like to be

near other firms engaged in similar activities, or in diverse locations. Finally, if the combination of  $\delta$  and  $\gamma$  does not fall into any of these categories, then we cannot identify any model as capturing the important elements in firms' location decisions. In this case, either two or more factors are of equal importance, different firms in the same industry rely primarily on proximity to different things, or firms' location decisions are based on factors not represented in any of the three models discussed above.

A beneficial feature of the fixed effects approach in this context is that variables that are constant over time cannot be distinguished from the regional fixed effects parameter,  $\alpha_s$ . This makes it particularly easy to control for the characteristics of regions that affect land rents, since many of these attributes are time-invariant. For example, climate, proximity to water, and local cuisine are all attributes that may affect land rents, but since they are unlikely to change over time, they cannot be included in the regression. In addition, it is difficult to pin down all of the local amenities that may influence land prices. Thus, the fixed effects model attenuates any omitted variables bias generated by omitting relevant but time-invariant variables (Wooldridge (2001)). Finally, determinants of land rents that are specific to a particular metropolitan area will also be captured in the fixed effects for the counties within that metropolitan area.<sup>7</sup>

One of the most difficult issues involved in constructing the data set is choosing the geographic unit of analysis that most closely resembles the theoretical notion of a region. Transportation costs determine what constitutes a region in each of the models. In the pecuniary externalities model, it is costless to transport output within a region and costly to transport it between regions. In the production externality model, production externalities are costlessly transported within a region and infinitely costly to transport across regions. In the natural advantage model, inputs are costless to transport within a region and infinitely costly to transport between regions. Thus, the appropriate empirical concept of a region is one in which costs of transporting inputs, outputs, and externalities within the region are low relative to the costs of transporting them between regions. For my initial analysis, then, I use counties as the geographic unit of analysis because transportation costs within counties are lower than transportation costs between counties, and spillovers are more likely to benefit firms within the same county than firms in different counties (Henderson (1999)).

I construct a panel data set with observations for 1980 and 1990 for counties in the continental U.S.<sup>8</sup> I use median imputed house rent in a county as a proxy for residen-

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<sup>7</sup>Consider the subset of counties that make up a particular metropolitan area. The average of the fixed effects for those counties is the metropolitan area fixed effect, and the deviation between each county's fixed effect and the average is the county-specific effect.

<sup>8</sup>Counties in Virginia are excluded because data on counties and independent cities geographically within those counties are reported separately, which makes the observations inconsistent with data

tial land rent (*RENT*) and include several variables to control for the characteristics of a county's housing stock. The control variables include the percent of the housing stock that consists of one-unit detached housing (*1UNIT*), that was built in the past ten years (*NEW*), that is owner-occupied (*OWNOCC*), that has electricity (*ELEC*), and that has gas (*GAS*). I control for the local tax structure by including the effective local property tax rate (*PROPTAX*). I also control for local public goods provision by including the number of crimes per capita (*CRIME*) and per capita spending on education (*EDUC*). The variables *PROPTAX* and *EDUC* are reported for 1977 and 1987, rather than for 1980 and 1990. To measure productivity in an industry, I use an index of total factor productivity for each manufacturing industry. This data is reported by the Bureau of Labor Statistics (BLS), which does not report an index of productivity for the tobacco products or leather and leather products industries. Finally, each industry's share of manufacturing employment in each county is calculated from employment data reported in *County Business Patterns*. Table 2 lists manufacturing industries for which the productivity index is available and their SIC codes, and Table 3 shows descriptive statistics. A more detailed discussion of the data and data sources is in Appendix D.

For each of the eighteen industries listed in Table 2, I estimate equation (35) with the sample restricted to those counties in which the industry is operating. For each industry, a county is included in the sample if there is employment in that industry in either 1980 or 1990. Since there are a large number of counties in each sample, I estimate equation (35) in time demeaned form. The reported estimates of the coefficients  $\beta$ ,  $\delta$ , and  $\gamma$  are the within estimators, which are based on variation over time within the same county, rather than variation across different counties. Since the share of manufacturing employment in a specific industry in a county could be affected by the price of housing in that county, I instrument for *SHARE* in some specifications using its lagged value. Both ordinary least squares (OLS) and two-stage least squares (2SLS) standard errors are corrected for the increase in degrees of freedom from estimating equation (35) in time demeaned form.<sup>9</sup> For the OLS results, I correct for heteroscedasticity using the method of White (1980). For the 2SLS results, I correct for heteroscedasticity using the equivalent method suggested

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from other states. Counties in Delaware and Wyoming are dropped for lack of data.

<sup>9</sup>Estimating equation (35) in time demeaned form eliminates the county fixed effects parameters from the estimation equation. If  $N$  is the number of counties,  $T$  is the number of time periods, and  $K$  is the number of explanatory variables in equation (35) *not* including the county fixed effects, then estimates of the standard errors of the coefficients from the time demeaned regression are calculated using  $NT - K$  degrees of freedom. However, the model described by equation (35) has  $NT - N - K = N(T - 1) - K$  degrees of freedom. Since the two models are equivalent, I need to correct the standard errors of the coefficients reported by both OLS and 2SLS estimation of equation (35) in time demeaned form. As a result, the reported standard errors are equal to the heteroscedasticity consistent standard errors multiplied by a factor of  $((NT - K)/(N(T - 1) - K))^{\frac{1}{2}}$ .

by Wooldridge (2001, p. 100).

## 6 Which Model Best Describes Firms' Location Decisions?

The results are reported in Table 4. I report both OLS and 2SLS estimates, both with and without controls for local fiscal structure, so there are four sets of coefficients for each industry. To conserve space, only the coefficients on *PROD* and *SHARE* are reported. Coefficients on the other variables have the expected signs and are available upon request. Recall that the combination of coefficients on *PROD* and *SHARE* ( $\delta$  and  $\gamma$ ) indicates whether the pecuniary externality, natural advantage, localization externality, or urbanization externality model is most appropriate. An *F*-test that the coefficients on the local fiscal controls, *CRIME*, *EDUC*, and *PROPTAX*, are jointly equal to zero is rejected at the one percent level for all industries for both OLS and 2SLS specifications. For each industry, I test whether or not *SHARE* is endogenous using the method of Hausman (1978). In the specification excluding local fiscal controls, the null hypothesis that *SHARE* is exogenous is rejected at the ten percent level for the apparel industry. I accept the null hypothesis for all other industries. When local fiscal controls are included, the null hypothesis is rejected for the food industry at the ten percent level and for the apparel industry at the five percent level. The null hypothesis is accepted for the remaining industries.

For eleven of the eighteen industries, all specifications are consistent with the predictions of the same model. For the food and food products, printing and publishing, and stone, clay, and glass industries, the data are consistent with the predictions of the pecuniary externalities model. The data indicate that proximity to other firms is the most important factor for firms in the apparel industry. In particular, firms in the apparel industry benefit from urbanization externalities and so prefer to locate in diverse environments. Finally, the natural advantages model best captures the important elements of the location decisions of firms in the paper, chemicals, petroleum and coal products, primary metals, electronic and other electric equipment, transportation equipment, and instruments industries.

For four industries, three specifications are consistent with the same model. OLS estimates of the coefficients for the fabricated metal products and the industrial machinery and equipment industries are consistent with the predictions of the pecuniary externalities model, both with and without local fiscal controls, as are 2SLS estimates including local fiscal controls. 2SLS estimates of the coefficients without local fiscal controls are consistent with the predictions of the natural advantages model for the fabricated metal products industry and with none of the models for the industrial machinery and equipment industry. For firms in miscellaneous manufacturing indus-

tries, estimates of the coefficients in the OLS specification with local fiscal controls are consistent with the predictions of the pecuniary externalities model, while all other specifications indicate that the natural advantages model best explains firms' location decisions. Finally, the model of production externalities in which firms' benefit from urbanization externalities best captures the behavior of firms in the textile mill products industry according to OLS estimates with local fiscal controls and both sets of 2SLS estimates. OLS estimates of the coefficients without local fiscal controls are consistent with the predictions of the natural advantages model. For all four industries, though, specification tests indicate that evidence provided by OLS estimates of the coefficients with local fiscal controls is most compelling. So, I conclude that the pecuniary externality model best explains the location decisions of firms in the fabricated metal products, industrial machinery and equipment, and miscellaneous manufacturing industries, and the urbanization externality variety of the production externality model best explains the location decisions of firms in the textiles industry.

For the furniture and fixtures industry, OLS estimates of the coefficients are consistent with the predictions of the natural advantage model, while 2SLS estimates are consistent with the predictions of the production externalities model, with firms enjoying urbanization externalities. Since we cannot reject the null hypothesis that the variable *SHARE* is exogenous for this industry, the OLS estimates are more appropriate.

For two industries, controlling for the local fiscal structure of a county alters the model with which the data are consistent. The estimates of the coefficients for the lumber and wood products and rubber and plastics industries are consistent with the predictions of the production externalities model prior to controlling for local fiscal structure in both the OLS and 2SLS specifications. However, once local fiscal controls are included, both OLS and 2SLS results indicate that none of the models captures the relevant elements of location decisions for firms in these industries. Since specification tests favor including local fiscal controls, the most compelling evidence is that none of the models discussed in this paper adequately explains the location decisions of firms in these industries. Table 5 summarizes these conclusions.

The relationship between these results and those reported in earlier work is somewhat mixed. These results complement Kim's (1995) findings that trends in industry localization are consistent with models based on scale economies at the plant level and natural advantages of locations, where scale economies explain time trends and natural advantages explain cross-industry trends. Since internal scale economies at the plant level are a characteristic of models with pecuniary externalities, this result lends support both to pecuniary externality and natural advantage models. Kim (1995) also finds little evidence that the localization externality variety of production externalities explains trends in industry localization.

These results are at odds with those reported by Davis and Weinstein (1999), who

find that Japanese data for the textiles, paper and pulp, iron and steel, chemicals, transportation equipment, precision instruments, nonferrous metals, and electrical machinery industries is consistent with the predictions of the pecuniary externalities model. Recall that U.S. data for all of these industries is consistent with the natural advantages model.

Finally, these results also disagree with both Henderson's (1999) and Rosenthal and Strange's (2002) evidence that specific industries benefit from localization externalities, but not from urbanization externalities. My conjecture is that since Henderson (1999) finds evidence of localization externalities via spillovers across plants, rather than through labor markets, and for high-tech and machinery industries defined at the 3-digit level, rather than the 2-digit level, the different results may be due to different proxies for production externalities and different industry definitions. In addition, Rosenthal and Strange (2002) find that the benefits of localization externalities attenuate rapidly with geographic distance, so counties may be too big for localization externalities to reveal their influence on firms' location decisions. On the other hand, though, Orlando (2000) concludes that geographic distance does not diminish the benefits of knowledge spillovers between firms engaged in similar activities, but it does do so for firms engaged in different activities. Thus, if firms benefit from proximity to firms, it must be from proximity to different firms.

## 7 Conclusion

This paper is an attempt to gain insight into why different firms concentrate in different places. I show that the relationship between local industry employment shares, technical change, and residential land rents is different when firms in an industry are most interested in proximity to specialized inputs, proximity to their customers, or proximity to other firms that can generate beneficial spillovers. Testing these relationships for manufacturing firms in U.S. counties for 1980 and 1990 reveals the following: Pecuniary externality models, which emphasize proximity to customers, are useful in explaining the geographic distribution of the fabricated metals, food, industrial machinery and equipment, miscellaneous manufacturing, printing and publishing, and stone, clay, and glass industries. Natural advantage models, which emphasize proximity to inputs, are useful in explaining the geographic distribution of the chemicals, electronic and other electric equipment, furniture and fixtures, instruments, paper, petroleum and coal products, primary metals, and transportation equipment industries. Production externality models, which emphasize proximity to other firms, explain the behavior of firms in the apparel and textiles industries. Finally, none of the models seem to explain the lumber and wood products and rubber and plastics industries. This is important, as it motivates new models that might be consistent with the data

for these industries.

While the models I discuss generate important insights in to firms' location decisions, they omit many concerns that may be relevant, especially for the industries with which none of the models are clearly consistent. It is not clear how increasing participation in international trade, in both inputs and outputs, affects where firms operate. This could be important in explaining the behavior of firms in the lumber and rubber industries. Changing government policies, such as environmental regulations, tariffs, taxes, and subsidies, trade agreements, and labor standards, may also be important.

It would also be interesting to know how these results will relate to those generated by data at different levels of aggregation and for other sectors. While there is a trade-off between the level of geographic and industry detail that can be obtained, repeating this experiment, say, at the state level with industries defined by the SIC at the three digit level would generate interesting insights into the behavior of firms in more narrowly defined industries. In addition, a similar analysis of firms in the service sector or in retail and wholesale trade sector would be illuminating, especially in light of the finding by Nakamura (1985) that firms in the financial services industry benefit from production externalities. Finally, it would be informative to see if these results are robust to substituting for employment shares other sources of production externalities, such as numbers of plants. These extensions to the basic approach taken in this paper offer interesting ideas for further research.

## Appendix A: Results for the Pecuniary Externality Model

Throughout the appendices, I drop the “\*” superscript designating equilibrium values of endogenous variables for simplicity.

The following preliminary lemmas will be useful.

**Lemma 5** *In equilibrium,*

- i. For all  $s, j \in \mathcal{J}_s$ ,  $p(j) = \frac{\sigma\beta}{\sigma-1}w_s$ ,*
- ii. For all  $j \in \mathcal{J}$ ,  $q(j) = \frac{(\sigma-1)\alpha}{\beta}$ , and*
- iii. For all  $s$ ,  $J_s = \frac{\mu}{\alpha\sigma}N_s$ .*

*Proof* (i.) A manufacturing firm in region  $s$  solves the problem

$$\max_{p(j)} \pi_s.$$

It follows from the constant elasticity utility function and the iceberg transportation cost that a consumer’s price elasticity of demand is independent of either the firm’s or the consumer’s location (Krugman (1980)). Thus, the profit maximizing price is

$$p(j) = \frac{\sigma\beta}{\sigma-1}w_s. \quad (36)$$

(ii.) Firms enter the manufacturing sector until all firms earn zero profits. Substituting for  $p(j)$ , this implies

$$\left( \frac{\sigma\beta}{\sigma-1} \right) w_s q(j) - w_s (\alpha + \beta q(j)) = 0.$$

It follows that

$$q(j) = \frac{(\sigma-1)\alpha}{\beta}, \quad (37)$$

so all manufacturing firms produce the same quantity, regardless of where they operate.

(iii.) Since all firms produce the same level of output,  $\sum_{j \in \mathcal{J}_s} (\alpha + \beta q(j)) = J_s (\alpha + \beta q(j))$ . So, substituting for  $q(j)$  gives us that for all  $s$ ,  $J_s \alpha \sigma = N_s \mu$ . Rearranging,  $J_s = \frac{\mu}{\alpha\sigma} N_s$ . ■

Regardless of the type of manufactured good it is producing, all firms in the same region set the same price, so the only difference between manufactured goods that matters for our purposes is the region in which they are produced. I can eliminate the

argument denoting the type of manufactured good and replace it with an argument denoting the region in which the good is manufactured, so for all  $j \in \mathcal{J}_1$ ,

$$p(j) = p(1) = \frac{\sigma\beta}{\sigma-1}w_1,$$

and for all  $j \in \mathcal{J}_2$ ,

$$p(j) = p(2) = \frac{\sigma\beta}{\sigma-1}w_2.$$

**Lemma 6** *In equilibrium, (1) workers in region  $s$  have demands*

$$m_s^W(s) = \left(\frac{\sigma-1}{\sigma\beta}\right)^\sigma \frac{\mu w_s G_s^{\sigma-1}}{(w_s)^\sigma},$$

*for manufactured goods produced in region  $s$ , and*

$$m_s^W(s') = \left(\frac{\sigma-1}{\sigma\beta}\right)^\sigma \frac{\mu w_s G_s^{\sigma-1}}{(w_{s'}/\tau)^\sigma},$$

*for manufactured goods produced in region  $s'$ ,  $s' \neq s$ , where the price index for workers in region  $s$  is*

$$G_s = \left(\frac{\sigma\beta}{\sigma-1}\right) \left(\frac{\mu}{\alpha\sigma}\right)^{\frac{1}{1-\sigma}} [N_s(w_s)^{1-\sigma} + N_{s'}(w_{s'}/\tau)^{1-\sigma}]^{\frac{1}{1-\sigma}};$$

*(2) workers in region  $s$  have indirect utility function*

$$V^W(w_s, w_{s'}) = \mu^\mu (1-\mu)^{1-\mu} w_s r_s^{-(1-\mu)} G_s^{-\mu},$$

*where  $G_s$  is given in part (1); and (3) landlords in region  $s$  have demands*

$$m_s^L(s) = \left(\frac{\sigma-1}{\sigma\beta}\right)^\sigma \frac{\mu r_s G_s^{\sigma-1}}{(w_s)^\sigma},$$

*for manufactured goods produced in region  $s$ , and*

$$m_s^L(s') = \left(\frac{\sigma-1}{\sigma\beta}\right)^\sigma \frac{\mu r_s G_s^{\sigma-1}}{(w_{s'}/\tau)^\sigma},$$

*for manufactured goods produced in region  $s'$ ,  $s' \neq s$ , where the price index for landlords in region  $s$  is*

$$G_s = \left(\frac{\sigma\beta}{\sigma-1}\right) \left(\frac{\mu}{\alpha\sigma}\right)^{\frac{1}{1-\sigma}} [N_s(w_s)^{1-\sigma} + N_{s'}(w_{s'}/\tau)^{1-\sigma}]^{\frac{1}{1-\sigma}}.$$

*Proof* (1) We will prove the result for workers in region 1; proof of the result for workers in region 2 is similar. Let  $p_1(j)$  be the price a worker in region 1 pays for good  $j$ . The utility maximization problem of a worker in region 1 is

$$\max_{l_1^W, m_1^W} U(l_1^W, m_1^W) \text{ s. t. } r_1 l_1^W + \int_{\mathcal{J}} p_1(j) m_1^W(j) dj = w_s.$$

It follows that

$$\begin{aligned} l_1^W &= \frac{(1 - \mu)w_1}{r_1}, \\ m_1^W(j) &= \frac{\mu w_1 G_1^{\sigma-1}}{(p_1(j))^\sigma}, \end{aligned}$$

where

$$G_1 = \left[ \int_{\mathcal{J}} (p_1(j))^{1-\sigma} dj \right]^{\frac{1}{1-\sigma}}.$$

It follows from Lemma 5 and the iceberg transportation cost that consumers in region 1 will pay  $p_1(j) = \frac{\sigma\beta}{\sigma-1}w_1$  for manufactured goods produced in region 1, and they will pay  $p_2(j) = \frac{\sigma\beta}{\sigma-1}w_2/\tau$  for manufactured goods produced in region 2. Since all manufacturing firms produce the same quantity, since  $J_1$  manufactured goods are produced in region 1 and since  $J_2$  manufactured goods are produced in region 2, I can simplify the price index for consumers in region 1,

$$G_1 = [J_1(p_1(j))^{1-\sigma} + J_2(p_2(j)/\tau)^{1-\sigma}]^{\frac{1}{1-\sigma}}.$$

Substituting for  $J_1$ ,  $J_2$ ,  $p_1(j)$ , and  $p_2(j)$  from Lemma 1 and simplifying, we see that

$$G_1 = \left( \frac{\sigma\beta}{\sigma-1} \right) \left( \frac{\mu}{\alpha\sigma} \right)^{\frac{1}{1-\sigma}} [N_1(w_1)^{1-\sigma} + (N_2)(w_2\tau^{-1})^{1-\sigma}]^{\frac{1}{1-\sigma}}.$$

Finally, substitute  $p_1(j)$  and  $p_2(j)/\tau$  into the demands for goods produced in regions 1 and 2, respectively, and the result follows.

(2) The result follows from substituting for  $l_s^W$  and  $m^W(j)$  from part (1) into workers' utility function.

(3) The proof is identical to the proof of part (1). ■

*Proof (Lemma 1)* The results of Lemmas 5 and 6 and the requirement that  $N_2 = 1 - N_1$ , imply that all of the endogenous variables can all be expressed as functions of  $w_1$ ,  $w_2$ ,  $r_1$ ,  $r_2$ , and  $N_1$ . Substituting the results stated in Lemmas 5 and 6 into the

equations describing equilibrium, substituting  $1 - N_1$  for  $N_2$ , and simplifying, we are left with the following:

$$\frac{w_1}{(r_1)^{1-\mu}\hat{G}_1^\mu} - \frac{w_2}{(r_2)^{1-\mu}\hat{G}_2^\mu} = 0, \quad (38)$$

$$\frac{N_1 w_1}{r_1} - \frac{1}{2} = 0, \quad (39)$$

$$\frac{(1 - N_1)w_2}{r_2} - \frac{1}{2} = 0, \quad (40)$$

$$\frac{\frac{1-\mu}{2}r_1 + N_1 w_1}{(w_1)^\sigma \hat{G}_1^{1-\sigma}} + \frac{\frac{1-\mu}{2}r_2 + (1 - N_1)w_2}{\tau \left(\frac{w_1}{\tau}\right)^\sigma \hat{G}_2^{1-\sigma}} - 1 = 0, \quad (41)$$

$$\frac{\frac{1-\mu}{2}r_1 + N_1 w_1}{\tau \left(\frac{w_2}{\tau}\right)^\sigma \hat{G}_1^{1-\sigma}} + \frac{\frac{1-\mu}{2}r_2 + (1 - N_1)w_2}{(w_2)^\sigma \hat{G}_2^{1-\sigma}} - 1 = 0, \quad (42)$$

where

$$\begin{aligned} \hat{G}_1 &= [N_1(w_1)^{1-\sigma} + (1 - N_1)(w_2/\tau)^{1-\sigma}]^{\frac{1}{1-\sigma}}, \\ \hat{G}_2 &= [N_1(w_1/\tau)^{1-\sigma} + (1 - N_1)(w_2)^{1-\sigma}]^{\frac{1}{1-\sigma}}. \end{aligned}$$

Equation (38) follows from the requirement that consumers in both regions enjoy the same utility level. Equations (39) and (40) follow from simplifying material balance in residential land in each region. Equations (41) and (42) follow from simplifying material balance in manufactured goods produced in regions 1 and 2, respectively. It follows from Walras' Law that we can eliminate equation (42). Furthermore, if  $w_2$  is the numeraire, we can see that the left hand sides of equations (38), (39), (40), and (41) are equations  $f_1$ ,  $f_2$ ,  $f_3$ , and  $f_4$ , respectively.  $\blacksquare$

*Proof (Proposition 1)* Substituting the values  $\frac{1}{2}$ , 1, 1, and 1 for  $N_1$ ,  $w_1$ ,  $r_1$ , and  $r_2$ , respectively, in equations  $f_1 - f_4$  it is easy to see that for any  $(\alpha, \beta, \mu, \sigma, \tau) \in \Phi$ ,  $(\frac{1}{2}, 1, 1, 1) \in f^{-1}(0)$ . It follows from Lemmas 5 and 6 that we can solve for the remaining elements of an interior equilibrium once the equilibrium values of  $N_1$ ,  $w_1$ ,  $r_1$ , and  $r_2$  are determined.  $\blacksquare$

*Proof (Proposition 2)* Fix  $(\mu, \sigma, \alpha, \beta, \tau) \in \Phi$ . Let  $f = [f_1 \ f_2 \ f_3 \ f_4]^T$ , so  $f : \mathbf{R}^4 \rightarrow \mathbf{R}_+^4$ . Let

$$Q = \begin{bmatrix} \frac{\partial f_1}{\partial w_1} & \frac{\partial f_1}{\partial r_1} & \frac{\partial f_1}{\partial r_2} & \frac{\partial f_1}{\partial N_1} \\ \frac{\partial f_2}{\partial w_1} & \frac{\partial f_2}{\partial r_1} & \frac{\partial f_2}{\partial r_2} & \frac{\partial f_2}{\partial N_1} \\ \frac{\partial f_3}{\partial w_1} & \frac{\partial f_3}{\partial r_1} & \frac{\partial f_3}{\partial r_2} & \frac{\partial f_3}{\partial N_1} \\ \frac{\partial f_4}{\partial w_1} & \frac{\partial f_4}{\partial r_1} & \frac{\partial f_4}{\partial r_2} & \frac{\partial f_4}{\partial N_1} \end{bmatrix}.$$

If zero is a regular value of  $f = [f_1 \ f_2 \ f_3 \ f_4]^T$ , then  $\det(Q) \neq 0$ . It follows from the preimage theorem that the set of equilibria forms a manifold of dimension equal to the number of unknowns minus the number of equations. Given  $(\mu, \sigma, \alpha, \beta, \tau)$ ,  $f$  has four equations with four unknowns, so the equilibrium manifold has dimension zero. In addition, it is easy to see that at an interior equilibrium,  $f$  is  $\mathcal{C}^2$ . As a result, I can apply the implicit function theorem, which implies that

$$\begin{bmatrix} \frac{\partial w_1}{\partial \alpha} & \frac{\partial w_1}{\partial \beta} \\ \frac{\partial r_1}{\partial \alpha} & \frac{\partial r_1}{\partial \beta} \\ \frac{\partial r_2}{\partial \alpha} & \frac{\partial r_2}{\partial \beta} \\ \frac{\partial N_1}{\partial \alpha} & \frac{\partial N_1}{\partial \beta} \end{bmatrix} = -Q^{-1} \begin{bmatrix} \frac{\partial f_1}{\partial \alpha} & \frac{\partial f_1}{\partial \beta} \\ \frac{\partial f_2}{\partial \alpha} & \frac{\partial f_2}{\partial \beta} \\ \frac{\partial f_3}{\partial \alpha} & \frac{\partial f_3}{\partial \beta} \\ \frac{\partial f_4}{\partial \alpha} & \frac{\partial f_4}{\partial \beta} \end{bmatrix}.$$

Inspecting  $f_1, f_2, f_3$ , and  $f_4$ , we see that  $\frac{\partial f_1}{\partial \alpha} = \frac{\partial f_2}{\partial \alpha} = \frac{\partial f_3}{\partial \alpha} = \frac{\partial f_4}{\partial \alpha} = 0$  and  $\frac{\partial f_1}{\partial \beta} = \frac{\partial f_2}{\partial \beta} = \frac{\partial f_3}{\partial \beta} = \frac{\partial f_4}{\partial \beta} = 0$ . The results follow from the fact that technological progress is either a change in  $\alpha$ , a change in  $\beta$ , or both.  $\blacksquare$

## Appendix B: Results for the Production Externality Model

**Lemma 7** *In equilibrium,*

$$\begin{aligned} l_s &= \frac{(1-a-b)w_s}{r_s}, \\ x_s &= \frac{aw_s}{p_X}, \\ y_s &= \frac{bw_s}{p_Y}, \end{aligned}$$

for  $s = 1, 2$  and  $j = X, Y$ ,

$$\begin{aligned} w_s &= p_j \alpha \xi_j G_{js} \left( \frac{\Gamma_{js}}{\Lambda_{js}} \right)^{1-\alpha}, \\ \rho_s &= p_j (1-\alpha) \xi_j G_{js} \left( \frac{\Lambda_{js}}{\Gamma_{js}} \right)^{\alpha}, \end{aligned}$$

and  $y^L = (r_1 + r_2)\bar{L} + (\rho_1 + \rho_2)\bar{\Gamma}$ .

*Proof (Lemma 7)* A worker living in region  $s$  solves the maximization problem

$$\max_{x_s, y_s, l_s} x_s^a y_s^b l_s^{1-a-b} \quad \text{s. t.} \quad p_X x_s + p_Y y_s + r_s l_s = w_s.$$

and a firm producing good  $j$  in region  $s$  solves the following profit maximization problem:

$$\max \lambda_{js} p_j \xi_j G_{js} (\Lambda_{js})^\alpha (\Gamma_{js})^{1-\alpha} - w_s \Lambda_{js} - \rho_s \Gamma_{js}.$$

The lemma follows from the first order conditions of the worker's and the firm's maximization problems, respectively, and the assumption that the landlord consumes only good  $Y$ .  $\blacksquare$

*Proof (Proposition 3)* Without loss of generality, assume that all  $X$  producers locate in region 1 and all  $Y$  producers locate in region 2. Thus, the entire population of region 1 and all the raw materials in region 1 will be employed in the  $X$  industry, and similarly, the entire population of region 2 and all the raw materials in region 2 will be employed in the  $Y$  industry. Substituting the results of Lemma 7 into the definition of a perfectly localized/specialized interior equilibrium generates the following system of equations:

$$\frac{w_1}{r_1^{1-a-b}} = \frac{w_2}{r_2^{1-a-b}}, \quad (43)$$

$$\text{for } s = 1, 2, N_s \frac{(1-a-b)w_s}{r_s} = \bar{L}, \quad (44)$$

$$w_1 = p_X \alpha \xi_X G_{X1} \left( \frac{\bar{\Gamma}}{N_1} \right)^{1-\alpha}, \quad (45)$$

$$w_2 = p_Y \alpha \xi_Y G_{Y2} \left( \frac{\bar{\Gamma}}{N_2} \right)^{1-\alpha}, \quad (46)$$

$$\rho_1 = p_X (1-\alpha) \xi_X G_{X1} \left( \frac{N_1}{\bar{\Gamma}} \right)^\alpha, \quad (47)$$

$$\rho_2 = p_Y (1-\alpha) \xi_Y G_{Y2} \left( \frac{N_2}{\bar{\Gamma}} \right)^\alpha, \quad (48)$$

$$N_1 + N_2 = 1, \quad (49)$$

$$Q_X = \xi_X G_{X1} (N_1)^\alpha (\bar{\Gamma})^{1-\alpha}, \quad (50)$$

$$Q_Y = \xi_Y G_{Y2} (N_2)^\alpha (\bar{\Gamma})^{1-\alpha}, \quad (51)$$

$$N_1 \frac{aw_1}{p_X} + N_2 \frac{aw_2}{p_Y} = Q_X, \quad (52)$$

$$N_1 \frac{bw_1}{p_Y} + N_2 \frac{bw_2}{p_Y} + (r_1 + r_2) \bar{L} + (\rho_1 + \rho_2) \bar{\Gamma} = Q_Y. \quad (53)$$

Let  $p_X$  be the numeraire. Walras' Law implies that one of the equations is redundant, so we eliminate the last. We can write all of the endogenous variables as functions of

$N_1$ , the share of workers in region 1:

$$w_1 = \alpha \xi_X G_{X1} \left( \frac{\bar{\Gamma}}{N_1} \right)^{1-\alpha}, \quad (54)$$

$$w_2 = \left( \frac{1-N_1}{N_1} \right)^{\frac{c}{1-c}} \alpha \xi_X G_{X1} \left( \frac{\bar{\Gamma}}{N_1} \right)^{1-\alpha}, \quad (55)$$

$$r_1 = \frac{1-a-b}{\bar{L}} \alpha \xi_X G_{X1} N_1 \left( \frac{\bar{\Gamma}}{N_1} \right)^{1-\alpha}, \quad (56)$$

$$r_2 = \frac{1-a-b}{\bar{L}} \alpha \xi_X G_{X1} (1-N_1) \left( \frac{\bar{\Gamma}}{N_1} \right)^{1-\alpha} \left( \frac{1-N_1}{N_1} \right)^{\frac{1-a-b}{a+b}}, \quad (57)$$

$$p_Y = \left( \frac{1-N_1}{N_1} \right)^{\frac{1-a-b}{a+b}+1-\alpha} \left( \frac{\bar{\Gamma}}{N_1} \right)^{1-\alpha} \left( \frac{\xi_X G_{X1}}{\xi_Y G_{Y2}} \right), \quad (58)$$

$$\rho_1 = (1-\alpha) \xi_X G_{X1} \left( \frac{N_1}{\bar{\Gamma}} \right)^\alpha, \quad (59)$$

$$\rho_2 = \left( \frac{1-\alpha}{\alpha} \right) \left( \frac{1-N_1}{\bar{\Gamma}} \right) \left( \frac{1-N_1}{N_1} \right)^{\frac{1-a-b}{a+b}} \alpha \xi_X G_{X1} \left( \frac{\bar{\Gamma}}{N_1} \right)^{1-\alpha}. \quad (60)$$

Substituting into equation (52) and solving for  $N_1$ , we see that

$$N_1 = \frac{1}{1 + \left( \frac{1-a\alpha}{a\alpha} \right)^{a+b}}.$$

Note that since  $a, b, \alpha \in (0, 1)$  it must be that  $N_1 \in (0, 1)$ . ■

*Proof (Lemma 2)* Recall that a type two equilibrium is characterized by a positive measure of both  $X$  and  $Y$  producers operating in each region. Substituting the results of Lemma 5 into the definition of an interior diversified equilibrium generates the following system of equations:

$$\frac{w_1}{r_1^{1-a-b}} = \frac{w_2}{r_2^{1-a-b}}, \quad (61)$$

$$\text{for } s = 1, 2, N_s \frac{(1-a-b)w_s}{r_s} = \bar{L}, \quad (62)$$

$$\text{for } j = X, Y, w_1 = p_j \alpha \xi_j G_{j1} \left( \frac{\Gamma_{j1}}{\Lambda_{j1}} \right)^{1-\alpha}, \quad (63)$$

$$\text{for } j = X, Y, w_2 = p_j \alpha \xi_j G_{j2} \left( \frac{\Gamma_{j2}}{\Lambda_{j2}} \right)^{1-\alpha}, \quad (64)$$

$$\text{for } j = X, Y, \rho_1 = p_j(1 - \alpha)\xi_j G_{j1} \left( \frac{\Lambda_{j1}}{\Gamma_{j1}} \right)^\alpha, \quad (65)$$

$$\text{for } j = X, Y, \rho_2 = p_j(1 - \alpha)\xi_j G_{j2} \left( \frac{\Lambda_{j2}}{\Gamma_{j2}} \right)^\alpha, \quad (66)$$

$$\text{for } s = 1, 2, \Lambda_{Xs} + \Lambda_{Ys} = N_s, \quad (67)$$

$$N_1 + N_2 = 1, \quad (68)$$

$$\text{for } s = 1, 2, \Gamma_{Xs} + \Gamma_{Ys} = \bar{\Gamma}_s, \quad (69)$$

$$\text{for } s = 1, 2, j = X, Y, Q_{js} = \xi_j G_{js} (\Lambda_{js})^\alpha (\Gamma_{js})^{1-\alpha}, \quad (70)$$

$$N_1 \frac{aw_1}{p_X} + N_2 \frac{aw_2}{p_Y} = Q_{X1} + Q_{X2}, \quad (71)$$

$$N_1 \frac{bw_1}{p_Y} + N_2 \frac{bw_2}{p_Y} + (r_1 + r_2)\bar{L} + (\rho_1 + \rho_2)\bar{\Gamma} = Q_{Y1} + Q_{Y2}. \quad (72)$$

Let  $p_X$  be the numeraire. Walras' Law implies that one of the equations is redundant, so eliminate equation (72). We can solve for the following endogenous variables in terms of  $\Lambda_{js}$  and  $\Gamma_{js}$ :

$$N_s = \Lambda_{Xs} + \Lambda_{Ys} \text{ for } s = 1, 2,$$

$$Q_{js} = \xi_j G_{js} (\Lambda_{js})^\alpha (\Gamma_{js})^{1-\alpha} \text{ for } s = 1, 2, j = X, Y,$$

$$w_s = \alpha \xi_X G_{Xs} \left( \frac{\Gamma_{Xs}}{\Lambda_{Xs}} \right)^{1-\alpha} \text{ for } s = 1, 2,$$

$$\rho_s = (1 - \alpha) \xi_X G_{Xs} \left( \frac{\Lambda_{Xs}}{\Gamma_{Xs}} \right)^\alpha \text{ for } s = 1, 2,$$

$$r_s = \frac{1 - a - b}{\bar{L}} (\Lambda_{Xs} + \Lambda_{Ys}) \alpha \xi_X G_{Xs} \left( \frac{\Gamma_{Xs}}{\Lambda_{Xs}} \right)^{1-\alpha} \text{ for } s = 1, 2, \text{ and}$$

$$p_Y = \frac{\xi_X G_{X1}}{\xi_Y G_{Y1}} \left( \frac{\Gamma_{X1}/\Lambda_{X1}}{\Gamma_{Y1}/\Lambda_{Y1}} \right)^{1-\alpha}.$$

Substituting into the remaining equations ((61), (71), and, for  $j = Y$ , (64), (65) and (66)), we are left with

$$\frac{G_{X1} (\Gamma_{X1}/\Lambda_{X1})^{(1-\alpha)(a+b)}}{(\Lambda_{X1} + \Lambda_{Y1})^{1-a-b}} = \frac{G_{X2} (\Gamma_{X2}/\Lambda_{X2})^{(1-\alpha)(a+b)}}{(1 - \Lambda_{X1} - \Lambda_{Y1})^{1-a-b}}, \quad (73)$$

$$\frac{G_{X2}}{G_{X1}} \left( \frac{\Gamma_{X2}/\Lambda_{X2}}{\Gamma_{X1}/\Lambda_{X1}} \right)^{1-\alpha} = \frac{G_{Y2}}{G_{Y1}} \left( \frac{\Gamma_{Y2}/\Lambda_{Y2}}{\Gamma_{Y1}/\Lambda_{Y1}} \right)^{1-\alpha}, \quad (74)$$

$$G_{X1} \frac{\Lambda_{X1}}{\Gamma_{X1}} = G_{Y1} \frac{\Lambda_{Y1}}{\Gamma_{Y1}}, \quad (75)$$

$$G_{X2} \frac{\Lambda_{X2}}{\Gamma_{X2}} = G_{Y2} \frac{\Lambda_{Y2}}{\Gamma_{Y2}}, \text{ and} \quad (76)$$

$$a \sum_{s=1,2} G_{X_s}(\Lambda_{X_s} + \Lambda_{Y_s}) \left( \frac{\Gamma_{X_s}}{\Lambda_{X_s}} \right)^{1-\alpha} = \sum_{s=1,2} G_{X_s}(\Lambda_{X_s})^\alpha (\Gamma_{X_s})^{1-\alpha}. \quad (77)$$

We know that

$$\Gamma_{Y_1} = \bar{\Gamma} - \Gamma_{X_1}, \quad (78)$$

$$\Gamma_{Y_2} = \bar{\Gamma} - \Gamma_{X_2}, \text{ and} \quad (79)$$

$$\Lambda_{Y_2} = 1 - \Lambda_{X_1} - \Lambda_{Y_1} - \Lambda_{X_2}. \quad (80)$$

So, substituting equations (78) - (80) into equations (73) - (77), we have a system of five equations in five unknowns,  $\Lambda_{X_1}$ ,  $\Lambda_{Y_1}$ ,  $\Lambda_{X_2}$ ,  $\Gamma_{X_1}$ , and  $\Gamma_{X_2}$ , that are satisfied in equilibrium. So, let

$$\begin{aligned} g_1 &= \frac{G_{X_1} (\Gamma_{X_1}/\Lambda_{X_1})^{(1-\alpha)(a+b)}}{(\Lambda_{X_1} + \Lambda_{Y_1})^{1-a-b}} - \frac{G_{X_2} (\Gamma_{X_2}/\Lambda_{X_2})^{(1-\alpha)(a+b)}}{(1 - \Lambda_{X_1} - \Lambda_{Y_1})^{1-a-b}}, \\ g_2 &= \frac{G_{X_2}}{G_{X_1}} \left( \frac{\Gamma_{X_2}/\Lambda_{X_2}}{\Gamma_{X_1}/\Lambda_{X_1}} \right)^{1-\alpha} - \frac{G_{Y_2}}{G_{Y_1}} \left( \frac{(\bar{\Gamma} - \Gamma_{X_2})/(1 - \Lambda_{X_1} - \Lambda_{Y_1} - \Lambda_{X_2})}{(\bar{\Gamma} - \Gamma_{X_1})/\Lambda_{Y_1}} \right)^{1-\alpha}, \\ g_3 &= G_{X_1} \frac{\Lambda_{X_1}}{\Gamma_{X_1}} - G_{Y_1} \frac{\Lambda_{Y_1}}{\bar{\Gamma} - \Gamma_{X_1}}, \\ g_4 &= G_{X_2} \frac{\Lambda_{X_2}}{\Gamma_{X_2}} - G_{Y_2} \frac{(1 - \Lambda_{X_1} - \Lambda_{Y_1} - \Lambda_{X_2})}{\bar{\Gamma} - \Gamma_{X_2}}, \text{ and} \\ g_5 &= \sum_{s=1,2} a G_{X_s}(\Lambda_{X_s} + \Lambda_{Y_s}) \left( \frac{\Gamma_{X_s}}{\Lambda_{X_s}} \right)^{1-\alpha} - G_{X_s}(\Lambda_{X_s})^\alpha (\Gamma_{X_s})^{1-\alpha}, \end{aligned}$$

where

$$\begin{aligned} G_{X_1} &= G_X(\Lambda_{X_1}, \Lambda_{Y_1}), \\ G_{X_2} &= G_X(\Lambda_{X_2}, 1 - \Lambda_{X_1} - \Lambda_{Y_1} - \Lambda_{X_2}), \\ G_{Y_1} &= G_Y(\Lambda_{X_1}, \Lambda_{Y_1}), \text{ and} \\ G_{Y_2} &= G_Y(\Lambda_{X_2}, 1 - \Lambda_{X_1} - \Lambda_{Y_1} - \Lambda_{X_2}). \end{aligned}$$

The lemma follows. ■

*Proof (Proposition 4)* If zero is a regular value of  $g = [g_1 \ g_2 \ g_3 \ g_4 \ g_5]^T$ , then the implicit function theorem says that the equilibrium values of  $\Lambda_{X_1}$ ,  $\Lambda_{Y_1}$ ,  $\Lambda_{X_2}$ ,  $\Gamma_{X_1}$ , and  $\Gamma_{X_2}$  are locally  $\mathcal{C}^1$  functions of the parameters  $a$ ,  $b$ , and  $\alpha$ . Note that the parameters  $\xi_X$  and  $\xi_Y$  do not appear in  $g$ , so  $\Lambda_{X_1}$ ,  $\Lambda_{Y_1}$ ,  $\Lambda_{X_2}$ ,  $\Gamma_{X_1}$ , and  $\Gamma_{X_2}$  do not depend on either  $\xi_X$  or  $\xi_Y$ .

Since

$$\begin{aligned} r_1 &= \frac{1-a-b}{\bar{L}}(\Lambda_{X1} + \Lambda_{Y1})\alpha\xi_X G_{X1} \left( \frac{\Gamma_{X1}}{\Lambda_{X1}} \right)^{1-\alpha}, \\ r_2 &= \frac{1-a-b}{\bar{L}}(1 - \Lambda_{X1} - \Lambda_{Y1})\alpha\xi_X G_{X2} \left( \frac{\Gamma_{X2}}{\Lambda_{X2}} \right)^{1-\alpha}, \end{aligned}$$

$r_1$  and  $r_2$  are locally  $\mathcal{C}^1$  functions of the parameters  $a$ ,  $b$ ,  $\alpha$ , and  $\xi_X$ . Since  $\Lambda_{X1}$ ,  $\Lambda_{Y1}$ ,  $\Lambda_{X2}$ ,  $\Gamma_{X1}$ , and  $\Gamma_{X2}$  do not depend on  $\xi_X$ , the result follows from differentiating  $r_1$  and  $r_2$  with respect to  $\xi_X$ . ■

*Proof (Lemma 3)* The result follows immediately from equation (22) and Definition 1. ■

*Proof (Lemma 4)* To simplify notation, let  $\theta = \Lambda_{X1}/(\Lambda_{X1} + \Lambda_{Y1})$ . Then, the Herfindahl index of employment concentration in region 1 is  $H = \theta^2 + (1 - \theta)^2$ . It follows that

$$\frac{\partial H}{\partial \theta} = 2(\theta - 1).$$

Thus,  $\partial H/\partial \theta > 0$  for  $\theta > 1/2$  and  $\partial H/\partial \theta < 0$  for  $\theta < 1/2$ . It follows from equation (22) that

$$\frac{\partial r_1}{\partial \theta} = \frac{\partial r_1}{\partial G_X} \frac{\partial G_X}{\partial H} \frac{\partial H}{\partial \theta}.$$

Clearly, the first term is positive. It follows from Definition 2 that the second term is negative. Thus, we can see that if  $\theta < 1/2$  then  $\partial r_1/\partial \theta > 0$  and if  $\theta > 1/2$  then  $\partial r_1/\partial \theta < 0$ . ■

## Appendix C: Results for the Natural Advantages Model

*Proof (Proposition 5)* The landlord consumes  $y^L = (r_1 + r_2)\bar{L} + \rho_1\bar{\Gamma}_X + \rho_2\bar{\Gamma}_Y$ . A worker living in region  $s$  solves the maximization problem

$$\max_{x_s, y_s, l_s} x_s^a y_s^b l_s^{1-a-b} \quad \text{s. t.} \quad p_X x_s + p_Y y_s + r_s l_s = w_s.$$

It follows that

$$l_s = \frac{(1-a-b)w_s}{r_s}, \tag{81}$$

$$x_s = \frac{aw_s}{p_X}, \tag{82}$$

$$y_s = \frac{bw_s}{p_Y}. \tag{83}$$

In addition, for  $j = X, Y$ , profit maximization implies that  $(Q_j, \Lambda_j, \Gamma_j)$  solves the following maximization problem:

$$\max_{\Lambda_j, \Gamma_j} p_j \xi_j (\Lambda_j)^\alpha (\Gamma_j)^{1-\alpha} - w_s \Lambda_j - \rho_s \Gamma_j,$$

where  $s = 1$  if  $j = X$  and  $s = 2$  if  $j = Y$ . The first order conditions imply that

$$w_s = \xi_j p_j \alpha (\Gamma_j / \Lambda_j)^{1-\alpha}, \quad (84)$$

$$\rho_s = \xi_j p_j (1 - \alpha) (\Lambda_j / \Gamma_j)^\alpha. \quad (85)$$

Substituting the landlord's consumption of good  $Y$  and equations (81) - (85) into the definition of interior equilibrium generates the following system of equations:

$$\frac{w_1}{r_1^{1-a-b}} = \frac{w_2}{r_2^{1-a-b}}, \quad (86)$$

$$\text{for } s = 1, 2, N_s \frac{(1 - a - b)w_s}{r_s} = \bar{L}, \quad (87)$$

$$w_1 = \xi_X p_X \alpha \left( \frac{\Gamma_X}{\Lambda_X} \right)^{1-\alpha}, \quad (88)$$

$$w_2 = \xi_Y p_Y \alpha \left( \frac{\Gamma_Y}{\Lambda_Y} \right)^{1-\alpha}, \quad (89)$$

$$\rho_X = \xi_X p_X (1 - \alpha) \left( \frac{\Lambda_X}{\Gamma_X} \right)^\alpha, \quad (90)$$

$$\rho_Y = \xi_Y p_Y (1 - \alpha) \left( \frac{\Lambda_Y}{\Gamma_Y} \right)^\alpha, \quad (91)$$

$$N_1 + N_2 = 1, \quad (92)$$

$$\Lambda_X = N_1, \quad (93)$$

$$\Lambda_Y = N_2, \quad (94)$$

$$\text{for } j = X, Y, \Gamma_j = \bar{\Gamma}_j, \quad (95)$$

$$\text{for } j = X, Y, Q_j = \xi_j (\Lambda_j)^\alpha (\Gamma_j)^{1-\alpha}, \quad (96)$$

$$N_1 \frac{aw_1}{p_X} + N_2 \frac{aw_2}{p_X} = Q_X, \quad (97)$$

$$N_1 \frac{bw_1}{p_Y} + N_2 \frac{bw_2}{p_Y} + (r_1 + r_2) \bar{L} + \rho_1 \bar{\Gamma}_X + \rho_2 \bar{\Gamma}_Y = Q_Y. \quad (98)$$

Let  $p_X$  be the numeraire. Walras' Law implies that one of these equations is redundant, so we eliminate the last one. It is easy to see that  $\Gamma_X = \bar{\Gamma}_X$  and  $\Gamma_Y = \bar{\Gamma}_Y$ . We can express the remaining endogenous variables as functions of  $N_1$ , as follows:

$$N_2 = 1 - N_1, \quad (99)$$

$$\Lambda_X = N_1, \quad (100)$$

$$\Lambda_Y = 1 - N_1, \quad (101)$$

$$Q_X = \xi_X(N_1)^\alpha(\bar{\Gamma}_X)^{1-\alpha}, \quad (102)$$

$$Q_Y = \xi_Y(1 - N_1)^\alpha(\bar{\Gamma}_Y)^{1-\alpha}, \quad (103)$$

$$w_1 = \xi_X \alpha \left( \frac{\bar{\Gamma}_X}{N_1} \right)^{1-\alpha}, \quad (104)$$

$$\rho_X = \xi_X(1 - \alpha) \left( \frac{N_1}{\bar{\Gamma}_X} \right)^\alpha, \quad (105)$$

$$w_2 = \alpha \xi_X \left( \frac{\bar{\Gamma}_X}{N_1} \right)^{1-\alpha} \left( \frac{1 - N_1}{N_1} \right)^{\frac{1-a-b}{a+b}}, \quad (106)$$

$$p_Y = \frac{\xi_X}{\xi_Y} \left( \frac{\bar{\Gamma}_X}{\bar{\Gamma}_Y} \right)^{1-\alpha} \left( \frac{1 - N_1}{N_1} \right)^{\frac{(1-a-b)(1-\alpha)}{a+b}}, \quad (107)$$

$$\rho_Y = \xi_X(1 - \alpha) \left( \frac{\bar{\Gamma}_X}{N_1} \right)^{1-\alpha} \left( \frac{1 - N_1}{\bar{\Gamma}_Y} \right) \left( \frac{1 - N_1}{N_1} \right)^{\frac{1-a-b}{a+b}}, \quad (108)$$

$$r_1 = \frac{1 - a - b}{\bar{L}} \alpha \xi_X (\bar{\Gamma}_X)^{1-\alpha} (N_1)^\alpha, \text{ and} \quad (109)$$

$$r_2 = \frac{1 - a - b}{\bar{L}} (1 - N_1) \alpha \xi_X \left( \frac{\bar{\Gamma}_X}{N_1} \right)^{1-\alpha} \left( \frac{1 - N_1}{N_1} \right)^{\frac{1-a-b}{a+b}}. \quad (110)$$

Equation (106) follows from substituting for  $r_1$  and  $r_2$  in equation (86) and solving for  $w_2$ . Equation (107) then follows from substituting for  $w_2$  in equation (89) and then solving for  $p_Y$ . Finally, substituting for  $w_1$  and  $w_2$  in equation (97), we have

$$a \alpha \xi_X N_1 \left( \frac{\bar{\Gamma}_X}{N_1} \right)^{1-\alpha} + a \alpha \xi_X (1 - N_1) \left( \frac{\bar{\Gamma}_X}{N_1} \right)^{1-\alpha} \left( \frac{1 - N_1}{N_1} \right)^{\frac{1-a-b}{a+b}} = \xi_X (N_1)^\alpha (\bar{\Gamma}_X)^{1-\alpha}.$$

Simplifying, we get that

$$N_1 = \frac{1}{1 + \left( \frac{a\alpha}{1-a\alpha} \right)^{a+b}}.$$

Since  $\alpha \in (0, 1)$  and  $a \in (0, 1)$ , it must be that  $a\alpha \in (0, 1)$ . Thus,  $\frac{a\alpha}{1-a\alpha} > 0$ . It follows that  $N_1 \in (0, 1)$ . Furthermore, we can calculate the other endogenous variables, given  $N_1$ . ■

*Proof (Proposition 6)* The lemma follows directly from Proposition 4 and the fact that  $N_1$  does not depend on  $\xi_X$ . ■

## Appendix D: Data Sources

The variables *1UNIT*, *NEW*, *OWNOCC*, *GAS*, *ELEC*, and *CRIME* are reported in *County and City Data Book (CCDB)* data sets. Data for the 1980 edition of *CCDB* are available online from the Inter-University Consortium for Political and Social Research (ICPSR) at the University of Michigan. The URL for ICPSR is <http://www.icpsr.umich.edu/>. Data for the 1990 edition of *CCDB* are available online from the Geospatial and Statistical Data Center at the University of Virginia. The URL is <http://fisher.lib.virginia.edu/ccdb/>.

The variable *RENT* is calculated by multiplying median house price by the 0.0785 rent-to-value ratio determined by Peiser and Smith (1985). Median house price in a county is reported in *CCDB*.

The variable *EDUC* comes from *Census of Governments, 1977: Finance Summary Statistics* and *Census of Governments, 1987: Finance Summary Statistics*, which are both available online from ICPSR.

The variable *PROPTAX* is constructed from the assessment-sales price ratio, local property tax revenue, and the net assessed value of property after partial exemptions. The assessment-sales price ratio comes from U.S. Dept. of Commerce, Bureau of the Census (1978) and U.S. Dept. of Commerce, Bureau of the Census (1984). Local property tax revenue are reported in *Census of Governments, 1977: Finance Summary Statistics* and *Census of Governments, 1987: Finance Summary Statistics*. Net assessed value of property after partial exemptions are reported in U.S. Dept. of Commerce, Bureau of the Census (1978) and U.S. Dept. of Commerce, Bureau of the Census (1989). The effective local property tax rate in a county is calculated by multiplying the nominal property tax rate by the assessment-sales price ratio (ASPR) (Gyourko and Tracy (1989)). The nominal rate is calculated by dividing local property tax revenues by the net assessed value of property after exemptions. These data are reported for every county in our sample. The ASPR is reported for a different subset of counties in 1977 and 1982. Only 77 counties report ASPRs for both years, so I impute missing values as follows. For observations missing in 1977, a county is assigned the average reported ASPR for the state it is in. For observations missing in 1982, I divide the sample of counties for which the ASPR is reported in both years into states. For each state, I estimate the equation  $\ln(ASPR_{1990}) = \alpha \ln(ASPR_{1980}) + \epsilon$ . I exclude the constant term from the regression because for many states, there is only one county for which the ASPR is reported for both years. For each county for which the ASPR is not reported for 1982, I calculate it using the ASPR for that county in 1977 and the estimated state-specific coefficient. For two states, Delaware and Wyoming, no counties report ASPR for either year, so they are dropped from the sample. The effective local property tax rates for 1977 and 1987 are computed using the ASPRs for 1977 and 1982, respectively.

Productivity data for all industries for 1980 and 1990 is published online by the Bureau of Labor Statistics at <http://www.bls.org/>.

Data on county employment by industry for 1979, 1980, 1989, and 1990 is mid-March employment reported in *County Business Patterns*, which is available online from ICPSR. I estimate nondisclosed observations using the method described by Gardocki and Baj (1985). In addition, the 1987 SIC industry definitions differ slightly from those used prior to 1988, so employment data from the CBP in 1979 and 1980 is adjusted using the concordance available online from the National Bureau of Economic Research at <http://www.nber.org/nberces/nbprod96.htm>.

**TABLE 1**  
**Comparative Statics**

Effect on residential land rents of a change in	Industry productivity	Local industry employment share
Pecuniary externality model	0	0
Production externality model		
Localization	+	+
Urbanization	+	+ or -
Natural advantage model	+	0

**TABLE 2**  
**Manufacturing Industries**

SIC Code	Industry
SIC 20	Food and kindred products
SIC 22	Textile mill products
SIC 23	Apparel and other textile products
SIC 26	Paper and allied products
SIC 27	Printing and publishing
SIC 28	Chemicals and allied products
SIC 29	Petroleum and coal products
SIC 30	Rubber and miscellaneous plastics products
SIC 24	Lumber and wood products
SIC 25	Furniture and fixtures
SIC 32	Stone, clay, and glass products
SIC 33	Primary metal industries
SIC 34	Fabricated metal products
SIC 35	Industrial machinery and equipment
SIC 36	Electronic and other electric equipment
SIC 37	Transportation equipment
SIC 38	Instruments and related products
SIC 39	Miscellaneous manufacturing industries

**TABLE 3**  
**Descriptive Statistics**

Variable	Mean	Standard Deviation	Minimum	Maximum
<i>ln(RENT)</i>	8.00	0.39	6.82	10.23
<i>1UNIT</i>	74.18	9.69	5.50	94.20
<i>NEW</i>	23.89	10.52	2.20	78.50
<i>OWNOCC</i>	73.17	7.17	15.70	88.70
<i>GAS</i>	47.71	27.00	0.00	98.60
<i>ELEC</i>	20.73	14.52	0.00	93.50
<i>CRIME</i>	0.03	0.02	0.00	0.32
<i>EDUC</i>	0.39	0.25	0.00	2.77
<i>PROPTAX</i>	0.99	0.76	0.03	11.45
<i>PROD</i> <sub>20</sub>	99.80	1.20	98.60	101.00
<i>PROD</i> <sub>22</sub>	82.05	8.55	73.50	90.60
<i>PROD</i> <sub>23</sub>	93.65	2.55	91.10	96.20
<i>PROD</i> <sub>26</sub>	95.50	1.90	93.60	97.40
<i>PROD</i> <sub>27</sub>	111.70	4.50	107.20	116.20
<i>PROD</i> <sub>28</sub>	92.85	7.15	85.70	100.00
<i>PROD</i> <sub>29</sub>	98.15	0.45	97.70	98.60
<i>PROD</i> <sub>30</sub>	85.65	6.75	78.90	92.40
<i>PROD</i> <sub>24</sub>	99.90	11.90	88.00	111.80
<i>PROD</i> <sub>25</sub>	95.00	1.50	93.50	96.50
<i>PROD</i> <sub>32</sub>	88.75	7.55	81.20	96.30
<i>PROD</i> <sub>33</sub>	94.95	1.45	93.50	96.40
<i>PROD</i> <sub>34</sub>	93.30	2.60	90.70	95.90
<i>PROD</i> <sub>35</sub>	69.80	11.80	58.00	81.60
<i>PROD</i> <sub>36</sub>	61.25	9.95	51.30	71.20
<i>PROD</i> <sub>37</sub>	95.45	3.45	92.00	98.90
<i>PROD</i> <sub>38</sub>	91.50	7.20	84.30	98.70
<i>PROD</i> <sub>39</sub>	91.20	9.30	81.90	100.50

**TABLE 3**  
**Continued**

Variable	Mean	Standard Deviation	Minimum	Maximum
<i>SHARE</i> <sub>20</sub>	2.64	5.58	0.00	72.00
<i>SHARE</i> <sub>22</sub>	1.53	5.66	0.00	66.70
<i>SHARE</i> <sub>23</sub>	3.34	7.33	0.00	100.00
<i>SHARE</i> <sub>24</sub>	3.21	6.74	0.00	77.40
<i>SHARE</i> <sub>25</sub>	0.79	3.02	0.00	54.70
<i>SHARE</i> <sub>26</sub>	0.94	3.57	0.00	60.90
<i>SHARE</i> <sub>27</sub>	1.21	1.85	0.00	43.70
<i>SHARE</i> <sub>28</sub>	1.06	4.12	0.00	89.30
<i>SHARE</i> <sub>29</sub>	0.15	1.11	0.00	45.50
<i>SHARE</i> <sub>30</sub>	1.18	3.04	0.00	55.40
<i>SHARE</i> <sub>32</sub>	0.99	2.27	0.00	42.20
<i>SHARE</i> <sub>33</sub>	1.13	4.02	0.00	76.00
<i>SHARE</i> <sub>34</sub>	1.72	3.44	0.00	53.00
<i>SHARE</i> <sub>35</sub>	2.50	4.49	0.00	46.90
<i>SHARE</i> <sub>36</sub>	1.64	4.33	0.00	80.40
<i>SHARE</i> <sub>37</sub>	1.42	4.27	0.00	71.10
<i>SHARE</i> <sub>38</sub>	0.47	1.98	0.00	42.20
<i>SHARE</i> <sub>39</sub>	0.47	1.65	0.00	32.10
Sample size = 5842				

Median imputed rent =  $0.0785 \times$  median house value. All house characteristics are measured as the percent of the housing stock with that characteristic. Education expenditures are measured in thousands of 1982-84 dollars per capita. Effective local property tax rate = Local property tax revenue  $\times$  ASPR / Net assessed value of property after partial exemptions.

**TABLE 4**  
**Regression Results**

INDUSTRY		OLS		2SLS	
<b>Food and Kindred Products</b> n=4734	<i>PROD</i> <sub>20</sub>	0.0047 (0.0062)	0.0010 (0.0072)	0.0044 (0.0039)	0.0007 (0.0064)
	<i>SHARE</i> <sub>20</sub>	0.0002 (0.0008)	0.0000 (0.0008)	-0.0012 (0.0014)	-0.0013 (0.0015)
	Adj. <i>R</i> <sup>2</sup>	0.4036	0.4417	0.4035	0.4416
<b>Textile Mill Products</b> n=2096	<i>PROD</i> <sub>22</sub>	0.0116** (0.0011)	0.0094** (0.0015)	0.0116** (0.0009)	0.0093** (0.0015)
	<i>SHARE</i> <sub>22</sub>	-0.0019 (0.0011)	-0.0025** (0.0011)	-0.0025* (0.0012)	-0.0031** (0.0013)
	Adj. <i>R</i> <sup>2</sup>	0.3794	0.4414	0.3796	0.4416
<b>Apparel and Other Textile Products</b> n=4074	<i>PROD</i> <sub>23</sub>	0.0118** (0.0031)	0.0071* (0.0036)	0.0118** (0.0019)	0.0068** (0.0031)
	<i>SHARE</i> <sub>23</sub>	-0.0018** (0.0006)	-0.0018** (0.0006)	-0.0027** (0.0007)	-0.0028** (0.0007)
	Adj. <i>R</i> <sup>2</sup>	0.3389	0.3838	0.3392	0.3841
<b>Lumber and Wood Products</b> n=4890	<i>PROD</i> <sub>24</sub>	0.0013** (0.0006)	0.0005 (0.0007)	0.0013** (0.0004)	0.0005 (0.0006)
	<i>SHARE</i> <sub>24</sub>	-0.0030** (0.0009)	-0.0030** (0.0009)	-0.0033** (0.0010)	-0.0033** (0.0010)
	Adj. <i>R</i> <sup>2</sup>	0.3706	0.4081	0.3703	0.4078
<b>Furniture and Fixtures</b> n=3196	<i>PROD</i> <sub>25</sub>	0.0342** (0.0058)	0.0239** (0.0070)	0.0342** (0.0039)	0.0241** (0.0065)
	<i>SHARE</i> <sub>25</sub>	-0.0019 (0.0014)	-0.0018 (0.0014)	-0.0029** (0.0014)	-0.0025* (0.0013)
	Adj. <i>R</i> <sup>2</sup>	0.3500	0.4016	0.3501	0.4016
Local fiscal controls?		No	Yes	No	Yes

**TABLE 4**  
Continued

INDUSTRY		OLS		2SLS	
<b>Paper and Allied Products</b> n=2388	<i>PROD</i> <sub>26</sub>	0.0337** (0.0051)	0.0203** (0.0068)	0.0338** (0.0042)	0.0203** (0.0066)
	<i>SHARE</i> <sub>26</sub>	-0.0024 (0.0014)	-0.0026 (0.0015)	-0.0020 (0.0014)	-0.0022 (0.0014)
	Adj. <i>R</i> <sup>2</sup>	0.3798	0.4348	0.3795	0.4345
<b>Printing and Publishing</b> n=5550	<i>PROD</i> <sub>27</sub>	0.0004 (0.0015)	0.0013 (0.0018)	0.0004 (0.0009)	0.0013 (0.0015)
	<i>SHARE</i> <sub>27</sub>	-0.0028 (0.0017)	-0.0027 (0.0017)	-0.0037 (0.0033)	-0.0038 (0.0033)
	Adj. <i>R</i> <sup>2</sup>	0.3948	0.4301	0.3948	0.43
<b>Chemicals and Allied Products</b> n=3398	<i>PROD</i> <sub>28</sub>	0.0043** (0.0012)	0.0031** (0.0015)	0.0043** (0.0008)	0.0031** (0.0014)
	<i>SHARE</i> <sub>28</sub>	-0.0015 (0.0010)	-0.0013 (0.0010)	-0.0019 (0.0012)	-0.0016 (0.0011)
	Adj. <i>R</i> <sup>2</sup>	0.3574	0.4069	0.3575	0.407
<b>Petroleum and Coal Products</b> n=1862	<i>PROD</i> <sub>29</sub>	0.1819** (0.0232)	0.1613** (0.0321)	0.1812** (0.0187)	0.1614** (0.0309)
	<i>SHARE</i> <sub>29</sub>	0.0051 (0.0032)	0.0038 (0.0034)	0.0032 (0.0038)	0.0012 (0.0042)
	Adj. <i>R</i> <sup>2</sup>	0.3578	0.4275	0.3569	0.4268
<b>Rubber and Misc. Plastics Products</b> n=3750	<i>PROD</i> <sub>30</sub>	0.0044** (0.0012)	0.0023 (0.0015)	0.0044** (0.0008)	0.0023 (0.0013)
	<i>SHARE</i> <sub>30</sub>	-0.0035** (0.0013)	-0.0034** (0.0012)	-0.0027** (0.0014)	-0.0026** (0.0013)
	Adj. <i>R</i> <sup>2</sup>	0.3784	0.4216	0.3775	0.4209
Local fiscal controls?		No	Yes	No	Yes

**TABLE 4**  
Continued

INDUSTRY		OLS		2SLS	
<b>Stone, Clay, and Glass Products</b> n=4956	<i>PROD</i> <sub>32</sub>	0.0007 (0.0010)	-0.0004 (0.0012)	0.0006 (0.0006)	-0.0004 (0.0010)
	<i>SHARE</i> <sub>32</sub>	0.0038 (0.0022)	0.0039 (0.0022)	0.0016 (0.0019)	0.0019 (0.0020)
	Adj. <i>R</i> <sup>2</sup>	0.3894	0.4220	0.3887	0.4214
<b>Primary Metals Industries</b> n=2704	<i>PROD</i> <sub>33</sub>	0.0361** (0.0067)	0.0185** (0.0082)	0.0003** (0.0008)	-0.0001** (0.0009)
	<i>SHARE</i> <sub>33</sub>	0.0008 (0.0012)	0.0005 (0.0012)	0.0003 (0.0008)	-0.0001 (0.0009)
	Adj. <i>R</i> <sup>2</sup>	0.3540	0.4100	0.3538	0.4099
<b>Fabricated Metal Products</b> n=4350	<i>PROD</i> <sub>34</sub>	0.0045 (0.0030)	0.0033 (0.0036)	-0.0009** (0.0010)	-0.0013 (0.0011)
	<i>SHARE</i> <sub>34</sub>	-0.0008 (0.0010)	-0.0012 (0.0010)	-0.0009 (0.0010)	-0.0013 (0.0011)
	Adj. <i>R</i> <sup>2</sup>	0.3821	0.4190	0.3821	0.419
<b>Industrial Machinery and Equipment</b> n=4968	<i>PROD</i> <sub>35</sub>	0.0005 (0.0006)	0.0006 (0.0007)	0.0021 (0.0010)	0.0015 (0.0010)
	<i>SHARE</i> <sub>35</sub>	0.0016 (0.0009)	0.0012 (0.0010)	0.0021** (0.0010)	0.0015 (0.0010)
	Adj. <i>R</i> <sup>2</sup>	0.4122	0.4475	0.4123	0.4475
<b>Electronic and Other Electric Equipment</b> n=3268	<i>PROD</i> <sub>36</sub>	0.0039** (0.0009)	0.0033** (0.0010)	-0.0016** (0.0011)	-0.0016** (0.0011)
	<i>SHARE</i> <sub>36</sub>	-0.0015 (0.0009)	-0.0014 (0.0009)	-0.0016 (0.0011)	-0.0016 (0.0011)
	Adj. <i>R</i> <sup>2</sup>	0.3630	0.4081	0.3627	0.408
Local fiscal controls?		No	Yes	No	Yes

**TABLE 4**  
Continued

INDUSTRY		OLS		2SLS	
<b>Transportation Equipment</b> n=3470	<i>PROD</i> <sub>37</sub>	0.0093** (0.0026)	0.0068** (0.0030)	0.0003** (0.0008)	0.0002** (0.0009)
	<i>SHARE</i> <sub>37</sub>	-0.0003 (0.0008)	-0.0003 (0.0008)	0.0003 (0.0008)	0.0002 (0.0009)
	Adj. <i>R</i> <sup>2</sup>	0.3640	0.4077	0.3639	0.4076
<b>Instruments and Related Products</b> n=2386	<i>PROD</i> <sub>38</sub>	0.0093** (0.0013)	0.0066** (0.0017)	0.0024** (0.0017)	0.0027** (0.0017)
	<i>SHARE</i> <sub>38</sub>	0.0004 (0.0016)	0.0005 (0.0015)	0.0024 (0.0017)	0.0027 (0.0017)
	Adj. <i>R</i> <sup>2</sup>	0.3557	0.4174	0.3558	0.4172
<b>Misc. Manufacturing Industries</b> n=3632	<i>PROD</i> <sub>39</sub>	0.0037** (0.0009)	0.0022 (0.0012)	-0.0021** (0.0020)	-0.0023** (0.0021)
	<i>SHARE</i> <sub>39</sub>	-0.0022 (0.0017)	-0.0021 (0.0016)	-0.0021 (0.0020)	-0.0023 (0.0021)
	Adj. <i>R</i> <sup>2</sup>	0.3742	0.4179	0.3742	0.4179
Local fiscal controls?		No	Yes	No	Yes

Dependent variable is  $\ln(RENT)$ . Standard errors are in parentheses. \* Significant at the 5 percent level. \*\* Significant at the 1 percent level.

**TABLE 5**  
**Summary of Results**

Model	Industries
Pecuniary externalities	Food and kindred products, printing and publishing, stone, clay, and glass, fabricated metals, industrial machinery and equipment, and miscellaneous manufacturing
Production externalities	
Localization	none
Urbanization	Textile mill products and apparel and other textile products
Natural advantages	Paper and allied products, chemicals and allied products, petroleum and coal products, primary metals, electronic and other electric equipment, transportation equipment, instruments and related products and furniture and fixtures
Other	Lumber and wood products and rubber and miscellaneous plastics products

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