Country size, technology and manufacturing location*

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February 1, 2009

Abstract

Country size, technology and trade costs jointly affect the location of manufacturing activity. In this paper, the combined effects of country size and technology differences on manufacturing location are examined in a simple New Economic Geography model. The specification yields a closed-form, analytic relationship between measures of relative productivity, country size and trade costs. The patterns of agglomeration are consistent with recent empirical evidence. Market and supplier access favor manufacturing agglomeration in large countries for high to intermediate trade costs. High productivity countries, however small, are favored for low trade costs. The model’s tractability facilitates policy and welfare analysis.

*Acknowledgements: I am thankful to Nuno Limao, Tim Moore, Gianmarco Ottaviano, John Rust and workshop participants at Maryland for comments and suggestions on earlier drafts.
1 Introduction

The new economic geography (NEG) has contributed to our understanding of firm location choices by explicitly modeling trade costs in general equilibrium. While NEG models have recently begun to explicitly account for country size and technology differences, the agglomeration effects of either size or technology are usually considered in isolation. Yet size and technology jointly interact as trade costs change. The outcome of this process is not immediately evident. Where firms locate, what they produce, and the employment patterns and wages that result are interdependent. In this paper, both size and technology differences are incorporated into a simple NEG model. The structure is highly stylized, but approximates empirical trade and firm location patterns quite well.

The role of distance and geography on trade flows remains unsettled. A recent review by Head and Disdier (2008), summarizing estimates from over 100 papers, finds that on average a 10% increase in distance results in a 9% reduction in bilateral trade volumes. A survey by Harrigan (2003) reviews the empirical role of distance in fitting standard and new trade theory to the data. Despite the empirical support, Harrigan notes that theoretically-grounded motivations for the role of distance remain difficult to disentangle from comparative advantage and factor abundance.

Recent empirical investigations reveal specific relationships between technology, country size and trade costs. Eaton and Kortum (2002) carefully estimate a general equilibrium model of trade and geography for OECD countries. This permits extensive counter-factual analysis. They find that as geographic barriers fall the share of manufacturing employment rises in larger, less productive countries. Further declines in geographic barriers reverse the pattern, favoring technological efficiency and manufacturing specialization in small countries. The welfare gains from technological improvements in the home country extend to trading partners. These gains decline with distance. Several results in Amiti and Javorcik (2008) indicate that interactions between market size, production costs and distance are important. They estimate a NEG model for the entry of foreign firms into Chinese provinces. In their model, firms require supplier access to sector-specific intermediate inputs and market access to customers. Measures of market and supplier access both within and outside provinces have a positive and significant effect on firm entry. These access effects are much lower outside the province. The authors suggest this is because poor transport infrastructure be-
tween provinces cause distance frictions to impede trade quickly. Variable production costs have a weaker but significant effect on location. A one standard deviation increase in wages decreases firm entry by 2%, while a one standard deviation increase in electricity costs decreases entry by 4%. Redding and Venables (2004) use an NEG structural model for cross-country analysis and find evidence that market and supplier access effects decline with distance. The effect of country-specific differences in wage costs are accounted for by fixed effects and not identified.

A central modeling challenge is to merge these elements together while maintaining some tractability. I extend the simple NEG model of Ottaviano (2002) to examine the relationship between country size, productivity and trade costs. Agglomeration is driven by input-output linkages between firms. The spatial allocation of manufacturing adjusts endogenously to maximize profits. The main qualitative contribution is the realistic emergence and structure of core-periphery style agglomeration. Market and supplier access effects dominate for high to intermediate trade costs. This favors agglomeration in large countries. Further trade cost reductions can reverse this pattern when the large country is less technologically efficient than a smaller neighbor. Even for relatively small countries, Ricardian efficiency in variable production costs dominates when trade costs are low. One consequence is that early industrializers in a nearly free trade world will gain a strong advantage. Once a manufacturing core has formed, the peripheral regions must do more than play technological catch-up and copycat to overcome the agglomeration rents. The results are broadly applicable to the entire class of NEG models with input-output linkages (such as Ottaviano and Robert-Nicoud, 2005). I derive a closed-form, analytical relationship for the interaction of technology with size and trade costs that can be used to determine the equilibria and critical points of the model. The main results hold even when factor price equalization is relaxed. In addition, I use the key equations of the model to demonstrate a simple method for analyzing changes to exogenous size and technology parameters. The evolution of industrial location can be inferred without extensive numerical simulation.

A recent set of theoretical extensions are closely related to this paper. A variety of NEG specifications show that industrial production can agglomerate against Ricardian comparative advantage. Venables (1999) embeds an NEG framework into a rather complex multi-sector Ricardian model with a continuum of goods. He finds differentiated goods industries can agglomerate against com-
parative advantage. Ricci (1999) analyzes comparative advantage in a model with labor migration and employs a non-full specialization condition to impose factor price equalization. He identifies the trade-off between size and comparative advantage as trade costs fall. Forslid and Wooton (2003) use heterogeneous fixed costs of developing new varieties that increase with the number of firms in each country. Each country has a fixed cost comparative advantage over a range of product varieties, and agglomeration occurs through labor migration. The fixed cost structure becomes a type of congestion externality that dominates market access advantages as trade costs fall. As a result, falling trade costs lead initially to manufacturing agglomeration and then to a dispersed production equilibrium. Forslid and Wooton conjecture in a footnote that qualitative results should be similar for variable cost differences, but I show this is not the case.

Country size has been analyzed in two-factor Hecksher-Ohlin models and in terms of relative labor endowments. Amiti (2005) and Epifani (2005) consider aspects of well-specified two factor models within a NEG framework. They show that agglomeration patterns can defy the predictions of factor abundance and lead to non-monotonic Stolper-Samuelson effects. New trade theory has also addressed country size in two factor models (Amiti, 1998) and one factor labor models (Laussel and Paul, 2007) while holding technology symmetric. This approach necessarily requires small countries to pay lower wages to attract manufacturing and ignores productivity differentials. Yet improving productivity is an especially relevant channel for regions that are unlikely to overcome pure size disadvantages through population growth or rapid capital investment. NEG models, such as the one developed below, frequently consider only relative labor endowments as a measure of country size. Size differences are evaluated using comparative statics by testing small deviations from symmetry (e.g. Forslid and Ottaviano, 2003). This partial equilibrium approach can miss more complex outcomes for large size and technology differences.

The rest of this paper is organized as follows. In section 2, I incorporate size and technological asymmetry into an NEG framework. Section 3 analyzes the features of long run equilibria using some convenient simplifying assumptions to preserve factor price equalization. This is a potentially limiting special case. In section 4, I relax factor price equalization and show that the qualitative results are the same. Some of the analytical results from section 3 continue to hold under this generalization. Section 5 explores policy and welfare implications and Section 6 concludes.
2 The Model

2.1 Endowments

There are two regions denoted Home and Foreign. Two goods are produced in a homogenous Agriculture (A) sector and differentiated Manufacturing (M) sector. Labor is the only primary factor of production. Labor is mobile within each country and between the Agriculture and Manufacturing sectors. Using $s_L$ to denote labor shares, the size of the labor endowment in Home is $s_L L^w$, the size of Foreign is $(1 - s_L)L^w$ and $\lambda = (1 - s_L)/s_L$ is the ratio of endowments. Foreign variables and parameters carry the superscript $\ast$ and world aggregates are denoted by superscript $w$.

Geography enters via iceberg transportation costs in the Manufacturing sector. Locally consumed goods have zero transport costs. A fraction of a shipped good melts away in transit. For one unit of a good to arrive at its destination $\tau \in [1, \infty)$ units of the good must be shipped. These costs are passed to consumers through higher prices.

2.2 Preferences

Consumers have Cobb-Douglas preferences for the A- and M-sectors with a Dixit-Stiglitz (1977) CES sub-utility for M-sector varieties:

$$U = C_A^{1-\mu} C_M^{\mu}, \quad C_M = \left( \int_i^{n+n^*} c_i^{\frac{\sigma-1}{\sigma}} di \right)^{\frac{\sigma}{\sigma-1}},$$

(1)

A price index for industrial varieties is defined in the usual way:

$$\mathbb{P} = (n^w \Delta)^{\frac{1}{1-\sigma}}, \quad \mathbb{P}^* = (n^w \Delta^*)^{\frac{1}{1-\sigma}}$$

(2)

$$n^w \Delta = \int_i^{n+n^*} p_i^{1-\sigma} di, \quad n^w \Delta^* = \int_i^{n+n^*} p_i^{1-\sigma} di,$$

where $p_i$ is the final destination price paid on imported and domestic goods and $n^w = n + n^*$ measures the aggregate mass of firms. The price index measures the cost of the entire basket of differentiated goods.

Varieties produced in the M-sector are indexed by $i$. Elasticity of substitution is restricted to
\( \sigma > 1 \). The indirect utility function for a representative consumer with aggregate income \( Y \) is:

\[
V = \frac{Y}{[p_A^{1-\mu}P^\mu]}
\]  

(3)

Market demand for variety \( i \) is obtained by applying Roy’s identity to (3):

\[
c_i = \frac{p_i^{1-\sigma}\mu Y}{n^\mu \Delta}.
\]  

(4)

The expression for Foreign demand is isomorphic.

The Dixit-Stiglitz CES sub-utility imparts a ‘love of variety’ to preferences. Utility is increasing in the number of goods available. So (4) implies that total consumption of good \( i \) is a function of its own price and total expenditure weighted by the price index of all other M-sector goods entering through the denominator \( n^\mu \Delta \).

2.3 Production and Market Structure

2.3.1 Agricultural Sector

The A-sector employs only labor and is characterized by perfect competition, constant returns to scale technology and zero transport costs.\(^1\) Variable costs are such that it requires one unit of labor to produce one unit of the Agricultural good in both countries. Marginal cost pricing will equate prices and wages, \( p_A = p_A^* = w_A = w_A^* = 1 \). The A-sector good is chosen as the numeraire with the price set to unity.

2.3.2 Manufacturing Sector

The M-sector is characterized by monopolistic competition and increasing returns. Firms produce using Labor and an intermediate input that is a composite of all M-sector goods. The intermediate input creates cost-linkages between manufacturing firms that are an agglomeration mechanism.

The production technology for Home is represented by the total cost function:

\[
C(x_i) = a_M q x_i w_M + F w_M^{1-\mu} P^\mu, \tag{5}
\]

\(^1\)Fujita et al. (1999) show that qualitative results are not affected by the zero transport cost assumption. Davis and Weinstein (1997?) provide evidence it is not satisfied in practice.
where $\mathbb{P}_P$ is the producer price index for the M-sector composite. Marginal costs are incurred in terms of labor where $a_M$ is the Home unit labor requirement and $q$ is a scaling parameter that is constant across countries. Firms also pay a fixed cost, $F$, that is Cobb-Douglas with expenditure shares of $(1 - \mu)$ for Labor and $\mu$ for an intermediate composite good of all M-sector varieties. The producer price index, $\mathbb{P}_P$, is identical to the consumer price index because the expenditure shares are equal.

Firm demand for each industrial variety is derived by applying Shepard’s lemma to (5):

\[
d_i = \frac{p_i^{-\sigma} \mu F w_M^{1-\mu} \mathbb{P}_P^{\mu}}{n^w \Delta}.
\]

Because the intermediate good appears only as a component of fixed costs, demand is invariant to firm scale. $F$ is normalized to unity so that each firm requires one unit of the composite good. Total firm profits are given by:

\[
\Pi = \pi - w_M^{1-\mu} \mathbb{P}_P^\mu
\]

where operating profits are $\pi_i = p_i x_i - a_M q w_M x_i$.

Each firm maximizes monopoly profits in its own differentiated variety. The first order conditions for profit maximization imply a markup rule of $p_i (1 - 1/\sigma) = a_M q w_M$. Following the markup rule, operating profits of each firm become $\pi_i = p_i x_i / \sigma$. The numerator is the value of total sales for each variety where $x_i = c_i + n_i d_i + \tau(c_i^* + n_i^* d_i^*)$. A higher elasticity of substitution (higher $\sigma$), lowers profits.

### 2.3.3 Labor Markets

From the cost function, total labor demand in the manufacturing sector for Home and Foreign is

\[
L_M = \left( \frac{\mathbb{P}}{w_M} \right) F(\sigma - \mu) n
\]

\[
L^*_M = \left( \frac{\mathbb{P}^*}{w_M^*} \right) F(\sigma - \mu) n^*.
\]

Labor is supplied inelastically to the sector with the highest wages. Manufacturing wages adjust to clear the labor market. If neither country is fully specialized and both sectors are in operation, factor price equalization implies wages are unity. In this case, labor employed in the manufacturing
sector is just a function of parameters and other endogenous variables. Labor market clearing can be ignored when solving for the equilibrium. If a country becomes fully specialized, then wages and labor allocations in (8) and (9) become endogenous and part of the equilibrium conditions of the model.

2.4 Relative Productivity

Labor productivity, the inverse of \( a_M \), is non-mobile and country specific. One interpretation of this specification is to define the firm as mobile with implicit, identical managerial or firm specific technology across countries. Remaining productivity differences measured by \( a_M \) and \( a^*_M \) are outside the firm’s control. Given that foreign direct investment often skips over the lowest wage and least skilled regions of the world, restricting some element of production technology to be country specific seems reasonable. A second interpretation sidesteps a global definition of the firm. Manufacturing firms are defined by the cost function (5) alone and not internationally mobile. Firms enter in response to profit opportunities and exit in response to losses within each country. Changes in industrial structure are accomplished by allocating labor between agriculture and manufacturing. These within country labor reallocations change the world manufacturing share across countries.

I construct a measure of relative unit labor requirements in Home and Foreign. With A-sector unit labor costs normalized to unity, differences in the variable costs of production (\( a_M \) and \( a^*_M \)) are the sole parameters of interest. Using notation in Baldwin et al. (2003), relative productivity is indexed by \( \chi \)

\[
\chi = \left( \frac{a_M}{a^*_M} \right)^{1-\sigma}. \tag{10}
\]

I choose units of \( a^*_M = 1 \) and \( q = (1 - 1/\sigma) \) to set foreign prices equal to wages. Then Home unit labor requirement in terms of \( \chi \) are \( a_M = \chi^{1/\sigma} \). A strictly Ricardian comparison of unit labor requirements maps directly to the index \( \chi \). Whenever Home has a manufacturing productivity advantage defined as \( a_M/a_A = a_M < a^*_M/a^*_A \), then \( \chi > 1 \). Larger productivity differences correspond to larger values of \( \chi \).

Using (10) and the normalization for foreign unit costs in the markup rule of firms gives the
following expressions for domestic and import prices:

\[ p_{hh} = \chi^{1/\sigma}w_M, \quad p_{hf} = \tau p_{hh}, \quad p_{ff} = w^*_M, \quad p_{fh} = \tau w^*_M. \]  

(11)

The first price subscript denotes the country of origin; the second denotes where the good is consumed. Note that export prices are simply domestic prices scaled by \( \tau \). At the individual variety level, Home’s local and export prices are decreasing in relative productivity. The ratio of Home export prices to local Foreign prices is \( \tau \chi^{1/(1-\sigma)}w_M/w^*_M \). Thus Home’s competitiveness depends multiplicatively on transport costs, relative productivity and relative wages. Substituting these price expressions into the price indices reduces the denominators in equation (2) to the following compact formulas:

\[ \Delta = \frac{np_{hh}^{1-\sigma} + n^*p_{fh}^{1-\sigma}}{nw} = w_M^{1-\sigma} \chi s_n + (w_M^*)^{1-\sigma} \phi (1-s_n) \]

(12)

\[ \Delta^* = \frac{np_{hf}^{1-\sigma} + n^*p_{ff}^{1-\sigma}}{nw} = w_M^{1-\sigma} \chi s_n + (w_M^*)^{1-\sigma} (1-s_n) \]

where \( s_n \equiv n/n^w \) and \( \phi = \tau^{1-\sigma} \). The parameter \( \phi \) is an index of trade costs on the interval \([0,1]\). When \( \phi = 0 \) trade costs are prohibitively high (\( \tau \to \infty \)). \( \phi = 1 \) implies completely free trade (\( \tau = 1 \)). The location of production impacts the price index in the presence of transport costs. Increasing a country’s share of firms, \( s_n \) or \((1-s_n)\) respectively, lowers the price index as local consumers avoid paying transport costs on a larger fraction of varieties. High productivity in only one country can lower the price index in both countries. This is true regardless of transport costs for both Home and Foreign when at least some firms are operating in the most productive location.

2.5 Short-Run Equilibrium and Market Clearing

The geographical allocation of industry is taken as given and there is no firm entry and exit in the short run. Consumers maximize utility, firms maximize profits and markets clear.

The goods market clearing condition for manufacturing requires the total value of sales to equal the total value of demand for each variety:

\[ p_i x_i = p_i (c_i + d_i) + \tau p_i (c^*_i + d^*_i). \]

(13)
Income for a representative Home consumer is the sum of labor earnings and firm profits \( Y = \left[ w_M L_M + w_A L_A \right] + s_n n^w \Pi \). Total M-sector sales are the share of expenditure in consumer and firm demand for each country, \( \mu E \) and \( \mu E^* \). Adding wage income to firm expenditure on intermediate goods and simplifying yields total expenditure:

\[
E = \left[ w_M L_M + w_A L_A \right] + s_n n^w \pi
\]  
\[
E^* = \left[ w_M^* L_M^* + w_A^* L_A^* \right] + (1 - s_n) n^w \pi^*
\]  

Total manufacturing sales must be equal to the total world manufacturing budget share, \( \mu E^w \), for markets to clear according to (13). This implies \( \mu \left[ s_n \pi + (1 - s_n) \pi^* \right] n^w = E^w \mu / \sigma \). An expression for world expenditure is obtained by summing (14) and (15) vertically and simplifying,

\[
E^w = \left[ w_M L_M + w_A L_A \right] + \left[ w_M^* L_M^* + w_A^* L_A^* \right] + b E^w, \quad b \equiv \frac{\mu}{\sigma}.
\]

The first two terms are world wage income and the third is total world operating profits. This can be solved for world expenditure \( E^w = (Wage \ Income)/(1 - b) \).

Substituting consumer and firm demand for individual varieties into \( \pi = px/\sigma \) and summing across sales in both Home and Foreign markets for a representative firm, operating profits are

\[
\pi = b \frac{E^w}{n^w} w_M^{1-\sigma} B \chi, \quad \pi^* = b \frac{E^w}{n^w} (w_M^*)^{1-\sigma} B^*
\]

\[
B = \left( \frac{s_E}{\Delta} + \frac{\phi(1 - s_E)}{\Delta^*} \right), \quad B^* = \left( \frac{\phi s_E}{\Delta^*} + \frac{(1 - s_E)}{\Delta^*} \right), \quad s_E = E/E^w.
\]

The expression for \( B \) represents shares of world sales expenditure weighted by the local price index.

Substituting (16) into Home and Foreign expenditure defined in (14) and (15) and diving through by \( E^w \) gives Home and Foreign expenditure shares in terms of the spatial allocation of wage income and firm operating profits:

\[
s_E = b B \chi s_n + (1 - b) Sh(w_A, w_M, w_M^*)
\]

\[
(1 - s_E) = b B^* (1 - s_n) + (1 - b) [1 - Sh(w_A, w_M, w_M^*)]
\]

\[
Sh(w_A, w_M, w_M^*) = \frac{w_M L_M + w_A L_A}{w_M L_M + w_A L_A + w_M^* L_M^* + w_A^* L_A^*}
\]

where \( Sh(w_A, w_M, w_M^*) \) is Home’s share of the wage bill. The size of each market in expenditure terms is directly related to its shares of manufacturing (\( s_n \)) and labor (\( s_L \)).
The expression for $s_E$ can be solved explicitly in terms of the division of manufacturing firms as:

$$s_E = \frac{(1 - b)Sh(w_A, w_M, w^*_M)s_L + b(\phi/\Delta^*)s_n\chi w^*_M}{1 - b\chi s_n w^*_M[1/\Delta + 1/\Delta^*]}.$$  \hfill (20)

Closed form expressions for total profits in terms of the mass, $n^w$, and allocation of firms, $s_n$ and wages are found by substituting (12),(16) and (20) into total profit equation (7). These two equations and the labor equations in (8) and (9) are used to establish long run equilibria in the next section.

3 Long Run Equilibrium Analysis

3.1 Non-full specialization and wages

To fix ideas, the model is simplified by imposing a non-full specialization condition. I relax this assumption in section 4. If the A-sector good is produced in both locations, factor price equalization prevails and manufacturing wages are $w^*_M = w_M = 1$. Labor market clearing can be ignored and the profit equations (7) are two equations in two unknowns $(s_n, n^w)$.

This requires a non-full specialization (NFS) condition of $(1 - \mu) > \max\{s_L, (1 - s_L)\}L^w$. The A-sector must be a large enough share of total consumption that no single country can be fully specialized in the M-sector. As a result, the Agricultural good is always produced in both countries.

3.2 Firm entry and exit

In the long-run, profits in each country are driven to zero by the entry and exit of firms. Atomistic and myopic firms will enter the M-sector in either location when profits in (7) are positive and exit when profits are negative.

The NFS condition admits three feasible and stable equilibria: (1) full agglomeration at Home when $n^* = 0$, $\Pi = 0$ and profits to entry in Foreign are negative , (2) full agglomeration in Foreign when $n = 0$, $\Pi^* = 0$ and Home profits are negative and (3) an interior case when $\Pi = \Pi^* = 0$ and firms are active in both locations. Assessing the stability conditions of these three equilibria is the subject of the rest of this section.
3.3 An illustrative example

Total profits are two nonlinear equations in two unknowns \((s_n\text{ and } n^w)\). Completely solving the model for all stable and unstable equilibria requires numerical simulation. Fortunately, most of the critical points in the model can be found without extensive numerical methods. Before proceeding to derive more analytical results, it will be useful to present a fully solved and informative case. Consider a stylized dichotomy of global integration where a relatively large country opens to trade with a small country that has a productivity advantage in manufacturing. How will the location of manufacturing respond as these two countries move from autarky to free trade?

A large labor force is a larger market for goods. When trade costs are high, profits of the representative firm will be higher by producing for a large local market and exporting abroad. This market access effect is clear from expenditure equations \((14),(15)\) and \((20)\). A production-cost effect is the second agglomeration force. A larger share of firms in one country will lower its producer price index, raise profits and encourage firm entry. Relative productivity differences enter through this channel, but the price lowering impact is on locally consumed and exported goods. This productivity advantage raises profits and supports a larger number of firms in equilibrium. Trade costs will moderate the relative strength of these forces when Home has high manufacturing productivity and Foreign is large.

[FIGURE 1]

In Figure 1, Home has a modestly higher productivity. The relative productivity index is \(\chi = 1.1\) and Foreign is twice as large, \(\lambda = 2\). Panel (a) plots the share of world manufacturing in Home against trade costs. All stable equilibria are shown as solid lines. Panel (b) shows the contemporaneous share of employment in manufacturing in Home and Foreign. There are three phases of integration as trade costs fall: (1) dispersion, (2) full agglomeration in the large Foreign market followed by (3) full agglomeration in the more efficient Home market.

Beginning from autarky, high trade barriers naturally favor the larger market of Foreign. A market crowding effect keeps a small share of manufacturing firms in Home. As trade costs fall, Foreign’s initial advantage is self-reinforcing. Higher consumer demand in Foreign results in a higher share of firms. This creates higher local demand for intermediate goods, lowers the Foreign
price index and raises profits. More firms in Foreign enter manufacturing leading consequently to a shift in manufacturing employment. This process continues until manufacturing fully agglomerates in Foreign and profits are driven to zero. The level of trade costs where agglomeration in Foreign becomes sustainable is denoted by $\phi_{s1}^f$. No manufactured goods are produced in Home even though it has higher manufacturing productivity.

This would be the end of the story with size asymmetry alone, but this economy continues to respond to falling trade costs. Agglomeration in Home eventually becomes stable (profitable) as trade costs fall. In this case though, the sustain point for Home, $\phi_{s1}^h$, comes after the sustain point for Foreign. As a result, when history has favored Foreign and the rents to agglomeration are high, firms will have no incentive to establish manufacturing operations in Home.

At an even lower level of trade costs, the rents to agglomeration in Foreign vanish. Despite the larger local market in Foreign, transport costs are low enough that it is cost effective to manufacture goods in Home and export to Foreign. This occurs for levels of trade costs above $\phi_{s2}^f$. The agglomeration is catastrophically reversed and a Ricardian pattern emerges. Panel (b) reflects this changes in labor market shares. Nearly all of Home’s labor endowment is engaged in manufacturing for very low trade costs.

While this bifurcation diagram is rich with features, they are not always robust to variation in size and technology. Figure 2 repeats the analysis of Figure 1 when Home has even higher relative productivity of $\chi = 1.3$. Now lowering trade costs from autarky benefit Foreign initially, but not enough that Foreign captures all manufacturing industry. Home maintains some manufacturing initially and achieves full agglomeration more quickly as trade costs fall. Home’s manufacturing employment falls slightly and then grows to a high level.

[FIGURE 2]

A more analytical approach will be necessary to answers a number of questions. For what relative productivity can the initial size effect be overcome as in Figure 2? Can the sustain points defined above be ordered? How do the equilibria respond to variation in relative productivity? Will

\footnote{Catastrophic refers to the discrete jump of all manufacturing firms from Foreign to Home.}
free trade always favor the country the highest manufacturing productivity, regardless of size? The rest of this section analyzing these cases.

### 3.4 The Mass of Firms with Full Agglomeration

Productivity differences in variable costs will effect the equilibrium number of firms for agglomeration outcomes, but labor endowments will not. A more productive labor force, will support a larger number of firms and varieties. This has important welfare implications for later. Deriving this result is straightforward.

Beginning with the case for Home, profits for a given level of $\phi$ are determined by $s_n$ and $n^w$. When $s_n = 1$ firms will enter the Home market until total profits are driven to zero. The equilibrium number of firms, denoted by $n_1$ is found by setting $s_n = 1$ and imposing the zero profit condition in Home:

$$\Pi(n_1, s_n = 1) = \frac{b\chi}{n_1} \left[ \frac{s_E}{\chi} + \frac{\phi(1-s_E)}{\phi\chi} \right] - (n_1\chi)^{-a} = 0$$

$$\Rightarrow n_1 = \left( \frac{b}{1-b} \right)^{1/(1-a)} \chi^{a/(1-a)}, \quad a = \frac{\mu}{\sigma - 1} < 1.$$  

The equilibrium number of firms is increasing in Home’s relative productivity and it is invariant to trade costs. The corresponding condition for Foreign is $n_0 = (b/(1-b))^{1/(1-a)}$. These two values for aggregate firms are related as follows:

$$n_1 = n_0\chi^{a/(1-a)} \quad (21)$$

The country with higher manufacturing productivity will support a larger number of firms.

### 3.5 Free trade produces a Ricardian allocation of industry

Perfectly free trade implies $\phi = 1$. Imposing this condition will equalize the price index in both countries. The location of firms is determined by evaluating the difference in Home and Foreign total profits:

$$\Pi(\phi = 1) - \Pi^*(\phi = 1) = \frac{b[\chi - 1]}{n^w(\chi s_n + (1-s_n))}. \quad (22)$$
The denominator is positive for any allocation of firms. When $\chi > 1$, Home has a productivity advantage and the difference in profits will be positive. For the case $\chi < 1$, the converse is true.

**Proposition 1** Under perfectly free trade ($\phi = 1$) with asymmetric technology ($\chi \neq 1$) full agglomeration in the country with higher productivity is the only stable, long-run equilibrium when the non-full specialization condition is satisfied.

For a small open economy, high manufacturing productivity can only be exploited by moving to free or nearly free trade. Faced with competition from a larger trading partner, the suggested response from Proposition 1 is to lower trade costs as far as possible. Falling trade costs diminish the effects of market and supplier access and intensify competition that favors greater efficiency. Near zero trade costs change the location incentives and firms will prefer to produce in the more efficient location and export to the large market.

This trivial confirmation of Ricardian trade patterns rectifies a fundamental indeterminacy of standard NEG models. In symmetric technology models with free trade, the equilibrium division of manufacturing is indeterminate even when countries differ in size. This can be seen by setting $\chi = 1$ in (22). Profits are equalized in both locations and the share of manufacturing firms is indeterminate.

### 3.6 Agglomeration and intermediate trade costs

Full agglomeration is a stable, long run equilibrium in Home if there are no positive profits to entering the Foreign market. The formal objective is to find the values of trade costs that support agglomeration. These are the ‘sustain points’ referred to in Section 3.3.

For the case of agglomeration in Home, the condition, $\Pi^*(n_1, s_n = 1) < 0$ must be satisfied or firms will have incentive to enter the market in Foreign. This is equivalent to requiring that agglomeration rents $\Omega$ are positive as follows:

$$\Omega \big|_{n_1, s_n = 1} = \Pi(n_1, s_n = 1) - \Pi^*(n_1, s_n = 1) = 0 - \Pi^*(n_1, s_n = 1) > 0$$

(23)

where the third equality follows from the zero profit condition.
A closed-form expression for agglomeration sustaining relative productivity as a function of trade costs and relative endowments is possible. Setting Foreign profits to zero and rearranging terms yields:

$$
\chi_s = \frac{1}{1 + \lambda} \left( \phi_s (1 + b\lambda) + \frac{(1 - b)\lambda}{\phi_s} \right) \phi_s^a
$$

(24)

where the ratio of Foreign to Home labor endowments is \( \lambda = (1 - s_L)/s_L \). The levels of of trade costs and relative productivity that solve this equation are denoted as \( \chi_s \) and \( \phi_s \). While exact solutions must be found numerically, the functional form for \( \chi \) in terms of exogenous parameters permits further quantitative and graphical analysis. The condition for Foreign is found by substituting \( 1/\lambda \) for \( \lambda \) in (24) and then inverting the entire right hand side.

[FIGURE 3]

Figure 3 plots the locus of sustain points defined in equation (24) for two cases of size asymmetry. Agglomeration in Home is stable for all ordered pairs \( (\phi, \chi) \) above the \( \chi_s^{home} \) locus. Above this line, the profits of an atomistic firm entering to Foreign are negative. Agglomeration in Foreign is stable below the \( \chi_s^{foreign} \) locus.

The value and ranking of the critical thresholds of \( \phi \) required to sustain agglomeration are determined by relative productivity. These sustain points occur where the horizontal line for \( \chi = 1.1 \) cuts the two loci. The location, ranking and number of sustain points depends on relative productivity. In panel (a), the parameters are set to match the scenario in the example of Section 3.2. The overlap of the stability ranges for \( \phi \) is easy to observe. Vertical lines denote the intersection of the relative productivity index with the sustain point locus allowing one to order the sustain points as \( \phi_{s1}^f < \phi_{s2}^h < \phi_{s2}^f \).

3.7 Agglomeration Rents

Many advanced, industrialized countries are relying on high productivity to prevent the erosion of manufacturing employment. In the case where Foreign is relatively large, Figure 3(a) indicates that nearly complete trade liberalization is required for Home to exploit its productivity advantage. Alternatively, the productivity advantage could be high enough that no level of trade costs supports
agglomeration in Foreign. Panel (b) depicts such a scenario when the size advantage of Foreign is reduced to $\lambda = 3/2$ and relative productivity remains at $\chi = 1.1$. Now there is a single sustain point and Home is the only stable agglomeration outcome.

A formal assessment of the above discussion is possible. Beginning with Home, equation (24) has a positive second derivative with respect to $\phi_s$ and attains a minimum at the point:

$$\tilde{\phi}_s = \min \left\{ \sqrt{\frac{(1-b)(1-a)\lambda}{(1+b\lambda)(1+a)}}, 1 \right\},$$

where the min operator is required for values of $\tilde{\phi} / \in [0, 1]$. The minimum relative productivity that sustains agglomeration in Home is:

$$\chi_{MIN}^s = \begin{cases} 
\frac{\lambda(a+1)}{2} & \text{if } \tilde{\phi}_s \in [0, 1) \\
1 & \text{if } \tilde{\phi}_s = 1
\end{cases}$$

Below this level of relative productivity, a bifurcation occurs and full agglomeration is never stable in Home. A corresponding maximum level of $\chi_{MAX}^s$ can be derived for Foreign. The value of $\chi_{MIN}^s$ is increasing in $\lambda$. Even slight size asymmetry requires that $\chi > 1$ must hold to sustain agglomeration when Home is small. Conversely, large countries can sustain agglomeration for somewhat severe levels of disadvantage.

The rents to agglomeration in Home decrease when $\chi$ falls. As defined, $\chi_{MIN}^s$ is the level of $\chi$ below which the rents to agglomeration are completely overwhelmed by the gains from superior technology in Foreign. This result is summarized in the following proposition:

**Proposition 2** The rents to agglomeration (23) in Home (Foreign) vanish when $\chi$ is less (greater) than $\chi_{MIN}^s$ ($\chi_{MAX}^s$) for any level of trade costs.

### 3.8 Relation to symmetric NEG models

Fully symmetric NEG models are included as a special case of this model when $\chi = \lambda = 1$. Asymmetry resolves some of the fundamental indeterminacy in standard NEG models. When trade costs fall, the pattern of agglomeration is predicted by relative size and technology rather than chance events. The model does display a mild form of hysteresis when trade costs are increased.
The qualitative pattern of manufacturing location is reversed, but at different threshold levels of trade costs.

This simple specification shares the same ‘genome’ with a large class of vertical linkage models examined in Ottaviano and Robert-Nicoud (2005). The qualitative behavior examined above should be the same in less tractable models. The results apply directly to regional NEG models such as Forslid and Ottaviano (2003) where cross-country, skilled labor migration, rather than vertical linkages are the agglomeration mechanism. Equations (24) and (25) for sustain point determination are identical with labor migration.

4 Generalizing the model

4.1 Relaxing the NFS condition

The NFS condition can be relaxed for the sake of realism at the expense of simplicity. Wages and the allocation of labor within each country are potentially endogenous without factor price equalization. The NFS condition is a restriction on the share of manufactured goods in consumer and firm expenditure. If \( \mu \) is larger than Home’s share of world labor but smaller than Foreign’s share, full manufacturing specialization in Home is possible. I will omit analyzing the case where \( \mu \) is larger than Home and Foreign’s labor share.

Consistent with Ricardian predictions, full specialization only occurs in the country with a higher productivity in manufacturing. For example, say Home is small and more productive. The entire manufacturing sector is too large to fit entirely in Home, but low trade costs combined with higher productivity can make entry profitable. For low enough trade costs specialization in Home will be inevitable. Home manufacturing wages will necessarily exceed those in agriculture to attract labor. Foreign, in this case, will still maintain some manufacturing and all agricultural employment at equalized wages of unity.

4.2 Qualitative Results

[FIGURE 4]
Figure 4 replicates Figures 1 except that $\mu = 0.5$. A higher share of intermediate goods in fixed costs strengthens the production-cost linkages. As before, Foreign’s initial size advantage in terms of market and supplier access is amplified as trade costs fall from autarky levels. Manufacturing shares will shift from Home to Foreign. This also effects the share of manufacturing employment in each country.

Similar to before, at some level of lower trade costs full specialization, rather than full agglomeration, in Home becomes possible but not inevitable. As trade costs fall further, full agglomeration in Foreign is no longer sustainable and Foreign loses part of it’s manufacturing core to Home. Labor shares follow suit, but now Foreign retains some manufacturing employment. Home devotes its entire labor endowment to manufacturing and imports all of it agricultural good from Foreign. Given these small adjustments to the nature of equilibria, the patterns and intuition of section three are qualitatively preserved.

4.3 Analytical Results

Some of the tractability of section three can be salvaged. The agglomeration sustaining locus for Home is lost because wages, the labor allocation and number of firms in Home are changing with trade costs. The situation with respect to the Foreign version of equation (24) is different. The condition in (24) assumes wages are unity in both countries. When manufacturing agglomerates in Foreign, these assumptions continue to hold. For the levels of trade costs ($\phi$) and technology ($\chi$) where it is exactly satisfied, a firm can enter the Home market at the prevailing wage and turn a profit in the short run. In the long run, more firms enter, compete for labor and bid up the wage rate until Home is fully specialized in manufacturing.

[FIGURE 5]

Figure 5 plots equation (24) to illustrate the Foreign agglomeration sustaining range of trade costs $\phi_{s1}^f$ and $\phi_{s2}^f$. The level of productivity were full agglomeration is not sustainable in the less productive country for any level of trade costs is still $\chi_{s}^{MAX}$ as determined above. In this case a relative productivity index of $\chi = 1.3$ is still sufficient to insure that Foreign cannot capture all
manufacturing industry. A partial version of proposition 2 continues to hold for the larger less productive country when \( \mu \) is between the labor endowment shares of Home and Foreign.

5 Policy and Welfare Implications

5.1 Technological Change

Many developing countries see a productive labor force as a means to attract manufacturing. Advanced industrialized countries worry about losing technological advantage. Are these hopes and concerns realistic? The setup of this model permits a useful way to conduct a stylized analysis for this type of question. Variation in relative productivity is analyzed using Figure 6. In this scenario, \( \lambda = 1 \) to simplify the analysis, but the technique for evaluation is the same for more complex cases.

Consider two countries, Home and Foreign, that gradually pursue trade liberalization. Home is technologically advanced relative to Foreign in the early years of its industrial history. Trade costs fall to a level of \( \phi \in (\phi_{s1}^f, \phi_{s2}^f) \) through trade liberalization and lower transport costs. Manufacturing firms gradually agglomerates in Home following the stable equilibrium path from left to right.

[FIGURE 6]

Now consider the impact of improving Foreign’s technology.\(^3\) The improvement could be due to exogenous government investment on infrastructure or education that enhances productivity. Foreign catches up to Home’s technological lead (i.e. reaching \( \chi = 1 \)) and surpasses it so that \( \chi < 1 \). The level of \( \chi \) falls to \( \chi' \) in the bottom panel of Figure 6. This series of events literally turns the tables on Home by reflecting the top panel of the figure around the horizontal axis \( s_n = 0.5 \). Full agglomeration at Home is still stable, but further erosion of its relative productivity will result in a catastrophic shift of manufacturing firms to Foreign if \( \chi \) falls below \( \chi_s^{MIN} \).

\(^3\)This step abuses the normalizations somewhat. Foreign technology is pinned down to \( a_{M}^f = 1 - 1/\sigma \) and now it is allowed to change. This will surely impact Foreign prices. More accurately, one should let Home technology get worse. But for the sake of this qualitative discussion, the ratio of productivity is what matters.
The sustain points are reordered, swapping the superscripts so that $\phi_s < \phi_{s1} < \phi_{s2}$. If $\phi$ is a policy variable that can be manipulated by either country, Home has limited options. Agglomeration is sustainable for only a narrow band of trade costs. Further opening of trade or incremental protectionist measures will cause agglomeration Foreign. If Home’s goal is to keep some industry, the best it can do is maintain an industry share of slightly less than one half by substantially restricting trade to levels of $\phi < \phi_s$.

A final insight concerns the issue of underdevelopment. Foreign may not be able to surpass Home’s technological edge. Perhaps the best it can do is catch-up to or copy frontier levels productivity (e.g. $\chi \rightarrow 1$ from above). The bifurcation diagram would evolve from the case in Figure 6 to the standard pitchfork bifurcation of symmetric NEG models. If historical productivity advantage allowed Home to capture all manufacturing activity, it will have secured an early industrializer advantage. The prospects would be even worse if the Foreign country was small.

5.2 Welfare

The CES functional form makes welfare analysis straightforward in the full agglomeration case with the NFS condition. The utility function in (3) is a ‘perfect’ price index. It measures utility and real purchasing power. Welfare results depend directly on relative magnitude of productivity and trade costs. The indirect utility functions in (3) for a representative worker in Home and Foreign become:

$$V = \frac{Y}{\Pi^a} = sL(n^w\Delta)^a, \quad V^* = \frac{Y^*/(\Pi*)^a}{(1-sL)(n^w\Delta^*)^a}.$$

Because $\Delta$ and $\Delta^*$ are in the denominator of the price index, utility is increasing in lower prices, the mass of varieties ($n^w$), trade costs and own country share of firms. A simple welfare comparison can be made by computing the log difference in $V$’s at $s_n = 1$ and $s_n = 0$ for Home and Foreign as below:

$$\ln \left( \frac{V_1}{V_0} \right) = a \ln \left( \frac{\chi^{1/(1-a)}}{\phi} \right) > 0 \text{ when } \phi < \chi^{1/(1-a)}$$

(27)

$$\ln \left( \frac{V^*_1}{V^*_0} \right) = a \ln \left( \frac{\chi^{1/(1-a)}\phi}{1} \right) < 0 \text{ when } \phi < \chi^{1/(a-1)}$$

The country with higher productivity will always prefer own country agglomeration. In the case of Home, $\phi < \chi^{1/(1-a)}$ for all levels of trade costs when $\chi > 1$. A less productive Foreign
country might be better off with Home agglomeration. This is true only for the right combination of low trade costs and high productivity (high $\chi$) in Home. There is a range for $\chi$ in the interval $\phi^{1-a} < \chi < \phi^{a-1}$ where full agglomeration causes a welfare loss to the periphery. High trade costs can overwhelm the benefit of low prices from more efficient production. This establishes the following result:

**Proposition 3** Full agglomeration in Foreign is welfare improving for the total world labor endowment if and only if $\phi > \chi^{1/(a-1)}$. Full agglomeration in Home is welfare improving for all if and only if $\phi > \chi^{1/(a-1)}$. Otherwise, Labor in in the periphery will experience a welfare loss.

Unlike symmetric models, agglomeration is not always welfare improving for a representative agent in the host country. The well-being of the periphery depends positively on the productivity level abroad and negatively on trade costs. There are ranges of trade costs where an improvement in Home technology would not necessarily benefit Foreign. Consider the example from Figure 1 where $\chi = 1.1$. Agglomeration of all manufacturing shifts from Foreign to Home for $\phi > 0.77$ but it is not welfare improving in Foreign until $\phi > 0.9$. A similar calibrated result is obtained by Eaton and Kortum (2002). Welfare is increasing when a trading partner’s technology improves for nearby countries, but less so for countries that are far away.

These comparisons are only relevant for the welfare of labor, not the profits motives of firms. The gains to firms from locating close to intermediate suppliers and within large markets creates a pecuniary externality. Low trade costs must be accompanied by high manufacturing productivity before agglomeration is a profitable, stable and welfare improving outcome for all.

6 Conclusion

The main results shed light on several issues of regional and global integration. Neither country size or relative productivity necessarily determine the location of manufacturing firms. Throughout a range of trade costs, size and productivity differences, a rich set of outcomes emerges. The dynamics of agglomeration are regulated by trade costs in three phases: (1) dispersion at high trade costs (2) large customer and supplier markets favored at intermediate trade costs, and (3) high productivity
favored for low trade costs. This application of the model is consistent with empirical findings and the geography of trade integration (Eaton and Kortum, 2002; Amiti and Javorcik, 2008).

For small countries attempting to attract manufacturing industries, mere trade liberalization might not be enough. Only a combination of trade liberalization and improved productivity will induce firms to move. Most advanced, industrialized economies have secured an early-industrializer advantage. Atomistic firms might stay put even when it would be more profitable if all firms relocated to the more productive country. This may account for the disparate effects of trade liberalization on small economies.

There are implications for industrialized countries as well. Countries may catch up to or surpass technological leaders like the United States. Fierce competition for industry could develop between countries, with important welfare implications. Labor does experience a welfare loss when manufacturing relocates unless a combination of higher productivity abroad and sufficiently low trade costs reduces the price of imported goods.

The model generally avoids the stark outcomes and indeterminate dynamics of NEG models that have been noted by Neary (2001). Moving from autarky to free trade leaves room for both country size and Ricardian predictions. For levels of trade costs in between, the rich features of NEG models are preserved.
References


Appendix: parameter values for figures

Figure 1: $\mu = 0.3$, $\sigma = 4$, $\lambda = 2$, $\chi = 1.1$

Figure 2: $\mu = 0.3$, $\sigma = 4$, $\lambda = 2$, $\chi = 1.3$

Figure 3: (a) $\mu = 0.3$, $\sigma = 4$, $\lambda = 2$, (b) $\mu = 0.3$, $\sigma = 4$, $\lambda = 3/2$

Figure 4: $\mu = 0.5$, $\sigma = 4$, $\lambda = 2$, $\chi = 1.1$

Figure 5: $\mu = 0.5$, $\sigma = 4$, $\lambda = 2, \chi = 1.1$ and $1.3$.

Figure 6: $\mu = 0.3$, $\sigma = 4$, $\lambda = 2$, $\chi = 1.03$, $\chi' = 0.97$
Figure 1: Evolution of manufacturing location and employment shares when Foreign is large ($\lambda = 2$) and Home has a manufacturing relative productivity index of $\chi = 1.1$

(a) Home share of world manufacturing

(b) Employment share of manufacturing - Home and Foreign
Figure 2: Evolution of manufacturing location and employment shares when Foreign is large ($\lambda = 2$) and Home has a larger manufacturing relative productivity index of $\chi = 1.3$

(a) Home share of world manufacturing

(b) Employment share of manufacturing - Home and Foreign
Figure 3: Agglomeration Sustaining Loci with Size Asymmetry ($\lambda$)

(a) $\lambda = 2$

(b) $\lambda = 3/2$
Figure 4: Evolution of manufacturing location and employment shares with full specialization permitted in Home: $\lambda = 2 \chi = 1.1$

(a) Home share of world manufacturing

(b) Employment share of manufacturing - Home and Foreign
Figure 5: Agglomeration sustaining loci when full specialization permitted in Home, $\lambda = 2$, $\mu = 0.5$.
Figure 6: Analyzing technological change – bifurcation diagram with $\chi_s$ subplot ($\chi = 1.03$, $\chi' = 0.9$, $\lambda = 1$)