International trade and domestic economic geography: the case of the port openings of Japan, 1859
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Abstract
Since the opening up to international trade in 1859, economic activities within Japan have been continuously shifting towards the east. This paper develops and applies to the case of Japan a simple economic geography model to provide a possible explanation for the origin of the east-west shift of economic activities through trade liberalization. The focus of the model is the location of manufacturing industry characterised by increasing returns to scale in the presence of agricultural raw materials and transport costs under different trade regimes. In autarky, manufacturing can be geographically dispersed. However, opening up to international trade is likely to make manufacturing agglomerated in the raw material region, in response to the competitive pressure of imported foreign manufactured goods. Applying the model to the case of Japan by focusing on the silk industry, which was the leading industry at the time, we can explain the geographic shift of economic activities in Japan may have occurred through migration of skilled workers or entrepreneurs associated with the silk industry after the opening up.

JEL Classifications: F12, L67, N95, R12
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1 Introduction

The impact of globalization on individual economies has been studied from various perspectives. However, almost all work studying the effects of globalization has been concerned with countries at the aggregate level and where they have investigated the effects within a country this typically has not had an internal geographic component. What then is the effect of globalization on different places within a country? It is of importance because countries are in fact not dimensionless points but a group of smaller internal regions. It is also of interest because regions within a country can have different characteristics and, given that production factors are usually more mobile internally and distances involve transport costs, the effect can be complex. Further, regional consequences of globalization must also be of interest from regional authorities’ point of view. This is not an entirely new topic: a theoretical study by Krugman and Livas-Elizondo (1996) suggests international trade liberalization brings about dispersion of economic activities within a country, while Paluzie (2001) suggests the opposite. According to Hanson (1998), the case of Mexico’s trade liberalization seems consistent with the former, but a recent cross-country econometric study by Nitsch (2006) does not support the Krugman and Livas-Elizondo hypothesis. The mixed results of existing theoretical studies and the ambiguity of existing empirical studies motivate us to further explore this topic.

This paper will attempt to clarify some of these issues by focusing on the case of Japan. It is known as an almost ideal subject for studying the impact of globalization: Japan in the 19th century was a rare case of a market economy transforming from a closed to an open economy, providing opportunities for natural experiments on the impact of international trade liberalization.

Investigating the case of Japan, we notice several distinct features of the economy and the geography around the time of the opening of Japanese ports to international trade: an eastward shift of economic activities after the port openings, the importance of textiles and the silk industry in particular, and the natural geography of Japan that affects agricultural production. The years around the port opening era are known as the “missing quarter century” in Japanese economic history and the fact that the origin of the well-known eastward shift in modern Japan has not been satisfactorily explained to date further motivates this study.

Our approach is to develop and apply to the case of Japan a simple economic geography model to study the impact of trade liberalization, building on the new economic geography literature. However, we depart from existing studies, in order to take into account the characteristics of the Japanese and the international economy in the 19th century, incorporating the following new aspects: first, there exists an input-output linkage between the two sectors in the sense that raw materials from the agricultural sector are used in the manufacturing sector.
Second, the transport cost of agricultural goods, including raw materials and food, is also taken into account. This leads to a regional asymmetry of manufacturing production cost. Third, unlike existing studies that assume all manufacturing labour is mobile, the present model assumes only the skilled workers who run the firms are mobile. This is the footloose entrepreneur assumption as in Forslid and Ottaviano (2003), and comes from the historical observation that those employed in the silk fabric industry were mainly local workers. Finally, we assume non-neutrality of natural geography that leads to concentration of agricultural raw material production in one region.

The analysis is presented in two steps; the first is the analysis of economic geography in autarky. After a general analysis of the regional distribution of the manufacturing industry and skilled workers, the model is applied to the case of Japan in autarky, focusing on the silk industry which was the leading industry. Using parameters for Japan, the result confirms the historical observation that the silk fabric industry was dispersed between the east and the west (with the west having a larger share) during economic isolation. In the second step, the autarky model is opened up to international trade. The main finding is that industry tends to move towards raw materials with trade liberalization in response to foreign competition; our explanation for the origin of the shift of economic activities from west to east Japan is that trade liberalization lead to migration of skilled workers or entrepreneurs towards the east and agglomeration of the silk related industry (such as silk fabrics) in the east where raw silk was mainly produced.

The remainder is organized in the following way. The next section presents some historical background that motivates the theoretical model. Section 3 shows analysis of the autarky model and its application to Japan. Section 4 compares domestic economic geography with international trade and autarky. The final section concludes, followed by appendices.

2. Historical background

2.1 Change in regional population trends after trade liberalization

Regional population data is available from the mid-18th century, which may indicate the extent of economic activities. Figure 1 shows population growth rates of east and west Japan. From the mid-18th to the mid-19th century population occasionally recorded negative growth, due partly to famine and diseases, and the level of population was stagnant. No data is available around the port opening era from 1846 to 1872. Growth rate turned positive from 1872. This can be

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1 Kudo and Ichikawa (1955), Hayami and Uchida (1976), and Hayami (1983) suggest rural-urban migration was present but it took place mostly within regions.
considered as a result of the improvements in medical infrastructure that reduced death rates leading to high population growth. Another clear change we observe is that the east constantly showing higher population growth rates than west Japan after the port openings. Those who know current Japan may take it for granted that east Japan which comprises the Tokyo region is the centre of Japanese economic activities. But before the port openings, west Japan was known to be the economic centre; it was after the port openings that the east overtook the west (Figure 2). One may argue that this may simply have been driven by concentration of population to Tokyo, the capital, which is located in east Japan. However, as shown in the breakdown of population growth of east Japan in Figure 3, Tokyo’s contribution to east Japan’s population growth is much less than a half. This is also shown graphically in Figures 4a and 4b which present regional population growth of pre- and post- port openings, respectively. We observe higher population growth rates in various regions of east Japan, in addition to Tokyo. (In fact Tokyo was already the largest city before the port openings.) Therefore we must consider other factors besides the ‘Tokyo effect’ that lead to higher growth in the east.

There are two possible factors leading to this east-west asymmetry in population growth rates, which are not mutually exclusive: one is a natural factor, that is, higher birth rates or lower death rates in the east. The other is a social factor: the regional shift of economic activities involving migration from the west to the east. We examine the possibility of the latter.

Note: Lengths of the periods differ due to data availability.

Figure 1: Average annual population growth rates of east and west Japan
Figure 2: Population share of the east and the west (east/west)

Figure 3: Total population change in east Japan and contribution of Tokyo and other Regions

Note: Lengths of the periods differ due to data availability.
Figure 4a: Regional annual population growth rate, 1750-1846 (before the port openings)

Figure 4b: Regional annual population growth rate, 1872-1888 (after the port openings)
2.2 Pattern of international trade following the port openings

Figure 5a and 5b show early trade statistics of Japan. International trade in this era was largely based on two-way trade of textiles, suggesting the importance of textile industries in this era.² Japan exported silk products, mostly raw silk, and imported other types of textiles such as cotton and woollen fabrics.

Figure 5a: Product share of Japan’s exports

Note: Silkworm eggs and cocoons are included in raw silk in this figure.
Source: Toyo keizai shinpo sha (1975)

Figure 5b: Product share of Japan’s imports

Note: The large shares of “others” in 1869 and 1870 are due to emergency imports of rice.
Source: Toyo keizai shipo sha (1975)

² In addition, Akimoto (1987) reports that clothing expenditure consisted around half of non-basic food expenditure. This suggests textile production was an important part of the industrial sector.
2.3 Geography of the silk industry in Japan

Production of silk fabrics has at least three steps: farmers raise silkworms which form cocoons. The cocoons are then reeled into silk thread or raw silk. Silk fabric producers purchase raw silk from farmers through traders and weave them into silk fabrics.

Geography of agricultural production is more likely to be affected by natural conditions than manufacturing. In the case of Japan, the difference in climate and landscape between the east and the west affect geography of agricultural production. The landscape of the west is relatively flat, and combined with warmer climate, it is suitable for crops like rice. On the other hand, the east is disadvantaged for rice production because of its mountainous landscape, colder climate and fewer rainfalls. This lead to the introduction of sericulture in the east after the closure of the country in the late 17th century when raw silk import stopped. Production statistics of silkworm cocoon is only available from 1887. As is shown in Figure 6, silkworm cocoons were produced intensively in east Japan. The earliest production data available for raw silk is that of 1876 (City of Yokohama (1965)), which also shows that raw silk production was highly concentrated in the east: 94% of raw silk output in quantity terms was concentrated in the east. Since natural conditions are not likely to change over a short period of time, we consider that silkworm cocoon and raw silk production had been concentrated in the east prior to the port openings.

As for silk fabrics, the historical literature suggests it originally evolved in west Japan, namely in cities including Hakata, Sakai and Kyoto. Production became more geographically dispersed during the late 17th to the 18th century in the isolation era between the west and the east, but the west, in particular Kyoto, was still the main silk fabric production site (Figure 7).

After the port openings, although the Kyoto in west Japan remained to be the largest silk fabric production location according to the 1874 data, its presence seems to have declined drastically. For example, Sasaki (1932) reports that in 1730 around 7,000 weaving machines existed in Kyoto and 5,174 in 1839, but it dropped to 3,819 in 1864. In addition Hamano (2003) finds net outflow of population from the Nishijin district shortly after the port openings. In contrast to the situation in Kyoto, according to Okada (2005), the city of Kiryu, the eastern rival of Kyoto in silk fabric production, became the first to succeed in exporting silk fabrics when the export boom came around the 1880s to the 1890s.

Our observation of the eastward shift of the population and the silk industry lead us to hypothesize that Japan’s eastward population shift may have been related to an industrial relocation involving migration. The rest of the paper attempts to shed light on this era by

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3 See Appendix 1 on the east-west differences in the natural conditions.
examining such a hypothesis and to provide a possible explanation for the origin of the eastward shift in Japan, considering the link between international trade and domestic economic geography.

Note: Cocoon production intensity is calculated as cocoon output (kg)/population. Population data is that of 1888 since that of 1887 is not available.

**Figure 6: Regional silkworm cocoon production intensity, 1887**

**Figure 7: location of silk fabric production**
3 The autarky model

3.1 Assumptions of the autarky model

Goods, production technology and market structure

There are three goods in the economy; differentiated manufactured goods and two homogeneous agricultural goods - raw material for manufactured goods production and food, a final good. Production of manufactured goods also requires two types of labour, skilled and unskilled. A firm producing a particular manufacturing variety requires a fixed number \( \alpha \) of skilled workers, and one unit of raw materials and \( \beta \) unskilled workers per unit output. The firm thus faces increasing return to scale. Its total cost for producing a given amount \( q^M \) is then

\[
c(q^M) = \alpha w^S + (\beta w^U + p^R) q^M,
\]

where \( w^S \) is the wage of skilled labour, \( w^U \) is the wage of unskilled labour, and \( p^R \) is the price of raw materials. It is assumed that manufacturing firms are monopolistically competitive.

On the other hand, agriculture is a constant returns sector which uses only unskilled labour. The agricultural sector can produce either food or homogeneous raw materials for manufacturing. A unit of unskilled labour produces a unit of food or a unit of raw materials. Therefore the total costs for producing given amount of food \( q^F \) and raw materials \( q^R \) are \( c(q^F) = w^U q^F \) and \( c(q^R) = w^U q^R \), respectively. Perfect competition is assumed for the agricultural sector.

Geography and transport cost

There are two domestic regions which will be called the east and the west. Inter-regional transport cost is expressed in iceberg form, \( t > 1 \). Iceberg transport cost of \( t \) implies that \( t \) units of a good needs to be shipped in order to supply a unit of the good to a destination. In other words, \( t - 1 \) units are lost during transport. We assume that the transport cost for manufactured goods and agricultural goods can differ with iceberg transport costs for manufactured goods and agricultural goods expressed as \( t^M \) and \( t^A \), respectively.\(^5\)

In addition to transport costs, non-neutrality of geography is introduced; the east and the west differ substantially in natural conditions which strongly affect the nature of agriculture so that agriculture in the east produces raw materials for manufactured goods and agriculture in the west produces food. Manufacturing can locate in either region (Figure 1).

\(^5\) The gap in the estimated transport (or trade) costs between manufactured goods (silk fabrics) and agricultural goods (food such as rice and raw silk) is observed to be much larger compared to the difference of transport costs within the agricultural goods. This is shown in Appendix 2.
Figure 8: The two regions, industrial location and transport costs for the autarky model

Labour endowment
Population of unskilled workers in the country is normalized at 1 and that of skilled workers is denoted by $S$. This implies that the total mass of firms in the country is fixed at $S/\alpha$ in equilibrium. Denoting the share of skilled workers in the east as $\lambda$, the mass of firms in the east will be $\lambda S/\alpha$ and $(1-\lambda)S/\alpha$ in the west. Therefore the mass of firms in each region is defined by the skilled labour allocation between the two regions. As was presented in the previous section, the population of the east and the west was nearly equal before the port openings in the late 19th century with the west being slightly larger. We assume that unskilled labour is evenly distributed between the east and the west so each region has half a unit of unskilled labour.

Consumer preference
All consumers have the same preferences, which are described by a two-tier utility function. The upper tier is

$$U = M^\mu F^{1-\mu} \quad (0 < \mu < 1),$$

(2)

which implies that income share of $\mu$ and $1-\mu$ is allocated for manufactured goods ($M$) and food ($F$), respectively. The second tier dictates the consumers’ preferences over the differentiated manufactured varieties, which is defined as

$$M = \left[ \int_0^n m(i)^\rho \, di \right]^\frac{1}{\rho} \quad (0 < \rho < 1),$$

(3)

where $M$ is the composite of all the differentiated manufactured varieties, $n$ is the mass of manufactured varieties, $m(i)$ is the consumption of variety $i$ and $\rho$ is the substitution parameter. It is assumed that $0 < \rho < 1$ to ensure manufactured varieties are imperfect substitutes. We use $\sigma = 1/(1-\rho)$ ($\sigma > 1$), to represent the elasticity of substitution between
any two varieties of manufactured goods. Consumers’ love-of-variety is stronger the smaller \( \sigma \) (or the smaller \( \rho \)).

By introducing a price index of manufactured goods

\[
G = \left[ \int_0^n p(i)^{-\sigma} di \right]^{1/(1-\sigma)}
\]

(4)
such that total expenditure on manufactured goods is \( GM \) and denoting the price of food as \( p^F \), indirect utility (or the real wage, \( \omega \)) can be expressed as

\[
\omega' = \frac{w^j}{G^\mu (p^F)^{1-\mu}} \quad (j = U, S).
\]

(5)

Labour mobility
As in the footloose entrepreneur model by Forslid and Ottaviano (2003), skilled workers are the only mobile factor between regions. Following Krugman (1991), we simply assume that skilled workers move toward the region that offers them higher real wages. Unskilled workers are not mobile between regions but can be employed in either sector within the region. We introduce parameter \( \theta_r \) \((r = E, W \text{ and } 0 < \theta_r \leq 1)\) to denote the share of unskilled workers employed in the agricultural sector in each region. (Hereafter we use subscripts \( E \) and \( W \) to describe the regions, the east and the west, respectively.)

3.2 Firm behaviour and prices by location
Denoting the (mill) price of manufactured goods in the east as \( p^M_E \), if an eastern firm sells quantity \( q_E \), its profit is

\[
p^M_E q_E - (\beta w^U_E + p^R_E)q_E - \alpha \omega^S_E.
\]

(6a)

Then to maximize its profit, the monopolistically competitive firm in the east will set price so that marginal revenue equals marginal cost:

\[
p^M_E \left( 1 - \frac{1}{\sigma} \right) = \beta w^U_E + p^R_E.
\]

(6b)

On the other hand, firms in the west must bear transport cost of raw materials since they are not produced in the west. (This is the key difference between firms operating in the east and in the west.) Given the iceberg transport cost \( t^A \), the delivered price of raw materials in the west is \( p^R_W t^A \). Therefore denoting the (mill) price of manufactured goods in the west as \( p^M_W \), if a western firm sells quantity \( q_W \), its profit is
\[ p^M_w q_w - (\beta w^U_w + p^E_t t^A) g_w - \alpha w^S_w. \]  

(7a)

Then the monopolistically competitive firm in the west will set price as

\[ p^M_w \left(1 - \frac{1}{\sigma}\right) = \beta w^U_w + p^E_t t^A. \]  

(7b)

Given the prices of the manufactured varieties supplied from the two regions, the price indices of the manufactured goods in the two regions are

\[ G_E = \left[ n_E \left(p^M_E \right)^{\sigma} + n_w \left(p^M_w \right)^{1-\sigma} \right]^{\frac{1}{1-\sigma}} \]  

(8a)

and

\[ G_W = \left[ p^E \left(p^M_E \right)^{\sigma} + n_w \left(p^M_w \right)^{1-\sigma} \right]^{\frac{1}{1-\sigma}}. \]  

(8b)

The price indices imply that, for a given level of prices, the region with the larger mass of manufacturing has the lower price index of manufactured goods (or the cost of living) because more varieties are produced locally without incurring transport costs.

### 3.3 Demand for goods by location

**Demand for food**

There are three sources of demand for food in addition to the own consumption by the unskilled workers producing food in the west. Denoting regional aggregate income as \( Y_r \) (\( r = E, W \)), since consumers spend a fixed share \( (1 - \mu) \) of income on food, demand for food from skilled workers in the west is

\[ \frac{(1 - \mu) Y^E E}{p^E_w}, \]  

(9a)

demand from unskilled workers employed in the western manufacturing sector is

\[ \frac{(1 - \mu)(1 - \theta^E) w^U_w}{2 p^E_w}, \]  

(9b)

and demand for food from the east, taking into account transport cost, is

\[ \frac{(1 - \mu) Y^E E}{p^E_w t^A}. \]  

(9c)

We denote the sum of the three expressions in (4.9a), (4.9b), and (4.9c) as \( D^E \).

**Demand for manufactured goods**

From the CES preferences of manufactured varieties, given the prices and income, total demand for a variety of manufactured good produced in the east, taking into account transport cost, is
\[ D^M_E = \left( p^M_E \right)^\mu Y_E + \left( p^M_W t^M \right)^\mu Y_W t^M. \]  

Likewise, total demand for a variety of manufactured good produced in the west is

\[ D^M_W = \left( p^M_W \right)^\mu Y_W + \left( p^M_W t^M \right)^\mu Y_W t^M. \]

Demand for raw materials from the manufacturing sector

Input demand for raw materials from manufacturing firms in both regions, given the firm output \( q_r \ (r = E, W) \), is

\[ n_E q_E + n_W q_W t^A, \]

including transport cost from the east to the west.

3.4 Spatial equilibrium in autarky

The economy is in spatial equilibrium when all goods and factor markets clear, firms achieve zero profits and the real wages of skilled workers are equalized. These conditions lead to the following results.

Unskilled wages and the price of manufactured goods

Perfect competition in the agricultural sector implies marginal cost pricing so that \( p^E_u = w^E_u \) and \( p^W_u = w^W_u \). Choosing food in the west as the numeraire good, \( p^W_u = w^W_u = 1 \). Then the prices of manufactured goods (6b and 7b) are now expressed as

\[ p^M_E = \frac{\sigma}{\sigma - 1} (\beta + 1) p^R_E \]

and

\[ p^M_W = \frac{\sigma}{\sigma - 1} \left( \beta + p^R_W t^A \right), \]

which are functions of raw material price \( p^R_E \). There are simple but important relationships between \( p^M_E \) and \( p^M_W \). First, an increase in agricultural transport cost \( (t^A) \) raises \( p^W \), because the delivered price of raw material rises in the west. Second, since

\[ \frac{d}{dp^R_E} \left( \frac{p^M_E}{p^M_W} \right) = \frac{\beta (\beta + 1)}{(\beta + p^R_W t^A)^2} > 0, \]

an increase in the price of raw material \( p^R_E \) raises the price of eastern manufactured goods relative to the west. This is because an increase in \( p^R_E \) implies local unskilled wage in the east is also rising, so the marginal cost of the east relative to the west rises. The effect is weaker with
a higher $t^A$. Given the mill prices, the price indices of manufactured goods (8a and 8b) in the two regions are

$$G_E = \left\{ n_E \left[ \frac{\sigma}{\sigma - 1} (\beta + 1) p^E_E \right]^{1-\sigma} + n_w \left[ \frac{\sigma}{\sigma - 1} (\beta + p^E_E t^A)^M \right]^{1-\sigma} \right\}^{1/1-\sigma} \tag{14a}$$

and

$$G_W = \left\{ n_E \left[ \frac{\sigma}{\sigma - 1} (\beta + 1) p^E_E t^M \right]^{1-\sigma} + n_w \left[ \frac{\sigma}{\sigma - 1} (\beta + p^E_E t^A)^M \right]^{1-\sigma} \right\}^{1/1-\sigma}, \tag{14b}$$

where full employment of skilled workers implies $n_E = \lambda S/\alpha$ and $n_w = (1-\lambda)S/\alpha$. Unlike the footloose entrepreneur model where the manufactured goods prices were constant, in the present model they are functions of the raw material price ($p^E_E$) and the price indices are non-linear in $p^E_E$. This prevents us from obtaining a general analytical solution of the model.

**Skilled wages**

In the manufacturing sector, assuming free entry and exit, equilibrium skilled wage corresponding to their full employment is determined by a bidding process for skilled workers, which continues until no firm can earn a positive profit at the equilibrium prices. This implies that in equilibrium a firm’s size is such that the operating profit exactly matches the fixed cost which is the wage paid for the skilled workers. In other words, a firm’s operating profit is entirely absorbed by the wage bill of its skilled workers. That is,

$$\alpha w^E_E = p^M_E q_E - (\beta + 1)p^E_E q_E \tag{15a}$$

and

$$\alpha w^S_W = p^M_W q_w - (\beta + p^E_E t^A)q_w, \tag{15b}$$

for the eastern and western firms, respectively. Substituting for $p^E_E$ and $p^W_W$ using (12a) and (12b), the equilibrium skilled wages are

$$w^E_E = \frac{(\beta + 1)p^E_E q_E}{\alpha(\sigma - 1)} \tag{16a}$$

and

$$w^S_W = \frac{(\beta + p^E_E t^A)q_w}{\alpha(\sigma - 1)}, \tag{16b}$$

where manufactured goods market clearing requires

$$q_E = D^M_E \tag{17a}$$

and
\[ q_w = D^M_w. \] (17b)

The aggregate regional incomes are total wages of unskilled and skilled workers:

\[ Y_e = \lambda S w^s_e + \frac{1}{2} p^r_e \] (18a)

and

\[ Y_w = (1 - \lambda) S w^s_w + \frac{1}{2} \] (18b)

The results so far imply that a higher level of \( \lambda \) increases (decreases) the market size of the east (west), which increases (decreases) per firm demand and output in the east (west), leading to a higher skilled wage in the east (‘market size’ effect). In addition, from (14a) and (14b), a higher \( \lambda \) lowers the eastern price index while raising it in the west. The change in the price indices has two opposite implications: on the one hand, lower price index in the east is beneficial for eastern consumers (‘cost-of-living’ effect). On the other hand, lower price indices reflect intensified local competition. From the manufacturing market clearing conditions (17a) and (17b), a lower price index reduces per firm demand and output in the east, which leads to lower skilled wage in the east (‘local competition’ effect).

**Unskilled labour market clearing**

Full employment of unskilled workers require that the supply of unskilled workers for manufacturing in each region meets the demand from manufacturing firms:

\[ \frac{1 - \theta_r}{2} = n, \beta q_r, \ (r = E, W). \] (19)

**Market clearing of the agricultural goods**

*Food market clearing.* Food supply from the west, except for own consumption of unskilled workers in the western agricultural sector, that is \( (\theta_w / 2) \mu \), should be equal to its total demand (9a, 9b, and 9c). Therefore,

\[ \frac{\theta_w}{2} \mu = D^F. \] (20)

*Raw material market clearing.* Supply of raw materials from the east, that is \( \theta_e / 2 \), should be equal to total input demand from the manufacturing sector (11).

\[ \frac{\theta_e}{2} = n_E q_E + n_W q_W t^d \] (21)
From the unskilled labour market clearing condition (19) and the raw material market clearing condition (21), we can delete $\theta$ to obtain

$$q_w = \frac{\alpha}{2S} - \lambda (\beta + 1) q_E. \tag{22}$$

From the unskilled labour market clearing condition (19) and the food market clearing condition (20), we can delete $\theta$ to obtain

$$p^E_r = 1 - \frac{2(1-\lambda)}{\alpha (1-\mu)} S \beta q_w - 2 S \left[ \lambda w^S_e + (1-\lambda) w^S_w \right]. \tag{23}$$

From (22) and (23),

$$p^E_r = 1 - \left[ \frac{\alpha \beta - 2 S \beta \lambda (\beta + 1) q_E}{\alpha (1-\mu) r^4} \right] - 2 S \left[ \lambda w^S_e + (1-\lambda) w^S_w \right]. \tag{24}$$

For a given level of output ($q_E$) and skilled wages ($w^S_r$, $r = E, W$),

$$\frac{dp^E_r}{d\lambda} = \frac{2 S \beta (\beta + 1) q_E}{\alpha (1-\mu) r^4} - 2 S \left[ \lambda w^S_e + (1-\lambda) w^S_w \right]. \tag{25}$$

Therefore if

$$\frac{\beta (\beta + 1)}{\alpha (1-\mu) r^4} > \frac{w^S_e - w^S_w}{q_E} \tag{26}$$

we have $dp^E_r/d\lambda > 0$, that is, increased manufacturing concentration in the east ($\lambda$) raises eastern local unskilled wage and raw material prices ($p^E_r$) as a result of congestion. This has two implications: on the one hand, as we have seen in (13), it makes eastern firms less competitive because a rise in $p^E_r$ raises the relative marginal cost of the eastern manufactured goods (‘relative cost’ effect). On the other hand, increased $p^E_r$ means a higher eastern aggregate income ($Y_E$) or a larger market size of the east (18a), which relatively favours eastern firms, by increasing its demand and output through the market size effect (‘indirect market size’ effect). The present model, therefore, has an additional channel through which the returns to the mobile factor are affected by the raw material price.

Finally, since skilled workers migrate to the region that offers the highest real wage, in equilibrium workers in the two regions achieve the same real wage ($\omega^M_1 = \omega^M_2$, $0 < \lambda < 1$). If this interior equilibrium is not achieved, the other possibility is a corner or a core-periphery outcome in which all skilled workers reside in one region, or are agglomerated, as a result of migration ($\lambda = 0$ or $\lambda = 1$). As the non-linearity of the price indices imply, we are unable to obtain analytical solutions for the interior equilibrium. We can, however, point out the forces
that determine geography.

**The forces affecting geography**

*Market size effect.* An increase in the share of the manufacturing sector in a region implies that expenditure of skilled workers shifts to that region, making the market size larger. For a given level of prices, this increases local demand per firm and raises profits. This supports agglomeration of the manufacturing sector.

*Cost-of-living effect.* The expression of the price indices in (14a) and (14b) imply that, at a given level of raw material price, an increase in the share of manufacturing in one region lowers the price index there and raises the price index in the other. This will attract skilled workers to the larger region, under a given level of nominal skilled wages. From a firm’s point of view, a lower price index reduces fixed costs which increase firm profits. This is another effect that supports agglomeration. The market size and the cost-of-living work in a cumulative way that reinforces each other.

*Local competition effect.* Competition is more intense in the region with the larger manufacturing sector. The decrease of the price index in the region with the larger manufacturing sector also implies that, given the level of prices and income, local demand per firm falls. Decreased demand leads to lower profits. Therefore, the increased size of the manufacturing sector in a region can work as a dispersion force. If this effect is not so strong, the cumulative causation of the cost-of-living and the market size effect sets in to create agglomeration of the manufacturing sector in one region.

*Additional forces caused by congestion in the east.* What is important in the present model is that there is an additional channel of congestion through which regional distribution of the manufacturing sector is affected. A larger share of the manufacturing sector in the east causes congestion in the east as it employs a larger share of local unskilled workers who produce raw materials in the eastern agricultural sector. As was shown in (25), congestion can drive up the raw material price \( p^R_E \) and equivalently the eastern unskilled wage \( w^U_E \). A rise in \( p^R_E \) has two opposite effects: on the one hand, as was shown in (13), it raises the marginal cost of manufacturing in the east relative to the west, making eastern firms less competitive (‘relative cost’ effect). This leads to lower demand and decreased profits in the east. On the other hand, a rise in \( p^R_E \) means larger market size in the east \( Y^e \), which relatively favours eastern firms through increased demand leading to higher profits (‘indirect market size’ effect).
Therefore, the formation of geography will be a net result of the market size effect and the cost-of-living effect plus potentially the indirect market size effect that support agglomeration versus the local competition effect and the relative cost effect that put brakes on agglomeration (Table 1). We will verify these forces in the numerical solution of the model for the case of Japan in Section 3.7. But before resorting to numerical solutions, we will work on the special case of complete agglomeration, $\lambda = 1$, which tells us part of the results; applying the sustainability analysis we consider under what conditions we can have complete agglomeration of the manufacturing industry.

<table>
<thead>
<tr>
<th>Table 1: The forces that affect the formation of geography</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Agglomeration forces</strong></td>
</tr>
<tr>
<td><em>Cost-of-living effect</em></td>
</tr>
<tr>
<td>Agglomeration of industry reduces the local price index. This implies higher real wages which further promote agglomeration.</td>
</tr>
<tr>
<td><em>Market size effect</em></td>
</tr>
<tr>
<td>Agglomeration implies having more skilled workers in a region. This also implies a larger market which raises profits and promotes further agglomeration.</td>
</tr>
<tr>
<td><strong>Dispersion forces</strong></td>
</tr>
<tr>
<td><em>Local competition effect</em></td>
</tr>
<tr>
<td>Agglomeration means intense competition in a region. This reduces firm profits and discourages agglomeration.</td>
</tr>
<tr>
<td><strong>Additional forces</strong></td>
</tr>
<tr>
<td>due to congestion in the east</td>
</tr>
<tr>
<td><em>Indirect market size effect</em></td>
</tr>
<tr>
<td>Agglomeration raises local unskilled wages. This means a larger market size which support further agglomeration.</td>
</tr>
<tr>
<td><em>Relative cost effect</em></td>
</tr>
<tr>
<td>Higher local unskilled wage and higher raw material price raises relative (marginal) cost of eastern firms. This discourages agglomeration in the east.</td>
</tr>
</tbody>
</table>

### 3.5 Solution for special cases

An analytical solution of the non-linear system described above is not available. However, we can solve for special cases, that is, $\lambda = 1$ and $\lambda = 0$, which are the cases of complete agglomeration in the east and in the west, respectively. This turns out to be useful because it helps us rough out the geography in the absence of a general analytical solution for $\lambda$. In this Subsection we derive solutions of the two cases. In the next subsection the solutions will be used for sustainability analyses.6

---

6 The $\lambda = 0$ case is omitted in this paper because it turns out to be irrelevant to the case of Japan.
Solution for $\lambda = 1$ (Complete manufacturing agglomeration in the east)

Suppose the manufacturing sector is completely agglomerated in the east so that $\lambda = 1$. The geography of this case can be described as in Figure 9. All manufactured goods are produced in the east, from which they are distributed to the east and the west.

![Figure 9: Geography of the $\lambda = 1$ case](image)

Since there is no manufacturing in the west, all unskilled workers in the west are employed in agriculture and total food supply is $\mu/2$. Then the food market clearing condition (20) reduces to

$$\frac{\mu}{2} = (1 - \mu)Y_E.$$  \hspace{1cm} (27)

Substituting for eastern aggregate income in (27) using (18a), we have

$$w^s_E = \frac{1}{2S} \left( \frac{\mu}{1 - \mu} - p^g_E \right).$$  \hspace{1cm} (28)

Unskilled labour market clearing (19) in the east and raw material market clearing (21) imply $(1 + \beta)n_E q_E = 1/2$ or

$$q_E = \frac{1}{2n_E(\beta + 1)}.$$  \hspace{1cm} (29)

where $n_E = S/\alpha$. Using (29) to substitute for $q_E$ in the equilibrium eastern skilled wage (16a) and solving for $p^g_E$, we obtain

$$p^g_E = 2Sw^s_E(\sigma - 1).$$  \hspace{1cm} (30)

From (28) and (30) eastern skilled wage and raw material price can be solved as

$$w^s_E = \frac{\mu}{2S\sigma(1 - \mu)}.$$  \hspace{1cm} (31a)
Several aspects of this solution are worth noting. First, (31a) and (31b) show that higher share of manufacturing in the economy ($\mu$) raises both the eastern skilled wage and raw material price, which expands the economy of the east. This is because the eastern economy as a whole represents the manufacturing industry under the assumption of $\lambda = 1$. Aggregate income ($Y_E$) is $\mu/2(1-\mu)$ in the east and $1/2$ in the west. Second, the elasticity of substitution between manufactured varieties ($\sigma$) has asymmetric effects on factor returns; when $\sigma$ is high the mark-up is small and firm sizes are larger, meaning that varieties are supplied in a larger quantity with lower prices. This leads to lower returns for skilled workers ($w^s_E$), while increased input demand for raw materials leads to higher returns for unskilled workers ($w^u_E$). Since $Y_E = \mu/2(1-\mu)$ and the eastern skilled wage bill is $\mu/2\sigma(1-\mu)$ and the eastern unskilled wage bill is $(\sigma-1)\mu/\sigma(1-\mu)$, the income share of skilled workers is $1/(\sigma-1)$; the income share of skilled workers decreases with $\sigma$.

### 3.6 Sustainability analysis of agglomeration

**Sustainability analysis of agglomeration in the east ($\lambda = 1$ case)**

We now consider whether $\lambda = 1$ is sustainable or not. $\lambda = 1$ is sustainable if no firm can start operating profitably by leaving (or defecting from) the east and relocating to the west. To analyse profitability, we need to derive and evaluate the hypothetical profit that can be earned if a firm relocated to the west.

Given the solution for $w^s_E$ in (31a) and for $p^R_E$ in (31b), the prices of manufactured goods, price indices and income in the two regions can be expressed as

$$p^M_E = \frac{\sigma}{\sigma-1}(\beta + 1)p^R_E = (\beta + 1)\frac{\mu}{1-\mu},$$

(32a)

$$G^M_E = \left(\frac{S}{\alpha}\right)^{1-\sigma}p^M_E,$$

(32b)

$$G^M_W = \left(\frac{S}{\alpha}\right)^{1-\sigma}p^M_E t^M,$$

(32c)

$$Y_E = Sw^s_E + \frac{p^R_E}{2} = \frac{\mu}{2(1-\mu)},$$

(32d)

and
Given \( p_E^R \), from (7b), a firm relocating to the west will set the mill price of its product as

\[
\tilde{p}_W = \frac{\sigma}{\sigma - 1} \left( \beta + p_E^R t^A \right) = \frac{\sigma \beta}{\sigma - 1} + \frac{\mu}{1 - \mu} t^A,
\]

where \( \tilde{p}_W \) is the price in the west that a firm in the east hypothesizes. (Tildes will be used hereafter to denote these hypothetical variables.) Substituting from (32a) to (32e), into the demand expression (10b) and rearranging, the hypothetical demand for a firm relocating to the west \( \tilde{D}_W^M \) can be derived as

\[
\tilde{D}_W^M = \frac{\mu}{\eta_E} \left( \tilde{p}_W^M \right)^{-\sigma} \left( p_E^M \right)^{-\sigma-1} \left[ t^M \right]^{-\sigma} Y_E + \left( t^M \right)^{-\sigma-1} Y_W \]

(33)

Substituting (34) into the hypothetical operating profit in the west, \( \tilde{\pi}_W = \tilde{p}_W \tilde{D}_W^M - (\beta + p_E^R t^A)\tilde{D}_W^M \), and rearranging, we have

\[
\tilde{\pi}_W = \frac{b \alpha}{S} \left[ \frac{p_E^M}{\tilde{p}_W^M} \right]^{\sigma-1} \left[ t^M \right]^{-\sigma} Y_E + \left( t^M \right)^{\sigma-1} Y_W \]

(35)

where \( b \equiv \mu / \sigma \).

The expression for the hypothetical profit in the west (35) can be interpreted as follows: the term inside the first bracket \( \left[ \cdot \right]^{\sigma-1} \) is the mill price of eastern manufactured goods relative to western manufactured goods. The higher (lower) it is, the higher (lower) the hypothetical operating profit in the west. In particular, a higher agricultural transport cost \( t^A \) always leads to lower operating profit in the west. This is because higher \( t^A \) increases the marginal cost of western manufacturing (33). The term in the second bracket reflects total market size adjusted for transport cost of manufactured goods from the viewpoint of operating in the west; the market size of the east \( Y_E \) is multiplied by \( \left( t^M \right)^{-\sigma} \), which means that higher transport cost of manufactured goods \( t^M \) works to the defecting firm’s disadvantage in its sales to the eastern consumers since delivered price increases when products are to be shipped from the west to the east. At the same time, however, higher \( t^M \) works to the advantage of the firm because it increases the delivered price of other manufactured goods to the west. Therefore, whether a higher \( t^M \) will favour the hypothetical operating profit in the west is ambiguous; it depends on relative market size of the east and the west. If \( \mu \) is small \((0 < \mu < 0.5)\), which implies a
smaller eastern market relative to the west, a higher $t^M$ leads to a higher hypothetical operating profit in the west because demand from the western market is more important than the east, and vice versa. Then high $t^M$ discourages relocation to the west while high $t^M$ may support relocation to the west when market size of the east is smaller than that of the west.

Whether relocation to the west will be profitable depends, however, also on fixed costs, that is, the wage bill paid to skilled workers. Since the cost of living is different in the west (food price is lower but manufactured goods are more expensive than in the east), a firm has to pay a compensated wage ($\tilde{w}_w^S$) to skilled workers in order to attract them to the west:

$$\tilde{w}_w^S = w_e^S \frac{(G_E^M t^M)^\mu}{(G_E^M)^\mu (t^M)^\mu} = w_e^S \left( \frac{t^M}{t^M} \right)^\mu. \tag{36}$$

Substituting (31a) into (36), the compensated wage for skilled workers relocating to the west is

$$\tilde{w}_w^S = \frac{bt^M}{2S(1-\mu)(t^M)^\mu}. \tag{37}$$

The term $\left( t^M \right)^\mu / (t^M)^\mu$ indicates the cost of living in the west relative to the east; higher $t^M$ means higher price of manufactured goods, while higher $t^M$ means lower price of food in the west compared to the east. Taken together, there are trade-offs for both $t^M$ and $t^M$ when we take into account both operating profits and fixed costs; increased $t^M$ may raise the hypothetical operating profit ($\tilde{\pi}_w$) in the west (depending on the market sizes of the east and the west), but at the same time it implies manufactured goods are more expensive in the west, which requires a higher compensated wage ($\tilde{w}_w^S$) for skilled workers, that is, higher fixed costs. Increased $t^M$ means lower hypothetical operating profits in the west because of higher transport costs of raw materials, but it also implies lower compensated wages for skilled workers (or lower fixed costs) in the west. We then need to evaluate the overall effect by inspecting hypothetical (pure) profit.

The hypothetical profit of relocating to the west ($\tilde{\Pi}_w$) is operating profit (35) minus fixed cost (37), that is, $\tilde{\Pi}_w = \tilde{\pi}_w - \alpha \tilde{w}_w^S$. A firm defects from the east when there is still a chance for starting profitable production in the west, by paying compensated wages for the skilled workers $\tilde{w}_w^S$.

---

7 Inspecting (35), the first derivative of $\left( t^M \right)^\mu / (t^M)^\mu$ with respect to $t^M$ is $\left( \frac{1-\sigma}{1-\mu} \right) \left( \frac{1-\sigma}{1-\mu} \right)^\sigma t^M \left( (t^M)^\mu + (t^M)^\mu - (t^M)^\mu \right)^2$, but its sign is ambiguous. The second derivative, $-\sigma (1-\sigma) t^M \frac{1}{1-\mu} \left( (t^M)^\mu + (t^M)^\mu - (t^M)^\mu \right)^2$, is positive. Also evaluating the first derivative at $t^M = 1$, we have $\frac{(1-\sigma)(1-2\mu)}{1-\mu}$. Therefore if $\mu < 0.5$, the first derivative will be positive for any $t^M > 1$ and if $\mu > 0.5$ the first derivative will be negative for any $t^M > 1$. 

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23
to attract them to the west. That is possible if $\tilde{\Pi}_W > 0$. Firms are indifferent between staying in the east and relocating to the west when $\tilde{\Pi}_W = 0$ or $\tilde{\pi}_W = \tilde{c}_w$. It is then convenient to define

$$\Omega_w \equiv \frac{\tilde{\pi}_W}{\tilde{c}_w}.$$  

We call $\Omega$ the potential function, and it is a function of parameters $\mu$, $\sigma$, $\beta$, $t^M$, and $t^A$. ($\Omega_w$ is the potential function of relocation to the west.) As long as $\Omega_w < 1$ agglomeration of firms in the east is sustainable since there is no incentive for a firm to relocate to the west. When $\Omega_w > 1$ firms defect from the east, hence agglomeration will no longer be sustainable. When $\Omega_w = 1$, a firm is indifferent between staying in the east and relocating to the west. Using the term introduced in Fujita et al. (1999), $\Omega_w = 1$ can be called sustain points; it is the border that agglomeration can be maintained, which is the key to describe economic geography.

Analysis of the effect of transport costs on the sustainability of agglomeration in the east

We now analyse how sustainability of $\lambda = 1$ is affected by transport costs, $t^M$ and $t^A$. We first consider the effect of $t^M$. By differentiating the potential ($\Omega_w$) with respect to $t^M$ we obtain

$$\frac{d\Omega_w}{dt^M} = \left[ \frac{p^M}{e^M} \right]^{\sigma-1} \left( t^A \right)^{\mu-\mu} \left[ \mu(1-\sigma-\mu)(t^M)^{\sigma-\mu} + (1-\mu)(\sigma-1-\mu)(t^M)^{\sigma-\mu} \right].$$  

Inspecting (39), since by assumption $1-\sigma-\mu < 0$, the first term in the final square bracket is negative. If $\sigma - 1 - \mu < 0$ (or $\sigma < \mu + 1$) then the second term is also negative, so $d\Omega_w/dt^M < 0$. Therefore if substitutability between manufactured varieties ($\sigma$) is low (or love-of-variety is strong) and/or share of manufacturing in the economy ($\mu$) is high, there is a possibility that higher $t^M$ reinforces agglomeration in the east. This is because, first, since low $\sigma$ implies low price elasticity of demand of manufactured goods, the advantage of a firm relocating to the west to supply for the western market compared to staying in the east and shipping its products to the west is small. Second, high $\mu$ implies larger market size of the east and low expenditure share of food, which makes the west less attractive, in terms of both market size and the cost of living. (Examples of this case is shown in Figures 13 and 14).

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8 We can equivalently ask if a firm relocating to the west can offer high enough nominal wages to skilled workers for them to attain higher real wages.

9 This corresponds to the ‘black-hole’ situation in which the agglomeration force is so strong that the ‘core’ is never
On the other hand, if
\[ \sigma - 1 - \mu > 0 \quad \text{and} \quad (t^M)^{(\sigma - 1)} > \frac{\mu(\sigma - 1 + \mu)}{(1 - \mu)(\sigma - 1 - \mu)}, \] (40)
then \( d\Omega_w / dt^M > 0 \). The second condition in (40) becomes effective when \( \mu \) is high, that is, when the eastern market is sufficiently large compared to the west. An example is shown in Figure 5b; when \( \mu \) is high, the potential curve may have a downward sloping area at \( t^M > 1 \).

The second condition tells that \( d\Omega_w / dt^M > 0 \) only holds when \( t^M \) is larger than its value at the local minimum of \( \Omega_w \).

One of the new aspects of the present model is that we can analyse the effect of \( t^A \) on geography. By differentiating the potential \( (\Omega_w) \) with respect to \( t^A \) we obtain
\[
\frac{d\Omega_w}{dt^A} = A \left[ \mu(\sigma - 1)(2 - \mu - \sigma)t^A + \beta\sigma(1 - \mu)t^A \right],
\] (41)
where
\[
A \equiv \left( t^A \right)^{-\sigma}(p^M)^{(\sigma - 1)}(p^M)^{-\sigma}d(t^M)^{(1 - \sigma - \mu)} + (1 - \mu)(t^M)^{(\sigma - 1 - \mu)} > 0.
\]
Inspecting (41), since by assumption \( 0 < \mu < 1, \sigma > 1, t^M > 1, \) and \( t^A > 1, \) if \( \mu + \sigma < 2 \) then \( d\Omega_w / dt^A > 0 \). This means that if (as was the case with \( t^M \)) substitutability between manufactured varieties \( (\sigma) \) is low and/or share of manufacturing in the economy \( (\mu) \) is small, an increase in \( t^A \) may raise the potential of the west. This is because, first, lower \( \sigma \) implies that higher production cost in the west due to transport cost of raw materials is less important.

Second, as we have seen in (31a) and (31b), smaller \( \mu \) implies smaller market size of the east and higher share of food in the cost-of-living, which makes the west more attractive. (An example of this case is shown in Figures 12 and 14).

On the other hand, if
\[
\mu + \sigma > 2 \quad \text{and} \quad \beta < \frac{\mu(\sigma - 1)(\mu + \sigma - 2)}{(1 - \mu)^2 \sigma} t^A
\] (42)
then \( d\Omega_w / dt^A < 0 \). Therefore if the unskilled labour input coefficient of manufacturing production \( (\beta) \), is not too large, higher \( t^A \) will strengthen agglomeration in the east. \( \beta \) being high and violating (42) means that the share of raw material cost in marginal cost of production is low (or production becomes more unskilled labour intensive). Then an increase in \( t^A \), which raises delivered price of raw materials in the west, becomes less important. Instead, resolved.
an increase in $t^d$ raises the cost-of-living (or food price) in the east, which makes the west more attractive. Figures 11a, 11b, and 13a are examples where (42) is satisfied. An extreme case of $\beta$ being high and violating the second condition of (42) is shown in Figures 5c and 7b. The result of the sustainability analysis of $\lambda = 1$ is summarized in Table 2 and in Figure 10, followed by examples of sustainability of $\lambda = 1$ and the corresponding geography in Figures 11 to 14.

### Table 2: Summary of sustainability analysis assuming manufacturing agglomeration in the east ($\lambda = 1$)

<table>
<thead>
<tr>
<th>Factors reinforcing agglomeration ($\Omega^W_\downarrow$)</th>
<th>Factors promoting dispersion ($\Omega^W_\uparrow$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t^M \uparrow$ raises the cost-of-living in the west because of high delivered price of manufactured goods in the west, thereby increasing fixed costs. (Important when $\mu$ is large.)</td>
<td>Raises the hypothetical western operating profit when the eastern market is smaller. (That is, when $\mu &lt; 0.5$.)</td>
</tr>
<tr>
<td>$t^d \uparrow$ lowers the hypothetical operating profit in the west because production in the west is disadvantaged due to high transport cost of raw materials</td>
<td>Raises the cost-of-living in the east because of high delivered food price in the east, thereby increasing fixed costs. (Important when $\mu$ is small.)</td>
</tr>
<tr>
<td>Overall effect on $\Omega^W$</td>
<td>Overall effect on $\Omega^W$ as long as $t^M \uparrow \Rightarrow \Omega^W_\uparrow$ as long as $\sigma &gt; \mu + 1$ and $(t^M)^{2(\sigma-1)} &gt; \frac{\mu(\sigma-1+\mu)}{(1-\mu)(\sigma-1-\mu)}$</td>
</tr>
<tr>
<td></td>
<td>$t^d \uparrow \Rightarrow \Omega^W_\downarrow$ as long as $\sigma &gt; 2 - \mu$ and $\beta &lt; \frac{\mu(\sigma-1)(\mu+\sigma-2)}{(1-\mu)^2 \sigma} t^d$</td>
</tr>
<tr>
<td></td>
<td>Opposite results for extreme parameters: $t^M \uparrow \Rightarrow \Omega^W_\downarrow$ when $\sigma &lt; \mu + 1$; $t^d \uparrow \Rightarrow \Omega^W_\uparrow$ when $\sigma &lt; 2 - \mu$</td>
</tr>
</tbody>
</table>
Note: * provided that $t^M$ satisfies condition (50) and $\beta$ satisfies condition (52).

Figure 10: Parameter zones and corresponding effect of transport costs on geography assuming agglomeration in the east ($\lambda = 1$)

**Sustainability of $\lambda = 1$ and geography in parameter zone I ($\sigma > \mu + 1$ and $\sigma > 2 - \mu$)**

Figures 11a, 11b and 11c are examples for the sustainability of $\lambda = 1$ in parameter zone I. In Figure 11a we have an upward sloping $\Omega_W = 1$ curve because $d\Omega_M/dt^M > 0$ and $d\Omega_M/dt^A < 0$ from our previous results. Agglomeration in the east is sustainable in the area above or to the left of the curve. As summarized in Table 2, the reason for this is that $t^M$ raises hypothetical operating profit in the west, while $t^A$ works against it by raising delivered price of raw materials in the west. Figure 11b is the result when $\mu$ is high and Figure 11c is the result when $\beta$ is high and violates the second condition in (42).

Note: This diagram is drawn assuming parameter values $\mu = 0.5$, $\sigma = 5$ and $\beta = 0.1$.

Figure 11a: Example of sustainability of $\lambda = 1$ and geography in parameter zone I
Sustainability of $\lambda = 1$ and geography in parameter zone II ($\sigma > \mu + 1$ and $\sigma < 2 - \mu$)

Figure 12 is an example for the sustainability of $\lambda = 1$ in parameter zone II. We have a downward sloping $\Omega_W = 1$ curve because $d\Omega_M/dt^M > 0$ and $d\Omega_M/dt^A > 0$. Agglomeration in the east is only sustainable in the area below the curve. The reason for this is that $t^M$ raises hypothetical operating profit in the west and $t^A$ lowers relative food price in the west, both leading to dispersion towards the west.
Sustainability of $\lambda = 1$ and geography in parameter zone III ($\sigma < \mu + 1$ and $\sigma > 2 - \mu$)

Figure 13a is an example for the sustainability of $\lambda = 1$ in parameter zone III. We have a downward sloping $\Omega_w = 1$ curve again because $\frac{d\Omega}{dt} < 0$ and $\frac{d\Omega}{dt} < 0$. But in contrast to Figure 12, agglomeration in the east is sustainable in the area above or to the right of the curve. The reason for this is that higher $\lambda$ raises cost of living in the west (high delivered price of manufactured goods) and higher $\lambda$ lowers hypothetical operating profit in the west, both making the west less profitable. As shown in Figure 13b, when $\beta$ is very high (that is, manufacturing technology is more unskilled labour consuming) the $\Omega_w = 1$ curve can be upward sloping (higher $\lambda$ leads to dispersion towards the west) because raw material price becomes less important and lower food price in the west makes operation in the west more profitable by lowering its fixed cost.
Figure 13b: Example of sustainability of $\lambda = 1$ and geography in parameter zone III (with high $\beta$)

Sustainability of $\lambda = 1$ and geography in parameter zone IV ($\sigma < \mu + 1$ and $\sigma < 2 - \mu$)

Figure 14 is an example for the sustainability of $\lambda = 1$ under parameter zone IV. We have an upward sloping $\Omega_W$ curve because $d\Omega_M/dt^M < 0$ and $d\Omega_M/dt^A > 0$. But in contrast to Figure 11a agglomeration in the east is sustainable in the area below or to the right of the curve. The reason for this is that higher $t^M$ raises cost of living in the west by raising delivered price of manufactured goods, while higher $t^A$ lowers relative food price in the west, making the west more profitable. In parameter zone IV, where $\sigma$ is very small, the cost of living or the fixed cost of production matters for the profitability of firm location.

Figure 14: Example of sustainability of $\lambda = 1$ and geography in parameter zone IV
3.7 Autarkic spatial equilibrium of the case of Japan

Numerical solution of autarkic spatial equilibrium of the case of Japan

In the previous subsection, we have seen various possible patterns of geography affected by parameter values using the sustainability analyses of the $\lambda = 1$ case. This subsection applies the analysis to the case of Japan in autarky. It can be done by relabelling ‘manufacturing’ as the silk fabric industry and ‘raw material’ as raw silk and also by employing appropriate parameter values for Japan. As seen above, parameters required are $\mu$, $\sigma$, $\beta$, $t^M$ and $t^A$. The parameters used are shown in Table 3.

<p>| | |</p>
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>$\mu$</td>
<td>0.25</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>6.6</td>
</tr>
<tr>
<td>$\beta$</td>
<td>0.03</td>
</tr>
<tr>
<td>$t^M$</td>
<td>1.5</td>
</tr>
<tr>
<td>$t^A$</td>
<td>1.25</td>
</tr>
</tbody>
</table>

$\beta$ is estimated using technological information of the silk-reeling industry in Minami and Makino (1995). It is estimated to be 0.03. The typical value of the share of the manufacturing sector in the economy ($\mu$) used in the literature is 0.4 as in Krugman (1991) or 0.5 as in Fujita et al (1999). However, in the 19th century the share of manufacturing is likely to have been lower. In fact Akimoto (1987) estimates that the Engel coefficient (the ratio of food expenditure over total expenditure) was 75%. Therefore we use $\mu = 0.25$ in the Japan case.

The elasticity of substitution $\sigma = 6.6$ for textiles is taken from Head and Mayer (2004). Transport cost parameters are estimated from regional price differential data: $t^A$ is estimated from Yamazaki (1983) that presents local agricultural prices and their delivered prices in major cities including Kyoto. $t^M$ is estimated based on information in Nakai and Shimada (1971) who studied financial data of Mitsui Echigoya department store containing procurement prices of Kyoto-made silk fabrics and the Edo (Tokyo) price of these products. We estimate from these sources that $t^M = 1.5$ and $t^A = 1.25$.

We note that our parameters in Table 3 has solutions for both $\lambda = 1$ and $\lambda = 0$. In addition,

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10 Parameters $S$ and $\alpha$ do not affect geography. We set $S = \alpha = 1$ in the numerical solutions.

11 Estimation is shown in Appendix 3.

12 Data is shown in Appendix 2.
it satisfies conditions (40) and (42), that is, \( \sigma - 1 - \mu > 0, \ t^M > 0.91, \ \mu + \sigma - 2 > 0 \) and \( \beta < 1.83 \kappa^A \), implying Japan's case is well within parameter zone I in Figure 10. It is also confirmed that \( \Omega_e \) always exceeds unity. Therefore \( \lambda = 0 \) is never sustainable. The sustain points for the case of Japan in autarky can be derived as shown in Figure 15. At the coordinate \((t^M, t^A) = (1.5, 1.25)\), the result suggests that the silk fabric industry was dispersed between the east and the west in autarky \((0 < \lambda < 1)\).

![Figure 15: Estimated autarkic spatial equilibrium of the case of Japan](image)

We need to solve the model numerically using the parameters in Table 3 to obtain the value of \( \lambda \). The result of the numerical solution of the case of Japan is shown in Figures 16 and 17. Figure 16 shows the value of \( \lambda \) for various combinations of \( t^M \) and \( t^A \) in three dimensions. Figure 17 shows \( \lambda \) for various levels of \( t^A \) in two dimensions by fixing \( t^M \) at 1.5. The value of \( \lambda \) obtained is 0.33 which means that a third of the silk fabric firms and skilled workers were located in east Japan and the rest in west Japan. This is consistent with historical observations that the silk fabric industry was dispersed between the east and the west, but with the west having a larger share.\(^{13}\)

\(^{13}\) In addition, as is shown in Table 4, the result that the western forms operate at a smaller scale is also consistent with the historical literature.
Figure 16: Estimated regional industrial distribution in autarkic Japan for various combinations of \( t^M \) and \( t^A \)

![Diagram showing estimated regional industrial distribution in autarkic Japan for various combinations of \( t^M \) and \( t^A \)](image)

Figure 17: Estimated regional industrial distribution in autarkic Japan for various levels of \( t^A \) holding \( t^M \) fixed at 1.5

![Diagram showing estimated regional industrial distribution in autarkic Japan for various levels of \( t^A \) holding \( t^M \) fixed at 1.5](image)

Whether the equilibrium is stable can be tested graphically as in Figure 18. It is confirmed that the autarkic spatial equilibrium is a stable one; suppose a fraction of firms move from the west to the east (which means an increase in \( \lambda \)). Figure 18 shows that profit will be higher in the west \((\pi_E - \pi_W < 0)\). Therefore firms will return to the west. On the contrary, moving a
fraction of firms to the west makes eastern profits higher \((\pi_E - \pi_W > 0)\), which again restores equilibrium.

![Figure 18: Stability test of autarkic spatial equilibrium of the Japan case](image)

**Explanation of forces at work based on numerical solutions of Japan’s case**

By perturbing \(\lambda\) in equilibrium, we can examine the forces at work. Starting from the autarkic spatial equilibrium \((\lambda = 0.33, E_0\) in Figure 19), suppose we moved a fraction of firms and skilled workers from the west to the east so that \(\lambda = 0.5\) \((E_1)\). The first column of Table 4 shows the solution of endogenous variables corresponding to \(E_0\) and the second column shows that of \(E_1\). By comparing these two, we see that firm profit in the east \((\pi_E)\) becomes negative, while it becomes positive in the west. This is the net outcome of the following effects; an increase in \(\lambda\) implies an increased market size in the east, which works to the advantage of eastern firms by increasing their demand (market size effect). A higher \(\lambda\) also leads to a lower price index in the east \((M_{EG}^E)\) which has two implications: one is that it benefits eastern firms through lower fixed cost as well as eastern consumers (cost-of-living effect). The other effect is that lower \(M_{EG}^E\), or more varieties being produced in the east, leads to reduced demand (local competition effect). In addition, in the present model with agricultural raw materials, a higher \(\lambda\) causes congestion in the east that raises local unskilled wage \((w_U^E)\) and raw silk price \((p_R^E)\).

An increase in \(p_R^E\) has two opposite effects: on the one hand it raises the eastern marginal production cost relative to the west (relative cost effect). (This is stronger the lower the agricultural transport cost \((t_A)\)). On the other hand, an increase in \(p_R^E\) raises eastern aggregate
income \( (Y_E) \) or market size (indirect market size effect). When \( \lambda \) is raised to 0.5, the relative cost effect through congestion in the east combined with the local competition effect is so strong that it reduces demand for eastern firms or output \( (q_E) \) and hence \( \pi_E \) turns negative. Therefore, firms and skilled workers will relocate back to the west to restore the equilibrium at \( E_0 \).

Suppose now, starting from \( E_0 \) again, we moved a fraction of firms and skilled workers from the east to the west this time so that \( \lambda = 0.1 \) \( (E_2 \) in Figure 19). We compare the first and the third column of Table 4. Since congestion in the east is relaxed, the price of raw silk \( (p_E^R) \) and equivalently the unskilled wage in the east \( (w_{E}^U) \) declines. This is advantageous for firms remaining in the east which now has lower relative costs \( (p_E^M/p_W^M) \) declines). In addition, the increased size of the western manufacturing sector means increased local competition leading to reduced demand for western firms. These effects combined outweigh the market size and the cost-of-living effects that support the larger manufacturing sector in the west. Therefore profits turn positive in the east and negative in the west, which again restores equilibrium, \( E_0 \), when firms and skilled workers relocate back to the east.

We can also confirm the effect of a change in the agricultural transport cost \( (t^A) \). Starting from \( E_0 \), suppose \( t^A \) increases from 1.25 to 1.3, to reach \( E_3 \) in Figure 19. Increased \( t^A \) means higher raw silk cost in the west. This can be seen in the fourth column of Table 5 as a decrease in the relative price of silk fabrics \( (p_E^M/p_W^M) \). This works to the disadvantage of western firms. In addition, higher local production cost raises the local price index \( (G_W^M) \) relative to the east, which also works to the disadvantage of western firms through increased fixed costs or higher cost of living of skilled workers in the west. Western profits \( (\pi_W) \) then turn negative, although there are food price increases in the east because of higher \( t^A \) which raises eastern cost of living and fixed costs. Therefore, \( E_3 \) is not a spatial equilibrium. Allowing for migration, firms and skilled workers will move to the east (or \( \lambda \) increases), until local competition and congestion in the east raises relative cost of production in the east put a brake on further relocation.

To summarize, on the one hand the silk fabric industry tends to agglomerate in one region through the market size effect and the cost-of-living effect which works in a circular way. On the other hand, one of the forces that keeps the silk fabric industry from agglomerating in either region is the local competition effect. The present model has additional forces that affect geography: the indirect market size effect and the relative marginal cost effect. The indirect
market size effect is the additional force that reinforces agglomeration in the east. Since agglomeration of the silk fabric industry in the east pulls unskilled labour from the eastern agricultural sector that produces raw silk, the local unskilled wage rises, which enlarges the size of the eastern market. Higher local unskilled wages, on the other hand, works to the disadvantage of eastern firms. This is the relative cost effect that works against agglomeration in the east. The level of $t^A$ affects the balance of these forces; the higher the $t^A$, the relative cost effect is weakened, which supports agglomeration in the east. Therefore, although it is standard in the literature to assume zero transport cost of the homogeneous good (that is, $t^A = 1$) and to only consider the effect of change in transport cost of the differentiated good ($t^M$), in the present model with raw materials, $t^A$ alone affects the location of industrial activities in the above manner.

![Figure 19: Perturbation exercise of the autarkic spatial equilibrium](image)

Figure 19: Perturbation exercise of the autarkic spatial equilibrium
## Table 4: Numerical solutions for the perturbation exercise

<table>
<thead>
<tr>
<th></th>
<th>$E_0$ (λ = 0.33)</th>
<th>$E_1$ (fixing λ = 0.5)</th>
<th>$E_2$ (fixing λ = 0.1)</th>
<th>$E_3$ ($t^4$ = 1.3) (fixing λ = 0.33)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autarkic spatial equilibrium</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$w^S_E$</td>
<td>0.02722</td>
<td>0.02637</td>
<td>-3.1%</td>
<td>0.02834</td>
</tr>
<tr>
<td>$w^S_W$</td>
<td>0.02373</td>
<td>0.02352</td>
<td>-0.9%</td>
<td>0.02428</td>
</tr>
<tr>
<td>$w^E_E$ = $p^E_E$</td>
<td>0.2637</td>
<td>0.2673</td>
<td>1.4%</td>
<td>0.2590</td>
</tr>
<tr>
<td>$w^E_W$ = $p^E_W$</td>
<td>1.000</td>
<td>1.000</td>
<td></td>
<td>1.000</td>
</tr>
<tr>
<td>$Y_E$</td>
<td>0.1408</td>
<td>0.1469</td>
<td>4.3%</td>
<td>0.1325</td>
</tr>
<tr>
<td>$Y_W$</td>
<td>0.5160</td>
<td>0.5118</td>
<td>-0.8%</td>
<td>0.5219</td>
</tr>
<tr>
<td>$p^M_E$</td>
<td>0.3201</td>
<td>0.3245</td>
<td>2.0%</td>
<td>0.3145</td>
</tr>
<tr>
<td>$p^M_W$</td>
<td>0.4239</td>
<td>0.4292</td>
<td>1.4%</td>
<td>0.4170</td>
</tr>
<tr>
<td>$p^M_E$ / $p^M_W$</td>
<td>0.7553</td>
<td>0.7561</td>
<td>0.1%</td>
<td>0.7541</td>
</tr>
<tr>
<td>$G^M_E$</td>
<td>0.3877</td>
<td>0.3659</td>
<td>-5.6%</td>
<td>0.4598</td>
</tr>
<tr>
<td>$G^M_W$</td>
<td>0.4377</td>
<td>0.4521</td>
<td>3.3%</td>
<td>0.4208</td>
</tr>
<tr>
<td>$n_E$</td>
<td>0.3277</td>
<td>0.5000</td>
<td></td>
<td>0.1000</td>
</tr>
<tr>
<td>$n_W$</td>
<td>0.6723</td>
<td>0.5000</td>
<td></td>
<td>0.9000</td>
</tr>
<tr>
<td>$θ_E$</td>
<td>0.9890</td>
<td>0.9855</td>
<td></td>
<td>0.9934</td>
</tr>
<tr>
<td>$θ_W$</td>
<td>0.9851</td>
<td>0.9879</td>
<td></td>
<td>0.9815</td>
</tr>
<tr>
<td>$q_E$</td>
<td>0.5612</td>
<td>0.4822</td>
<td>-14.1%</td>
<td>1.1029</td>
</tr>
<tr>
<td>$q_W$</td>
<td>0.3696</td>
<td>0.4027</td>
<td>9.0%</td>
<td>0.3435</td>
</tr>
<tr>
<td>$Ω^E_E = Ω^E_W$</td>
<td>0.02918</td>
<td>0.02868</td>
<td>-1.7%</td>
<td>0.0301</td>
</tr>
<tr>
<td>$π_E$</td>
<td>0.0000</td>
<td>-0.002663</td>
<td>-</td>
<td>0.0232</td>
</tr>
<tr>
<td>$π_W$</td>
<td>0.0000</td>
<td>0.002663</td>
<td>-</td>
<td>-0.0026</td>
</tr>
<tr>
<td>$λ$</td>
<td>0.3277</td>
<td>0.5 (fixed)</td>
<td>-</td>
<td>0.1 (fixed)</td>
</tr>
</tbody>
</table>

Note: % changes are calculated in comparison to the autarky equilibrium in the first column.

### Sensitivity analyses of the case of Japan

The above analysis is based on the set of parameters shown in Table 3. Sensitivity of results to parameter values are shown in Figures 20a to Figure 20c. Figure 20a shows the effect of changing the share of the silk fabric industry in the economy ($µ$). A lower $µ$ reinforces agglomeration in the east because it reduces eastern cost relative to the west. A higher $µ$ works in the opposite way to support dispersion toward the west. But the increase in the relative marginal cost of the east is small when $t^4$ is high, in which case a higher $µ$, that also implies

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14 See (32a) and (33).
a larger eastern market size, reinforces agglomeration in the east. This is why the slope of the sustain point curve for \( \mu = 0.4 \) becomes flatter. Our autarky result that the silk fabric industry was dispersed between the east and the west holds as long as \( \mu \) is larger than approximately 0.1.

Figure 20a: Sensitivity to \( \mu \) (expenditure share of silk fabrics)

Figure 20b shows the effect of changing the elasticity of substitution between varieties of silk fabrics (\( \sigma \)). A lower \( \sigma \) tends to reinforce agglomeration in the east because it raises the hypothetical price that a relocating firm will set in the west (\( \tilde{\mu}_W^M \)), which leads to lower potential in the west (\( \lambda_W \)). (But this effect is weakened when \( t^A \) is high.) \( \sigma = 6.6 \) is used as the base case but Hummels (1999) reports \( \sigma = 8.32 \) for textile yarn and \( \sigma = 5.17 \) for textile fibres. \( \sigma \) in this range does not affect our result that the silk fabric industry was dispersed between the east and the west in autarky.

Figure 20b: Sensitivity to \( \sigma \) (elasticity of substitution between varieties of silk fabrics)
Figure 20c shows the effect of changing the value of the unskilled labour input coefficient of silk fabric production ($\beta$). (Higher $\beta$ implies the industry is unskilled labour intensive and lower $\beta$ implies it is raw material intensive.) An increase in $\beta$ increases unskilled labour cost and the (marginal) cost of production in both regions. But the rate of increase is lower in the east than in the west as long as $p^e_t t^A < 1$, which leads to a lower hypothetical operating profit in the west.\(^{15}\) This is why a higher value of $\beta$ reinforces the agglomeration of the silk fabric industry in the east. Our autarky result holds as long as $\beta$ is smaller than approximately 0.1. This is considered to be the upper bound estimate of $\beta$.\(^{16}\)

![Figure 20c](image)

**Figure 20c:** Sensitivity to $\beta$ (unskilled labour input coefficient for silk fabric production)

### 4. The International Trade Model

#### 4.1 Additional assumptions of the international trade model

We now introduce a foreign location and international transport cost between home and foreign denoted by $T > 1$. The two domestic regions, the east and the west, have equal access to foreign, that is, international transport cost from the east and from the west are the same. This can be interpreted as both regions having ports for international trade. In fact, multiple ports were opened in the case of Japan. Therefore, results presented hereafter are not due to such factors as port advantage in one region. For simplicity, internal geography of foreign is not considered. This means that the foreign country is treated as a dimensionless point: transport costs $t^M$ and $t^A$ are not assumed within the foreign country (Figure 21). Factors are not

\(^{15}\) See (32a) and (33).

\(^{16}\) See Appendix 3 for the estimation of $\beta$. 

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mobile internationally.

As we have seen in Section 2, Japan mainly exported raw silk (later with some silk fabrics) and imported cotton and woollen fabrics. We would like to analyse the effect of both raw silk and silk fabric exports which can be considered as intra-industry trade in textiles between Japan and foreign. For this purpose we assume foreign is an economy which produces raw materials (such as cotton and wool) and manufactured goods (such as cotton and woollen fabrics) that are substitutable for manufactured goods produced in home (such as silk fabrics). The foreign economy spends a fixed share, $\chi$, of its income on imported raw materials (raw silk) and $1 - \chi$ on final goods (textiles) both locally produced and imported. We abstract from modelling how the imported raw material is used in foreign. We first analyse the base case in which Japan only exports raw silk and imports foreign textiles, that is, the $\chi = 1$ case, which is followed by sensitivity analyses.

![Image of geographical setting of the international trade model](image)

**Figure 21: Geographical setting of the international trade model**

### 4.2 Some modifications of the model

International trade of manufactured goods affect local price indices, reflecting the fact that foreign varieties are now available for domestic consumers. Using subscript $f$ to denote foreign variables, introducing the mill price of foreign manufactured goods ($p^M_f$) and the mass of foreign firms ($n_f$), the price indices in each location are amended as follows:

$$G^M_E = \left[ n_E \left( p^M_E \right)^{1-\sigma} + n_W \left( p^M_W T^E \right)^{1-\sigma} + n_f \left( p^M_f T \right)^{1-\sigma} \right]^{\frac{1}{1-\sigma}}, \quad (43a)$$

$$G^M_W = \left[ n_E \left( p^M_E \right)^{1-\sigma} + n_W \left( p^M_W \right)^{1-\sigma} + n_f \left( p^M_f T \right)^{1-\sigma} \right]^{\frac{1}{1-\sigma}}, \quad (43b)$$

Tamura (2001) finds that imported woollen fabrics in particular became popular among the general public of Japan and that it imposed competitive pressure on domestic silk fabric producers.
and
\[ G_f^M = \left[ n_E \left( p_E^M T \right)^{-\sigma} + n_W \left( p_W^M T \right)^{-\sigma} + n_f \left( p_f^M \right)^{-\sigma} \right]^{-\frac{1}{\sigma}}. \] (43c)

Denoting foreign skilled and unskilled labour stock as \( S_f \) and \( L_f \), respectively, foreign aggregate wage income is written as
\[ Y_f = S_f w^S_f + (1 - \gamma)w^U_f L_f + \gamma p^E_f L_f, \] (44)
where \( \gamma \) is the share of foreign unskilled labour producing raw materials. Then demand for home produced raw materials from foreign, including transport cost, is
\[ \frac{\chi Y_f}{p_f^E T}, \] (45)
and demand for manufactured goods produced in the east, the west, and foreign, including transport costs, are expressed as follows,
\[ D^M_E = \mu \left( p_E^M T \right)^{-\sigma} \left( G_E^M \right)^{\sigma-1} Y_E + \mu \left( p_W^M T \right)^{-\sigma} \left( G_W^M \right)^{\sigma-1} Y_W + \left( 1 - \chi \right) \left( p_f^M T \right)^{-\sigma} \left( G_f^M \right)^{\sigma-1} Y_f T, \] (46a)
\[ D^M_W = \mu \left( p_W^M T \right)^{-\sigma} \left( G_W^M \right)^{\sigma-1} Y_W + \mu \left( p_W^M T \right)^{-\sigma} \left( G_W^M \right)^{\sigma-1} Y_W + \left( 1 - \chi \right) \left( p_f^M T \right)^{-\sigma} \left( G_f^M \right)^{\sigma-1} Y_f T, \] (46b)
and
\[ D^M_f = (1 - \chi) \left( p_f^M T \right)^{-\sigma} \left( G_f^M \right)^{\sigma-1} Y_f + \mu \left( p_f^M T \right)^{-\sigma} \left( G_f^M \right)^{\sigma-1} Y_f + \mu \left( p_f^M T \right)^{-\sigma} \left( G_f^M \right)^{\sigma-1} Y_f T, \] (46c)
where \( \chi = 1 \) in our base case.

The value of home imports and exports should be equalised in equilibrium, where export is foreign demand for raw silk (45) and import is the demand for manufactured goods produced in foreign (46c).

4.3 Comparison of autarky and trading equilibrium of the case of Japan

Parameters for international transport cost and foreign size

In addition to the parameters used in the previous section for autarky equilibrium, we need to specify international transport cost and foreign size to describe economic geography in trading equilibrium. First, concerning international transport cost, City of Yokohama (1999) reports f.o.b. price of Japanese silk and its prices in Lyon and London in the 1860s. Taking the ratio of the two prices, we can obtain an estimate of international iceberg transport cost of silk to be around 1.8. However, Sugiyama (1979) reports Yokohama price was around 80% of the price of Japanese silk in European markets, which leads to a much lower iceberg transport cost of 1.25.
We use an intermediate value of 1.5 as a base case.\textsuperscript{18} Second, we choose the size of the foreign exporting sector so that half of Japanese raw silk is exported. This comes from the data in Table 4.6 that depending on the year, 40 to 80% of domestic production was exported.\textsuperscript{19}

\textbf{Table 5: Domestic raw silk output and export (units in 1,000 kan)}

<table>
<thead>
<tr>
<th>Year</th>
<th>Output</th>
<th>Export</th>
<th>Export/Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>1887</td>
<td>805</td>
<td>504</td>
<td>62.5%</td>
</tr>
<tr>
<td>1890</td>
<td>922</td>
<td>338</td>
<td>36.6%</td>
</tr>
<tr>
<td>1892</td>
<td>1,173</td>
<td>869</td>
<td>74.1%</td>
</tr>
<tr>
<td>1895</td>
<td>1,709</td>
<td>930</td>
<td>54.4%</td>
</tr>
<tr>
<td>1897</td>
<td>1,641</td>
<td>1,107</td>
<td>67.5%</td>
</tr>
<tr>
<td>1900</td>
<td>1,893</td>
<td>741</td>
<td>39.1%</td>
</tr>
<tr>
<td>1902</td>
<td>1,834</td>
<td>1,292</td>
<td>70.5%</td>
</tr>
<tr>
<td>1905</td>
<td>1,949</td>
<td>1,167</td>
<td>59.9%</td>
</tr>
<tr>
<td>1907</td>
<td>2,452</td>
<td>1,500</td>
<td>61.2%</td>
</tr>
<tr>
<td>1910</td>
<td>3,174</td>
<td>2,416</td>
<td>76.1%</td>
</tr>
<tr>
<td>1912</td>
<td>3,644</td>
<td>2,790</td>
<td>76.6%</td>
</tr>
<tr>
<td>1916</td>
<td>3,741</td>
<td>3,318</td>
<td>88.7%</td>
</tr>
</tbody>
</table>

Note: 1 Kan=3.75kg  
Source: City of Yokohama (1965)

Comparison of autarky and trading equilibrium: change in regional distribution of firms

By numerically solving the international trade model using the parameters, we obtain the share of the silk fabric industry (and skilled workers) in the east (\( \lambda \)) after the port openings. The result for various combinations of domestic transport costs are shown in Figure 22.

For \( t^M = 1.5 \) and \( t^d = 1.25 \), we have \( \lambda = 0.89 \). Recalling the result in the previous section that the share of the silk industry in the east was 33% in autarky, it is estimated to increase to 89% in trading equilibrium. Our explanation for the west-east shift of economic activities in Japan after the port openings is that trade liberalization promoted agglomeration of such industries as the silk fabric industry from the west to the east, where raw materials were produced.

\textsuperscript{18} As a comparison, using data in North (1958), iceberg transport cost of wheat from Australia to Britain in the 19th century can be calculated to be around 1.25 to 1.3.

\textsuperscript{19} Sensitivity of results to parameters is considered in the next subsection.
Figure 22: Estimated regional industrial distribution in Japan after the port openings for various combinations of $t^M$ and $t^A$.

Table 6a compares numerical solutions of 1) the endogenous variables in autarky (first column), 2) the impact of introducing international trade while keeping the regional share of the silk fabric industry unchanged at $\lambda = 0.33$ (second column), and 3) the effect of international trade when firm relocation and migration of skilled workers are allowed for (third column).

In autarky, firms operate in the west even though it is a disadvantaged location in terms of raw material cost. The reason for firms being able to operate in the west is because there is a large enough local market, protected by the domestic transport cost of final goods ($t^M$), and a low enough domestic agricultural transport cost ($t^A$). In fact, as shown in Table 6b, the western firms almost totally rely on the local market; 98.6% of their output is sold locally, in contrast to eastern firms that sell 53.7% locally and 42.7% in the west.

With international trade, consumers enjoy increased varieties available due to imported foreign textiles to which some of their income is allocated. According to Table 6c, in autarky, eastern consumers spend most of their income on local varieties, but after trade liberalization they spend 71.2% on imported varieties and 26.9% on (local) eastern varieties. Consumers in the west spend 73.3% on western varieties and 26.7% on eastern varieties in autarky, but spend 81.2% on foreign varieties after the introduction of trade.

On the other hand, home firms lose with the pattern of trade that Japan exports raw silk only, because home firms’ domestic market share declines and increased raw silk cost worsens the competitiveness of silk fabrics. Both eastern and western firms’ output drop considerably (second column, Table 6a). The effect, however, is asymmetric: although the rise in the raw silk
price works against the eastern firms by raising relative cost of the east, eastern firms do better (or survive) because they are always operating at a lower (marginal) cost than the western firms; the loss of local market is larger for western firms, since consumers in the west allocate higher expenditure on imported textiles than the eastern consumers. In addition, the rise in the raw silk price implies an increased market size of the east. (This is the indirect market size effect induced by foreign demand for raw silk.) Eastern profits therefore turn positive. Allowing for migration, western firms and skilled workers relocate from the west to the east, to reach a spatial equilibrium with trade until congestion in the east stops further relocation (third column, Table 6a). Therefore our finding is that the majority of firms can locate in the west in autarky, but with international trade implying import competition by substitutable foreign varieties, the west becomes a disadvantaged location compared to the east.

### Table 6a: Effect of international trade on the endogenous variables, base case ($\chi = 1$)

<table>
<thead>
<tr>
<th></th>
<th>Autarkic spatial equilibrium ($\lambda = 0.33$)</th>
<th>Introducing international trade fixing $\lambda = 0.33$</th>
<th>Spatial equilibrium with trade ($\lambda = 0.89$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$w^W_E$</td>
<td>0.02722</td>
<td>0.007635</td>
<td>0.006950</td>
</tr>
<tr>
<td>$w^S_W$</td>
<td>0.02373</td>
<td>0.006513</td>
<td>0.006075</td>
</tr>
<tr>
<td>$w^E_W = p^E_W$</td>
<td>0.2637</td>
<td>0.3155</td>
<td>0.3189</td>
</tr>
<tr>
<td>$w^E_W = p^E_W$</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>$Y^E_E$</td>
<td>0.1408</td>
<td>0.1602</td>
<td>0.1656</td>
</tr>
<tr>
<td>$Y^W_W$</td>
<td>0.5160</td>
<td>0.5044</td>
<td>0.5007</td>
</tr>
<tr>
<td>$P^M_E$</td>
<td>0.3201</td>
<td>0.3830</td>
<td>0.3872</td>
</tr>
<tr>
<td>$P^M_W$</td>
<td>0.4239</td>
<td>0.5001</td>
<td>0.5052</td>
</tr>
<tr>
<td>$P^M_E / P^M_W$</td>
<td>0.7553</td>
<td>0.7657</td>
<td>0.7663</td>
</tr>
<tr>
<td>$G^E_E$</td>
<td>0.3877</td>
<td>0.3886</td>
<td>0.3605</td>
</tr>
<tr>
<td>$G^M_W$</td>
<td>0.4377</td>
<td>0.4019</td>
<td>0.4111</td>
</tr>
<tr>
<td>$n^E_E$</td>
<td>0.3277</td>
<td>0.3277</td>
<td>0.8895</td>
</tr>
<tr>
<td>$n^W_W$</td>
<td>0.6723</td>
<td>0.6723</td>
<td>0.1105</td>
</tr>
<tr>
<td>$\theta^E_E$</td>
<td>0.9890</td>
<td>0.9989</td>
<td>0.9937</td>
</tr>
<tr>
<td>$\theta^W_W$</td>
<td>0.9851</td>
<td>0.9969</td>
<td>0.9995</td>
</tr>
<tr>
<td>$q^E_E$</td>
<td>0.5612</td>
<td>0.1580</td>
<td>0.1185</td>
</tr>
<tr>
<td>$q^W_W$</td>
<td>0.3696</td>
<td>0.07610</td>
<td>0.07936</td>
</tr>
<tr>
<td>$\omega^E_E = \omega^W_W$</td>
<td>0.02918</td>
<td>0.008180</td>
<td>0.007587</td>
</tr>
<tr>
<td>$\pi^E_E$</td>
<td>0.0000</td>
<td>0.00153</td>
<td>0.0000</td>
</tr>
<tr>
<td>$\pi^W_W$</td>
<td>0.0000</td>
<td>-0.0007467</td>
<td>0.0000</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>0.3277</td>
<td>0.3277 (fixed)</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

Note: % changes are calculated in comparison to the autarky equilibrium in the first column.
Table 6b: Effect of international trade on the source of demand of typical eastern and western firms, base case ($\chi = 1$)

<table>
<thead>
<tr>
<th>Location of production</th>
<th>Source of demand</th>
<th>Autarkic spatial equilibrium ($\lambda = 0.33$)</th>
<th>Introducing international trade fixing $\lambda = 0.33$</th>
<th>Spatial equilibrium with trade ($\lambda = 0.89$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>East</td>
<td>East</td>
<td>57.3%</td>
<td>71.8%</td>
<td>60.6%</td>
</tr>
<tr>
<td></td>
<td>West</td>
<td>42.7%</td>
<td>28.2%</td>
<td>39.4%</td>
</tr>
<tr>
<td></td>
<td>Foreign</td>
<td>-</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>West</td>
<td>East</td>
<td>1.4%</td>
<td>2.6%</td>
<td>1.6%</td>
</tr>
<tr>
<td></td>
<td>West</td>
<td>98.6%</td>
<td>97.4%</td>
<td>98.4%</td>
</tr>
<tr>
<td></td>
<td>Foreign</td>
<td>-</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Note: Includes transport costs.

Table 6c: Effect of international trade on the expenditure of eastern and western consumers, base case ($\chi = 1$)

<table>
<thead>
<tr>
<th>Location of consumers</th>
<th>Origin of product</th>
<th>Autarkic spatial equilibrium ($\lambda = 0.33$)</th>
<th>Introducing international trade fixing $\lambda = 0.33$</th>
<th>Spatial equilibrium with trade ($\lambda = 0.89$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>East</td>
<td>East</td>
<td>93.8%</td>
<td>26.9%</td>
<td>49.7%</td>
</tr>
<tr>
<td></td>
<td>West</td>
<td>6.2%</td>
<td>1.9%</td>
<td>0.2%</td>
</tr>
<tr>
<td></td>
<td>Foreign</td>
<td>-</td>
<td>71.2%</td>
<td>50.1%</td>
</tr>
<tr>
<td>West</td>
<td>East</td>
<td>26.7%</td>
<td>4.7%</td>
<td>13.0%</td>
</tr>
<tr>
<td></td>
<td>West</td>
<td>73.3%</td>
<td>14.1%</td>
<td>2.3%</td>
</tr>
<tr>
<td></td>
<td>Foreign</td>
<td>-</td>
<td>81.2%</td>
<td>84.7%</td>
</tr>
</tbody>
</table>

Note: Includes transport costs.

Comparison of autarky and trading equilibrium: welfare

The Impact on welfare of the port openings on the three factors can be examined by comparing the real wages in autarky and in trading equilibrium (Figure 23). All consumers gain from increased availability of varieties. However, the net effect differs; eastern farmers, who raised silkworms to supply raw silk, are likely to gain most from increased raw silk prices, while the skilled workers lose due to foreign competition and increased raw silk prices. This result is consistent with historical observations that emphasize port openings brought huge gains to (raw silk) farmers in east Japan. The additional finding in this analysis is the strong negative impact on skilled workers’ welfare.

20 For example, Saito and Tanimoto (2003).
4.4 Sensitivity analyses

Different patterns of trade

We vary the foreign expenditure share on textiles ($\chi$, $0 \leq \chi \leq 1$). $\chi = 0$ corresponds to the case in which all trade is intra-industry trade in the final good (textiles). As shown in Figure 24, at any level of $\chi$, opening up to international trade promotes agglomeration of the silk fabric industry in the east, compared to the autarky situation.

As $\chi$ is reduced from one, meaning that home firms can export silk fabrics, increased relative cost of the east (due to higher local unskilled wage and raw material prices) starts working to the advantage of western firms in exporting to the foreign market. This is why $\lambda$ is not as high as it was in the $\chi = 1$ case where there were no export of silk fabrics. However, when $\chi$ is close to zero, meaning that raw silk is not directly exported, the rise in raw silk price ($p^R_E$) is small. Then the rise in the relative cost of eastern firms will be small and it is outweighed by increased foreign demand for eastern silk fabrics, making the east profitable (Table 7). This leads to the non-linear relation between $\chi$ and $\lambda$.
We can also examine the welfare effects of the port openings on the three production factors by comparing real wages in autarky and in trading equilibrium for different levels of $\chi$. Figure 25 shows the change in real wages after the port openings for various levels of $\chi$. (The result of $\chi=1$ was highlighted in Figure 23.) The negative effect on skilled workers is much milder if $\chi$ is low, that is, if Japan exported silk fabrics instead of raw silk. The is because, with $\chi < 0$, both foreign demand for silk fabrics and reduced demand for raw silk or the cost of home firms that makes silk fabrics competitive to foreign textiles, alleviates import competition of foreign textiles.

Figure 25: Effect of port openings on welfare for various levels of foreign expenditure share on raw silk ($\chi$)
Table 7: Effect of international trade on the endogenous variables, the case of intra-industry trade in textiles ($\chi = 0$)

<table>
<thead>
<tr>
<th></th>
<th>Autarkic spatial equilibrium ($\lambda = 0.33$)</th>
<th>Introducing international trade fixing $\lambda = 0.33$</th>
<th>Spatial equilibrium with trade ($\lambda = 0.57$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$w^S_E$</td>
<td>0.02722</td>
<td>0.02732</td>
<td>0.02622</td>
</tr>
<tr>
<td>$w^S_W$</td>
<td>0.02373</td>
<td>0.02374</td>
<td>0.02341</td>
</tr>
<tr>
<td>$w^U_E = p^*_E$</td>
<td>0.26371</td>
<td>0.2655</td>
<td>0.2712</td>
</tr>
<tr>
<td>$w^U_W = p^*_W$</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
<tr>
<td>$y^A_E$</td>
<td>0.14077</td>
<td>0.1417</td>
<td>0.1506</td>
</tr>
<tr>
<td>$y^A_W$</td>
<td>0.5160</td>
<td>0.5160</td>
<td>0.5100</td>
</tr>
<tr>
<td>$p^E_M$</td>
<td>0.3201</td>
<td>0.3223</td>
<td>0.3292</td>
</tr>
<tr>
<td>$p^W_M$</td>
<td>0.42385</td>
<td>0.4265</td>
<td>0.4348</td>
</tr>
<tr>
<td>$p^E_M / p^W_M$</td>
<td>0.75526</td>
<td>0.7557</td>
<td>0.7570</td>
</tr>
<tr>
<td>$g^E_M$</td>
<td>0.3877</td>
<td>0.3841</td>
<td>0.3586</td>
</tr>
<tr>
<td>$g^W_M$</td>
<td>0.4377</td>
<td>0.4274</td>
<td>0.4447</td>
</tr>
<tr>
<td>$n^E$</td>
<td>0.3277</td>
<td>0.3277</td>
<td>-</td>
</tr>
<tr>
<td>$n^W$</td>
<td>0.6723</td>
<td>0.6723</td>
<td>0.4265</td>
</tr>
<tr>
<td>$\theta^E$</td>
<td>0.99890</td>
<td>0.99873</td>
<td>0.9819</td>
</tr>
<tr>
<td>$\theta^W$</td>
<td>0.98509</td>
<td>0.9865</td>
<td>0.9909</td>
</tr>
<tr>
<td>$q^E$</td>
<td>0.5612</td>
<td>0.6474</td>
<td>0.5258</td>
</tr>
<tr>
<td>$q^W$</td>
<td>0.3696</td>
<td>0.3350</td>
<td>0.3553</td>
</tr>
<tr>
<td>$\omega^E_M = \omega^M_W$</td>
<td>0.02918</td>
<td>0.02936</td>
<td>0.02867</td>
</tr>
<tr>
<td>$\pi^E$</td>
<td>0.000</td>
<td>0.004290</td>
<td>-</td>
</tr>
<tr>
<td>$\pi^W$</td>
<td>0.000</td>
<td>-0.002092</td>
<td>-</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>0.3277 (fixed)</td>
<td>0.3277 (fixed)</td>
<td>0.5735</td>
</tr>
</tbody>
</table>

Note: % changes are calculated in comparison to the autarky equilibrium in the first column.

**Different size of the foreign economy**

Figure 26 shows the effect of changing the foreign size on the share of industry after trade liberalization compared to the base case. A smaller foreign size weakens the agglomeration effect in home while a larger foreign economy strengthens domestic agglomeration. The reason why the east becomes more attractive is because increased foreign demand for raw silk (and the resulting higher raw silk price) relatively supports eastern firms through the indirect market size effect, particularly when $\chi$ is high, and also because eastern firms (that are operating at lower costs than western firms) increase their exports when $\chi$ is low.
Different levels of international transport cost ($T$)

Figure 27 shows the effect of changing the international transport cost ($T$) from the base case of 1.5. A lower value of $T$ strengthens the agglomeration effect in home. Domestic agglomeration effect of the port openings is weaker with a higher level of $T$. This reason why the east attracts more firms with lower $T$ is because increased mutual market access relatively supports the east where firms operate at lower costs.

Figure 26: Regional distribution of industry for different foreign sizes

Figure 27: Regional distribution of industry for different levels of international transport cost ($T$)
5. Conclusion

A distinct feature of modern economic geography of Japan is the bias toward the east. In the past it was west Japan, in particular the Kinai region comprising Kyoto and Osaka, which was the industrialised economic core. The origin of the eastward shift of economic activities within Japan is found to be in its port opening era in the mid-19th century, the era also known as the “missing quarter century”. Studying the economy of Japan at the time revealed the importance of textiles (silk in the case of Japan), both in the domestic economy and international trade.

Inspired by the characteristics of the Japanese economy and geography around the 19th century, we developed a geography model with several new features. The model incorporated the existence of agricultural raw materials and its transportation. In this sense we gave a bigger role to the agricultural sector. The analysis of the model revealed new channels through which economic geography can be affected. Working on special cases, we showed under what conditions agglomeration of industrial activities occur in our setting.

We applied the model to the case of Japan. Our first finding is that in the case of Japan silk fabric production and skilled labour may well have been dispersed between the east and the west in autarky, which is consistent with historical observations; in autarky, firms operate in the west even though it is a disadvantaged location in terms of raw material prices because there is a large enough local market, given that it is protected with a high enough transport cost of the final good. However, opening up to international trade has asymmetric effects on the two domestic regions; firms both in the east and in the west lose due to import of cotton/woollen fabrics but eastern firms do better due to their cost advantage in raw materials compared to the western firms and the indirect market size effect of increased local unskilled wage through raw silk exports. Then the western firms exit the western market and entry occurs in the east, which involves migration of skilled workers towards the east. This leads to a new spatial equilibrium with international trade in which mobile resources and economic activities are more agglomerated in the east. This may be considered as one of the impacts of Japan’s opening up during the “missing quarter century” that lead to the creation of the economic centre in east Japan.

The historical literature has emphasized raw silk exports and the gains to the eastern (raw silk) farmers in Japan’s trade liberalization experience in the mid-19th century. In addition to this effect, however, our general equilibrium approach that takes into account the effect of import competition of cotton and woollen fabrics, suggests a geographic reallocation of skilled or entrepreneurial human resources, which may have had an important long-run effect on the making of the economic geography of Japan characterized by the eastward shift.

Existing studies including Krugman and Livas-Elizondo (1996) and Paluzie (2001) have
worked with neutrality of geography, that is, only the distance between locations are considered as a geographic factor. Our analysis introduced non-neutrality of geography, that is, the differences in natural conditions between regions that affect the nature of agriculture. An implication of the case of Japan is that such natural characteristics of geography may also be important in determining the internal impact of international trade liberalization and therefore in this sense the effect can be situation-specific.

Appendices

Appendix 1: Differences in natural conditions between east and west Japan

In terms of natural conditions, high mountain ranges with mountains exceeding 3,000 metres, named the Japan Alps, exist in the centre of the country dividing the nation. The regions to the east are generally mountainous and the west is flatter (Figure A.1a). In addition the west has warmer climate and more rainfalls than the east (Figures A.1b and A.1c). These factors affect agricultural production in the east and west: the west is more suitable for crops such as rice.

Source: Drawn from data in Geographical Survey Institute (2002).

**Figure A.1a: East and west Japan, elevation (in meters)**
Source: Drawn from data in the online database of Japan Meteorological Agency.
(www.data.jma.go.jp/obd/stats/etrn/index.php)

**Figure A.1b**: East and west Japan, annual average temperature (in centigrade)

Source: Drawn from data in the online database of Japan Meteorological Agency
(http://www.data.jma.go.jp/obd/stats/etrn/index.php)

**Figure A.1c**: East and west Japan, annual rainfall (in millimetres)
Appendix 2: Inferences of transport costs from regional price differentials

The Production structure of silk in Japan from a geographic viewpoint can be inferred from regional price data: Yamazaki (1983) reports regional prices of the isolation era. Figure A.2a shows the Kyoto price of raw silk made in the Shindatsu area, a major raw silk producing region, in east Japan. The delivered price in Kyoto is approximately 1.2 or 1.25 times higher than the price at the origin. Given that raw silk production was concentrated in the east, other things equal, this indicates that silk fabric producers in Kyoto were disadvantaged in terms of raw silk procurement. A similar but opposite price differential is found in the case of rice which was the main agricultural product of Japan: Yamazaki (1983) also estimates that in the years from 1856 to 1859, the price of rice in Hachioji in east Japan was on average 1.25 times higher than the price in Osaka in west Japan.

Data also reveals regional price differentials of silk fabrics: Financial data of Mitsui Echigoya department store contains procurement prices of Kyoto-made silk fabrics and the Edo (Tokyo) price of these products (Nakai and Shimada (1971)). Figure A2.b shows the price of Kyoto-made silk fabrics in Edo (Tokyo) relative to the price at the origin (Kyoto); when Kyoto-made silk fabrics were delivered to Edo, the prices became 1.5 to 1.7 times higher. Ono (1979) also reports that prices of Kyoto-brand silk fabrics in Edo were twice as expensive as those produced in the east and that the price gap increased after the port openings. These regional price data suggest manufactured goods had higher transport costs or trade costs compared to agricultural goods.

![Figure A.2a: Relative price of raw silk in Kyoto compared to Shindatsu area in east Japan](image)

Note: The 1838 data remains unexplained
Source: Drawn from the data in Yamazaki (1983)
Figure A.2b: Relative price of Kyoto-made silk fabric in Edo (Tokyo) compared to the origin

Appendix 3: Estimation of per unit output unskilled labour input coefficient ($\beta$) for silk fabric production

Combining survey data including Minami and Makino (1995) that reports silk reeling mill data, we estimated labour inputs at different production stages as shown in Figure A.3. We then calculated $\beta$ which is the unskilled labour input requirement in silk fabric production relative to that of the raw silk production, to be 0.03 units.

One problem is that in the theoretical model we have only skilled and unskilled workers as production factors, while in reality such inputs as mulberry leaves are necessary to raise silkworms. We have assumed all factors necessary to produce silkworm cocoons are represented by unskilled labour (179.50 man-day) but this may be an overestimate. If there are other inputs like mulberry leaves not taken into account then such amount of labour input may not be necessary. Therefore the upper bound of $\beta$ can be 6.06/52.58=0.1152. The sensitivity analysis in Section 3.7 shows that the autarky result that silk fabric production was dispersed holds as long as $\beta < 0.1$. 

Source: Drawn from data in Nakai and Shimada (1971)
Figure A.3: Estimation of per unit output unskilled labour input coefficient (β) for silk fabric production

Notes:
1) According to Minami and Makino (1995), 10.27 kans of silkworm cocoons are required to produce 1 kan of raw silk. The price per a kan of cocoon was 2.08 yen, so the value of cocoon is 10.27*2.08=21.36 yen. Since wage was 0.119 yen per man-day, we estimate that total labour embodied in cocoon production necessary to produce 1 kan of raw silk was 21.36/0.119=179.50 man-day. (These data are for 1888.)
2) According to Minami and Makino (1995), it requires 52.58 man-days to produce 1 kan of raw silk.
3) 165 monme (=0.165 kan) is required to produce 1 tan of silk fabrics. (This is estimated from taking the median value of raw silk input requirement among different varieties of silk fabrics introduced in Yamawaki (2002)). Therefore 1 kan of raw silk can be woven into 6.06 tans of silk fabrics. It is also shown in Kawaura (1965) that to weave 1 tan of textiles requires 1 man-day. So 1 kan of silk and 6.06 man-day of weaving can produce 6.06 tans of silk fabrics. (1 tan is roughly the amount of fabrics necessary to produce clothes for one person.)

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