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Silk and Sakoku: a simulation analysis of industrial location in Edo period Japan

Toshihiro ATSUMI*
Faculty of Economics, Meiji Gakuin University
GEP, University of Nottingham

Abstract

Japan closed itself to international trade from the 17th century to the mid-19th century during the Edo period, known as the *Sakoku*. After the closure, industries dispersed from western coastal cities to inland areas in western and eastern Japan. This paper investigates how the *Sakoku* may have affected industrial locations within Japan by applying a footloose entrepreneur type geography model to an economy with agricultural raw materials in a continuous space setting. The simulations based on this model show that agglomeration of industries such as silk fabric production in western coastal cities no longer become sustainable after the closure, and relocates to inland places forming new cities.

JEL Classifications: F12, L67, N95, R12
Keywords: International trade, economic geography, Japan

1. Introduction

Silk fabric production in Japan first emerged in western ports which had better access to the Asian continent to import raw silk, because Japan at the time could not produce raw silk efficiently on a commercial basis. The earliest silk fabric production sites include Hakata, Sakai and Kyoto

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E-mail: atsumito@eco.meijigakuin.ac.jp

which is also known as the first case of industrial agglomeration in Japan.

However, the Tokugawa regime that came into power in the 17^{th} century decided on a policy of self-imposed isolation that lasted two centuries. The port closure in the late 17^{th} century resulted in the introduction of raw silk production in eastern Japan, where climate and mountainous land was not suitable for crops like rice. Following the isolation, the silk fabric industry dispersed to the eastern inland regions, while Kyoto in the west also remained as a major silk fabric production site. Newly developed silk fabric manufacturing sites in the east in this era include the city of Kiryu, which is known to have become a rival of Kyoto.

The silk fabric industry of Japan had experienced drastic changes in its environment: the first phase can be characterized by silk fabric production based on imported raw materials; the first shock occurred in the late 17^{th} century when the ports were closed (phase 2); the second shock came in the mid-19^{th} century when the ports were reopened and international trade in textiles started (phase 3). The aim of this paper is to explain the phase 1 geography and the transition to phase 2.[1] This is done by applying a footloose entrepreneur type geography model developed by Forslid and Ottaviano (2003) to an economy with agricultural raw materials in a continuous space setting. By introducing continuous space, cities and hinterland within regions can be taken into account, which allows an analysis of economic geography at a finer level.

The analysis of cities and hinterland based on the new economic geography framework was developed by Fujita and Krugman (1995), which is known as the monocentric economy model. This paper also makes use of their idea of modelling a city as a manufacturing site in one dimensional continuous space. However, it departs from their monocentric economy model in which the economy consists of one type of worker and a simple agricultural sector supplying agricultural goods to the city, by introducing skilled and unskilled workers who are mobile between sectors, or mobile between the city and the hinterland, and the agricultural sector that produces raw materials in the hinterland.

The evolution of cities and the system of cities have been investigated by researchers including Fujita and Mori (1997) and Fujita et al. (1999), based on the monocentric economy model. Their analyses demonstrate systems of cities created by exogenously increasing population. The focus of this paper is on the impact of external shocks such as the port closure, since population was stagnant in this era.

The main finding of this paper is that while providing feasible economic reasoning, the model can roughly simulate the changing location of the silk fabric industry in relation to the changing economic environment: agglomeration in the west as an initial equilibrium in phase 1, dispersion of silk

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1 The geographic impact of the reopening of the ports in the mid-19^{th} century is analysed in Atsumi (2010).

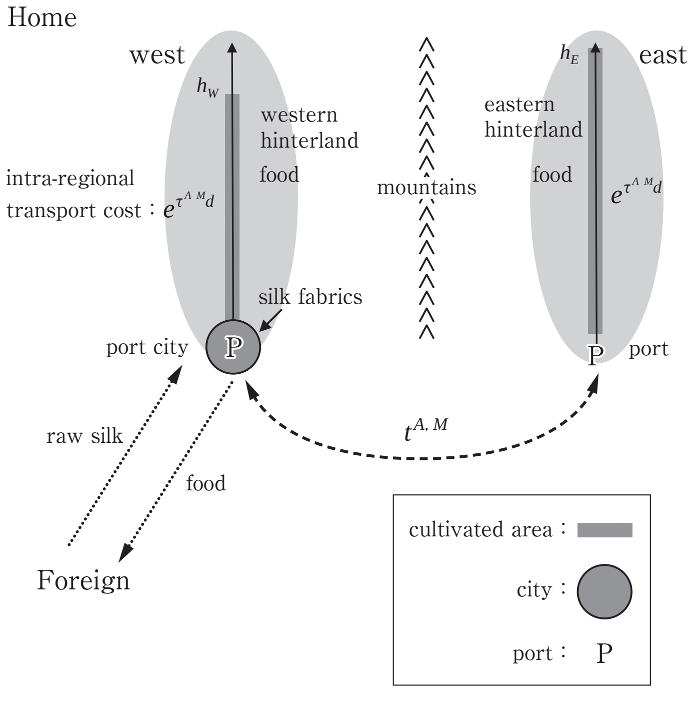
fabric production to the eastern inland region in phase 2 during isolation.

This paper is organised in the following way. The next section presents the basic model and its application to the phase 1 geography. The initial equilibrium and the sustainability of the geographic structure are examined. In Section 3 the impact of the port closure is analysed. Section 4 demonstrates a possible dynamic process that leads to the formation of a new geographic structure in phase 2 during the economic isolation in the Edo period. Section 5 concludes.

2. Explaining economic geography in phase 1

The economic geography of Japan in this era is modelled as in Figure 1, which is described in detail in the next subsection.

Figure 1: The phase 1 geography



2.1 Basic assumptions

Goods, production technology, and market structure

There are three goods in the economy; differentiated silk fabrics and two homogeneous agricultural goods - raw silk for silk fabric production and food. Production of silk fabrics requires raw silk and two types of labour, skilled and unskilled. A firm producing a particular variety of silk fabrics requires a fixed number (α) of skilled workers and one unit of raw silk and β 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

$$c\left(q^M\right) = \alpha w^S + \left(\beta w^U + p^R\right) q^M, \tag{1}$$

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 combined with land. Due to the climate differences between the east and the west, we assume that food production is less efficient in the east. In other words, the east has a comparative advantage in raw silk while the west has a comparative advantage in food. Perfect competition is assumed for food production.

Geography and transport cost

There are two domestic regions, the east and the west. Transport costs exist between them and inter-regional transport can only take place through the two ports: goods cannot be shipped directly to the other region from hinterlands or non-port cities. This assumption fits into a country like Japan where inland locations are mountainous, and so inter-regional transport took place between port cities on the coastline.[2] Inter-regional transport cost is expressed in iceberg form, t (>1). An 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. Transport costs for silk fabrics and agricultural goods (food and raw silk) can differ with iceberg transport costs for silk fabrics and agricultural goods expressed as t^M and t^A, respectively.

Further, one dimensional continuous space is introduced within regions in order to distinguish between cities, ports and hinterlands. Cities are defined as silk fabric production sites and can locate anywhere. This implies that in addition to the inter-regional transport costs $t^{M\ A}$, intra-regional transport costs, that is, the transport costs between the port, the city, and its hinterland are take into account. The iceberg transport cost function of silk fabrics between locations with distance d is $\tau^M(d) = e^{\delta^M d}$ ($\delta^M > 0$, $d > 0$). In particular, if the length of the hinterland is h_r (r=E, W) then the iceberg transport cost between the port and the frontier, or the edge of hinterland, will be $e^{\delta^M h}$.[3] Similarly, the ice-

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2 Ochiai (2007) describes the goods transported through the main ocean route between Osaka and Edo (current Tokyo), which includes basic food (such as rice), fabrics, soy sauce, sake, and vegetable oil. See also the map in Subsection 2.6.

3 h_r is variable depending on the size of agriculture in each region.

berg transport cost function for the agricultural goods, is $\tau^{A}(d)=e^{\delta^{A}d}$ ($\delta^{A}>0$, $d>0$).

Labour endowment

The population of unskilled workers in the country is normalized at one and that of skilled workers is denoted by S. This implies that the total mass of firms in the country is fixed at S/α in equilibrium. It is also assumed that unskilled labour is evenly distributed between the east and the west. [4] Therefore each region has half a unit of unskilled labour.

Introduction of land as a factor of production requires modelling owners of land or landlords. However, following Fujita and Krugman (1995), the present analysis abstracts from modelling landlords explicitly: landlords reside on the land they own and earn land rents from the unskilled workers who are cultivating the land. However, they are immobile and do not exist beyond the frontier.[5]

Consumer preference

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

$$U=M^{\mu}F^{1-\mu},\ 0<\mu<1 \tag{2}$$

which implies that the income shares of μ and $1-\mu$ are allocated for silk fabrics (M) and food (F), respectively. The second tier dictates the consumers' preferences over the differentiated varieties of silk fabrics, which is defined as

$$M=\left[\int_0^n m(i)^{\rho}\,di\right]^{\frac{1}{\rho}},\ 0<\rho<1 \tag{3}$$

where M is the composite of all the differentiated silk fabric varieties, n is the mass of silk fabric varieties, $m(i)$ is the consumption of variety i, and ρ is the substitution parameter. $0<\rho<1$ is assumed to ensure that the silk fabric varieties are imperfect substitutes. To represent the elasticity of substitution between any two varieties of silk fabrics, $\sigma=1/(1-\rho)$ ($\sigma>1$). Consumers' love-of-variety is stronger the smaller σ (or the smaller ρ).

By introducing a price index of silk fabrics

$$G=\left[\int_0^n p(i)^{1-\sigma}di\right]^{\frac{1}{1-\sigma}} \tag{4}$$

such that total expenditure on silk fabrics is GM, and denoting the price of food as p^{F}, indirect utility (or the real wage, ω) can be expressed as

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4 The total population of the east and the west was nearly equal before the port openings in the late 19th century. (The west was slightly larger.) The east overtook the west after the port openings.

5 In other words, a landlord exists only when the land is used. They 'disappear' when the land they own is no longer cultivated.

$$\omega^{j}=\frac{w^{j}}{G^{\mu}\left(p^{F}\right)^{1-\mu}}\,(j=U,\ S). \tag{5}$$

Labour mobility

As in the footloose entrepreneur model by Forslid and Ottaviano (2003), skilled workers are the only mobile factor between and within the regions. Following Krugman (1991), it is simply assumed that skilled workers move to the location that offers them the highest real wages. Unskilled workers are not mobile between the regions but are mobile within the region they reside, and can be employed in either sector within the region, that is, they can either work in the city in the silk fabric sector or in the hinterland in the agricultural sector producing food or raw silk.

2.2 Specific assumptions in phase 1

Eastern natural conditions are less suitable for food production. Specifically, a unit of unskilled labour combined with a unit of land produces a unit of food in the west, while f_E units of unskilled labour and land are required to produce a unit of food in the east. $f_E > 1$ means that eastern food production is less efficient compared to the west.

Raw silk is not produced domestically in phase 1: Japan exports food from the western port to the Asian continent to trade for raw silk.[6] The only silk fabric production site is the western port, that is, there is only one city at the western port, where S/α silk fabric firms locate.

2.3 Firm behaviour and prices by location

Denoting the (mill) price of silk fabrics in the western port city as P^{M}_{PW}, and the price of (imported) raw silk as P^{R}_{PW}, if a firm sells quantity q^{M}_{PW}, its profit (value of sales minus variable and fixed costs) is

$$p^{M}_{PW}\ q^{M}_{PW}-\left(\beta w^{U}_{PW}+p^{R}_{PW}\right)q^{M}_{PW}-\alpha w^{S}_{PW}. \tag{6}$$

Then to maximize its profit, the monopolistically competitive firm will set price as

$$p^{M}_{PW}\left(1-\frac{1}{\sigma}\right)=\beta w^{U}_{PW}+p^{R}_{PW}\,. \tag{7}$$

The price (index) of silk fabrics at a location of distance d from the western port in the western hinterland can be expressed as

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6 Japan's main exports in the 16th and the 17th century before the port closures were primary goods including minerals such as silver (and later copper) and other miscellaneous goods such as sulphur, handicraft, rice, wheat and dried seafood. It can be interpreted that these are included in 'food'.

$$G_W^M(d) = \left\{ n_W \left[p_{PW}^M \tau^M(d) \right]^{1-\sigma} \right\}^{\frac{1}{1-\sigma}}. \tag{8a}$$

(Hereafter, a location of distance d from the port is called "location d".) In the eastern hinterland the price index at location d is

$$G_E^M(d) = \left\{ n_W \left[p_{PW}^M t^M \tau^M(d) \right]^{1-\sigma} \right\}^{\frac{1}{1-\sigma}}.^{7} \tag{8b}$$

2.4 Demand for goods by location

Demand for food

Demand sources of food are the western port city and foreign, in addition to the demand from unskilled agricultural workers and landlords in hinterlands. Denoting aggregate income of the western port city as Y_{PW}, food demand from the western port city is

$$D_{PW}^F = \frac{(1-\mu) Y_{PW}}{p_{PW}^F}. \tag{9}$$

Demand for silk fabrics

Demand sources of silk fabrics are the western port city and the farms in the hinterlands consisting of unskilled agricultural workers and landlords. Denoting farm income (the sum of unskilled agricultural workers' and landlord's income) of location d in the west and the east as $Y_W(d)$ and $Y_E(d)$, respectively, total demand for a typical variety of silk fabric, including inter-regional and intra-regional transport costs, is

$$\begin{aligned} D_{PW}^M = & \left(p_{PW}^M\right)^{-\sigma} \left(G_{PW}^M\right)^{\sigma-1} \mu Y_{PW} \\ & + \int_{s=0}^{h_E} \left[p_{PW}^M t^M \tau^M(s)\right]^{-\sigma} \left[G_E^M(s)\right]^{\sigma-1} \mu Y_E(s)\, t^M \tau^M(s)\, ds, \\ & + \int_{0}^{h_w} \left[p_{PW}^M \tau^M(s)\right]^{-\sigma} \left[G_W^M(s)\right]^{-\sigma} \mu Y_W(s)\, \tau^M(s)\, ds. \end{aligned} \tag{10}$$

where $G_{PW}^M = G_W^M(0)$.

Demand for raw silk

Total input demand for raw silk from the silk fabric firms in the western port city, given the output q_{PW}^M, is $D_{PW}^R = n_W q_{PW}^M$.

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7 The mill price is further multiplied by t^M to reflect the inter-regional transport cost from the western port to the eastern port.

2.5 Spatial equilibrium in phase 1

Equilibrium requires that all goods and factor markets clear, firms achieve zero profits, and the real wage of unskilled workers in the city and the real wages in the agricultural hinterland to be equalized in the west. These conditions lead to the following results.

The agricultural sector

Farm income. Perfect competition in food production implies marginal cost pricing. Then if the food price in the western port city is p^F_{PW}, the income of a farm at location d in the west is $Y_W(d)=p^F_{PW}[\tau^A(d)]^{-1}$ and income of a farm at location d in the east is $Y_E(d)=p^F_{PW}[f_E t^A \tau^A(d)]^{-1}$. Food and raw silk are internationally traded and their prices at the western port, p^F_{PW} and p^R_{PW}, respectively, are given for Japan.

Market clearing of food. Food supply to the western port city from the western and eastern hinterlands, except for their own consumption in the farms, should be equal to its total demand from the western port city and its exports to foreign (E^F_f):

$$\int_{s=0}^{h_w} \mu\left[\tau^A(s)\right]^{-1} ds + \int_{s=0}^{h_E} \frac{\mu}{f}\left[t^A\tau^A(s)\right]^{-1} ds = D^F_{PW} + E^F_f \tag{11}$$

Unskilled wage in the western port city

Unskilled workers are mobile within the region they reside. In addition, in the west they are mobile between the silk fabric sector in the western port city and the agricultural sector in the western hinterland. The real wage of unskilled workers in the western port city is

$$\omega^U_{PW} = \frac{w^U_{PW}}{\left(G^M_{PW}\right)^{\mu}\left(p^F_{PW}\right)^{1-\mu}}, \tag{12}$$

and the real wage of agricultural workers in the western frontier, where the land rent is zero, is

$$\omega^U_W(h_W) = \frac{p^F_{PW}\left[\tau^A(h_W)\right]^{-1}}{\left[G^M_W(h_W)\right]^{\mu}\left\{p^F_{PW}\left[\tau^A(h_W)\right]^{-1}\right\}^{(1-\mu)}} = \left[\frac{p^F_{PW}}{G^M_W(h_W)\tau^A(h_W)}\right]^{\mu}. \tag{13}$$

Intra-regional and inter-sectoral mobility of unskilled workers imply that these are to be equalized in equilibrium. Therefore,

$$W^U_{PW} = p^F_{PW}\left[\frac{G^M_{PW}}{G^M_W(h_W)\tau^A(h_W)}\right]^{\mu}. \tag{14}$$

Unskilled labour market clearing

Full employment of unskilled workers require that the supply of unskilled workers for silk fabric production meets the demand from the firms in the western port city, that is,

$$\frac{1}{2} - h_W = n_W \beta q^M_{PW}, \tag{15}$$

where full employment of skilled workers implies $n_W = S/\alpha$. The east does not have silk fabric production, so all eastern unskilled workers are employed in food production. Therefore $h_E = 1/2$.

Skilled wages

In the silk fabrics 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. That is,

$$\alpha w^S_{PW} = p^M_{PW}\, q^M_{PW} - \left(\beta w^U_{PW} + p^R_{PW}\right) q^M_{PW}. \tag{16}$$

Substituting for p^M_{PW} using (7), the equilibrium skilled wage is

$$w^S_{PW} = \frac{\left(\beta w^U_{PW} + p^R_{PW}\right) q^M_{PW}}{\alpha(\sigma - 1)}, \tag{17}$$

where the silk fabric market clearing requires $q^M_{PW} = D^M_{PW}$.

Balance of trade

The value of food export and raw silk import should be balanced:

$$P^E_{PW} E^F_f = p^R_{PW} D^R_{PW}. \tag{18}$$

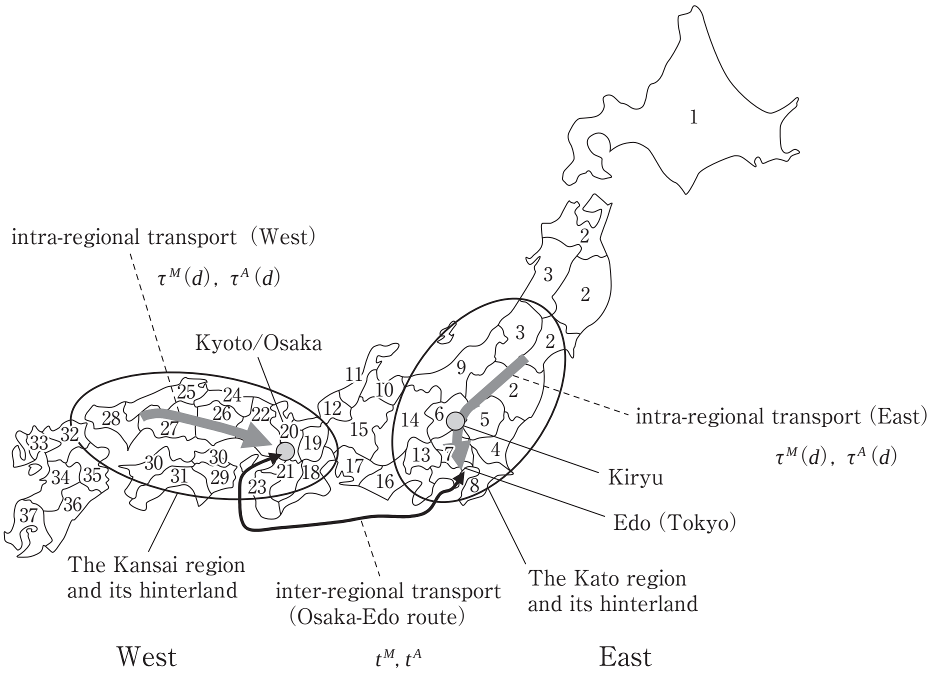
2.6 Solution of the phase 1 model

Parameter settings

A common set of parameters is used throughout the analysis to solve the model numerically. Their values are $\mu = 0.25$, $\sigma = 6.6$, $\beta = 0.03$, $t^M = 1.5$, and $t^A = 1.25$.[8] In order to extend the analysis to a continuous space setting as in Figure 2, the additional parameters to be set are the δ's for the intra-regional transport cost functions, $\tau^{M\,A}(d)$. Since each region has half a unit of unskilled labour, the maximum length of the hinterlands are also 0.5 (when all unskilled labour is employed in the agricultural sector). It is assumed that $\delta^A = 0.45$ so that the iceberg transport cost of agricultural goods be-

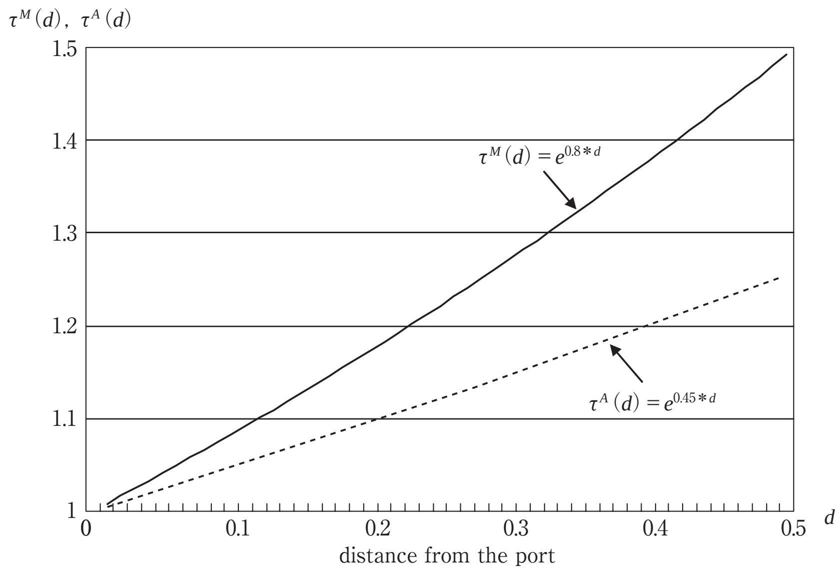
[8] See Atsumi (2010) for the background information of these parameter values and further historical evidence. The values of S and α do not affect geography. Therefore, $S = 1$ and $\alpha = 1$ are used for the numerical solutions.

Figure 2: Inter-regional and intra-regional transport in Japan



Note: The Hokkaido island (region 1 in the map) was not well integrated to the mainland economy until the 20th century. The southern part of regions 2 is considered as the peripheral areas (or the frontier) of eastern Japan.

Figure 3: Intra-regional transport cost function



tween the port and the frontier of the hinterland within each region is at most $\tau^A(0.5) = e^{0.45*0.5} \cong 1.25$. This assumption is used because according to a survey by Dainihon Sanshi Kai (The Silk Industry Association of Japan) (1935), the delivered price of raw silk from the city of Maebashi, located in the North end of the Kanto region in eastern Japan, to Yokohama port was on average around 20% higher than the price at the origin during the period 1859 to 1867. As for the intra-regional transport cost of manufactured goods, it is assumed that the transport cost (loss) is twice compared to that of the agricultural goods. Therefore, $\delta^M = 0.8$ so that $\tau^M(0.5) = e^{0.8*0.5} \cong 1.5$. The intra-regional transport cost functions for agricultural and manufactured goods are graphed in Figure 3.

Numerical solution

The model is solved choosing food at the western port as the numeraire, that is $p^F_{PW} = 1$. Solutions of the main endogenous variables for different levels of the eastern food productivity (f_E) and the port price of imported raw silk (p^R_{PW}) are shown in Table 1. It can be seen that higher productivity of food in the east and/or lower relative price of raw silk leads to higher wages and real wages. In addition, lower relative price of raw silk leads to a smaller western hinterland. This is because the silk fabric industry in the western port city expands and employs more unskilled workers from the western hinterland.

Table 1: Solution of the phase 1 model for different levels of eastern food productivity (f_E) and imported raw silk price (p^R_{PW})

	$f_E = 1$			$f_E = 2$			$f_E = 3$		
	$p^R_{PW} = 2$	$p^R_{PW} = 1$	$p^R_{PW} = 0.25$	$p^R_{PW} = 2$	$p^R_{PW} = 1$	$p^R_{PW} = 0.25$	$p^R_{PW} = 2$	$p^R_{PW} = 1$	$p^R_{PW} = 0.25$
w^S_{PW}	0.03173	0.03174	0.03177	0.02468	0.02469	0.02471	0.02233	0.02234	0.02236
w^U_{PW}	0.8560	0.8567	0.8605	0.8559	0.8564	0.8594	0.8558	0.08563	0.08590
$P^M_{PW} = G^M_{PW}$	2.387	1.209	0.325	2.387	1.209	0.325	2.387	1.209	0.325
h_W	0.497	0.495	0.481	0.498	0.496	0.485	0.498	0.496	0.486
ω^S_{PW}	0.0255	0.0302	0.0421	0.0196	0.0235	0.0327	0.0180	0.0213	0.0296

Note: $f_E > 1$ implies that the eastern food production is less efficient than to that of the west. See Subsection 2.2.

Since this is a continuous space geography model, it is useful to express the equilibrium prices of different locations in the following "price schedule" form; Figures 4a and 4b show the prices of food and silk fabrics, respectively, of all domestic locations for the $f_E=3$ case. Figure 4a indicates that the western port city, where food from the eastern and western hinterlands were shipped to, has the highest food price. The gap between the western port price and the eastern price reflects both the transport cost and the productivity difference. Figure 4b indicates that, since silk fabrics were only produced in the western port city, its price in the city is lowest and prices for the consumers in the eastern hinterland were high because of the inter-regional transport cost.

Figure 4a: Equilibrium price schedules of food in phase 1 with $f_E=3$ and $p_W^R=1$

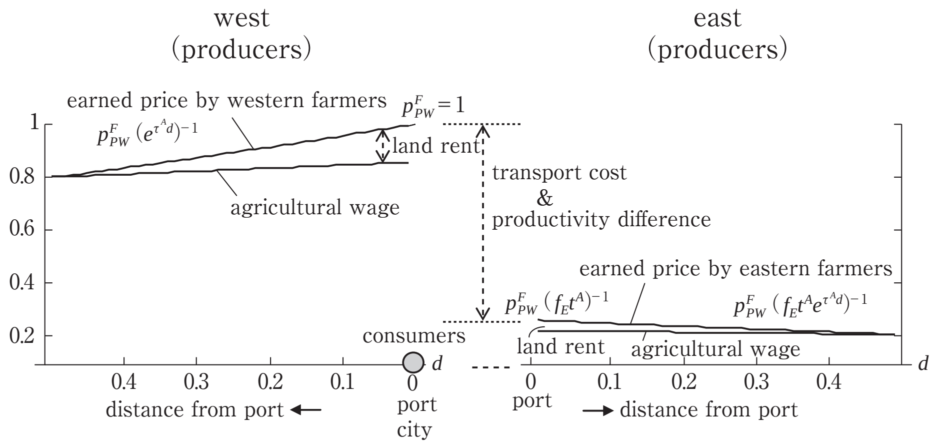
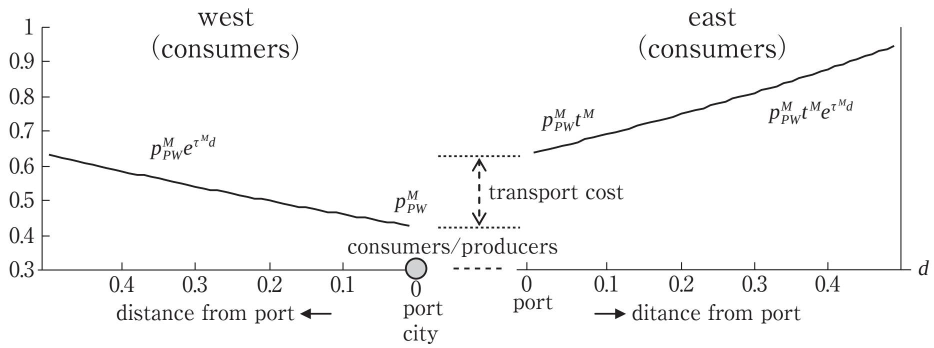


Figure 4b: Equilibrium price schedules of silk fabrics in phase 1 with $f_E=3$ and $p_{PW}^R=1$



2.7 Sustainability of the western port city

The market potential functions are defined and are evaluated for all values of $d \leq h_r$ $(r=E, W)$ using the results from the numerical solution in Table 1. They indicate under what conditions the geography with a single western port city can be sustainable.

The geographic structure with a single port city in the west can be considered sustainable when no location has a market potential exceeding unity, because this indicates that no location is more profitable than the city, and that no firm has an incentive to leave the city.

The market potential function of the west

Given the equilibrium prices, firms calculate hypothetical profits (the operating profit minus fixed costs of locations other than the city), that is,

$$\tilde{\pi}_W(d) = \tilde{p}_W^M(d)\tilde{D}_W^M(d) - \left[\beta w_W^U(d) + p_W^R(d)\right]\tilde{D}_W^M(d), \tag{19}$$

where $p_W^R(d)$ is the price of raw silk at location d in the west,

$$w_W^U(d) = w_{PW}^U \frac{\left[G_W^M(d)\right]^{\mu}\left\{p_{PW}^F\left[\tau^A(d)\right]^{-1}\right\}^{(1-\mu)}}{\left(G_{PW}^M\right)^{\mu}\left(p_{PW}^F\right)^{1-\mu}}, \tag{20a}$$

$$\tilde{p}_W^M(d) = \left(\frac{\sigma}{\sigma-1}\right)\left[\beta w_W^U(d) + p_W^R(d)\right], \tag{20b}$$

and

$$\tilde{D}_W^M(d) = \mu\left[\tilde{p}_W^M(d)\right]^{-\sigma} \times \left\{ \begin{aligned} & Y_{PW}\left(G_{PW}^M\right)^{\sigma-1}\left[\tau^M(d)\right]^{1-\sigma} + \int_{s=0}^{h_W} Y_W(s)\left[G_W^M(s)\right]^{\sigma-1}\left[\tau^M(|d-s|)\right]^{1-\sigma} ds \\ & + \int_{s=0}^{h_E} Y_E(s)\left[G_E^M(s)\right]^{\sigma-1}\left[\tau^M(d)\, t^M\, \tau^M(s)\right]^{1-\sigma} ds \end{aligned} \right\}. \tag{20c}$$

(20a) is the unskilled workers' wage at location d in the west. This is reflected in (20b) which means that the hypothetical mill price at that location will be based on the unskilled wage and the price of raw silk at that location. The hypothetical demand shown in (20c) is therefore based on this hypothetical mill price.

The hypothetical fixed cost of operating at location d in the west is $\alpha\tilde{w}_E^S(d)$, where

$$\tilde{w}_W^S(d) = w_{PW}^S \frac{\left[G_W^M(d)\right]^{\mu}\left\{p_{PW}^F\left[\tau^A(d)\right]^{-1}\right\}^{(1-\mu)}}{\left(G_{PW}^M\right)^{\mu}\left(p_{PW}^F\right)^{1-\mu}} \tag{21}$$

is the hypothetical skilled wage compensated for the changes in the living cost of relocating to location d. The market potential function in the west is defined as

$$\Omega_W(d) = \frac{\tilde{\pi}_W(d)}{\alpha\tilde{w}_W^S(d)}. \tag{22}$$

The market potential function of the east

The hypothetical operating profit at location d in the east is

$$\widetilde{\pi}_E(d)=\widetilde{p}_E^M(d)\widetilde{D}_E^M(d)-\left[\beta w_E^U(d)+p_E^R(d)\right]\widetilde{D}_E^M(d), \tag{23}$$

where $p_E^R(d)$ is the price of raw silk at location d in the east,

$$\widetilde{p}_W^M(d)=\frac{\sigma}{\sigma-1}\left[\beta w_E^U(d)+p_E^R(d)\right], \tag{24a}$$

$$w_W^U(d)=p_{PW}^F\left[f_E t^A\tau^A(h_E)\right]^{-1}\left[\frac{G_E^M(d)}{G_E^M(h_E)}\right]^{\mu}\left[\frac{\tau^A(h_E)}{\tau^A(d)}\right]^{1-\mu}, \tag{24b}$$

and

$$\widetilde{D}_E^M(d)=\mu\left[\widetilde{p}_E^M(d)\right]^{-\sigma}\times\left\{\begin{aligned}&Y_{PW}\left(G_{PW}^M\right)^{\sigma-1}\left[\tau^M(d)t^M\right]^{1-\sigma}\\&+\int_{s=0}^{h_W}Y_W(s)\left[G_W^M(s)\right]^{\sigma-1}\left[\tau^M(d)\,t^M\,\tau^M(s)\right]^{1-\sigma}ds\\&+\int_{s=0}^{h_E}Y_E(s)\left[G_E^M(s)\right]^{\sigma-1}\left[\tau^M(|d-s|)\right]^{1-\sigma}ds\end{aligned}\right\}. \tag{24c}$$

The hypothetical fixed cost of operating at location d in the east is $\alpha\widetilde{w}_E^S(d)$, where

$$\widetilde{w}_E^S(d)=w_{PW}^S\frac{\left[G_E^M(d)\right]^{\mu}\left\{p_{PW}^F\left[t^A\tau^A(d)\right]^{-1}\right\}^{(1-\mu)}}{\left(G_{PW}^M\right)^{\mu}\left(p_{PW}^F\right)^{1-\mu}} \tag{25}$$

is the hypothetical skilled wage compensated for the changes in the living cost of relocating to location d. The market potential function of location d in the east is defined as

$$\Omega_E(d)=\frac{\widetilde{\pi}_E(d)}{\alpha\widetilde{w}_E^S(d)}. \tag{26}$$

The city is sustainable if $\Omega_E(d)\leq 1$ and $\Omega_W(d)\leq 1$ for all d, because otherwise firms decide they can leave the western port city and profitably move to other locations.

The calculated market potentials of all locations for different levels of the eastern agricultural productivity (f_E) are shown in Figure 5a for the east and in Figure 5b for the west. Figures 6a and 6b show the market potentials for different levels of the port price of imported raw silk (p_{PW}^R), fixing the level of f_E. They indicate that the geography with a single port city in the west is sustainable in phase 1 if agricultural (food) productivity of the east is sufficiently lower than the west and/or if raw silk is sufficiently expensive relative to food. Low food productivity in the east is consistent with the historical understanding that the natural condition of eastern Japan (particularly in mountainous places) was not suitable for crops like rice and that the farmers there were poor before the introduction of sericulture.

The result can be interpreted as follows. The western port is the best location in terms of raw silk cost. However, it is not necessarily the best location for supplying silk fabrics for (domestic) consumers because in this era Japanese silk fabrics were not exported. If the eastern agricultural technology is high, which implies higher agricultural income, firms in the western port may find profitable locations in the east, because it is advantageous to supply to the eastern market (as in the $f_E=1$ or the $f_E=2$ cases in Figure 5a). The eastern regions are, however, understood to have been inferior in agricultural productivity due to natural conditions. Therefore, the east was not as attractive as the western port which had the best access to imported raw materials; under low food production technology in the east and/or high raw silk price, it is likely that the economic geography with a single western port city was sustainable in phase 1 as in the $f_E=3$ case shown in Figures 5a and 5b.

Figure 5a: Market potential of the east in phase 1 ($p^R_{PW}=1$)

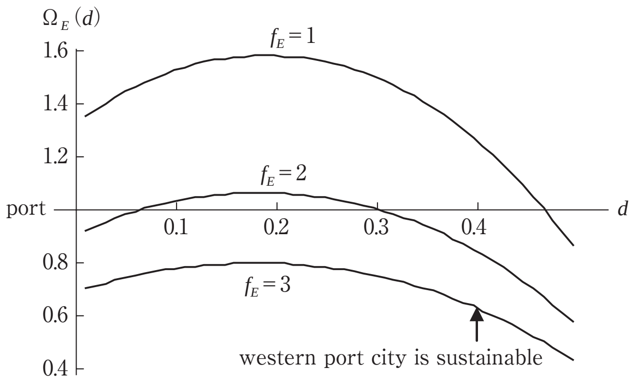


Figure 5b: Market potential of the west in phase 1 ($p^R_{PW}=1$)

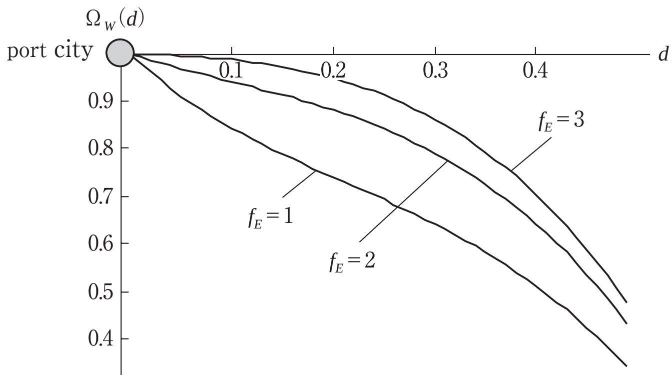


Figure 6a: Market potential of the east in phase 1 (f_E=3)

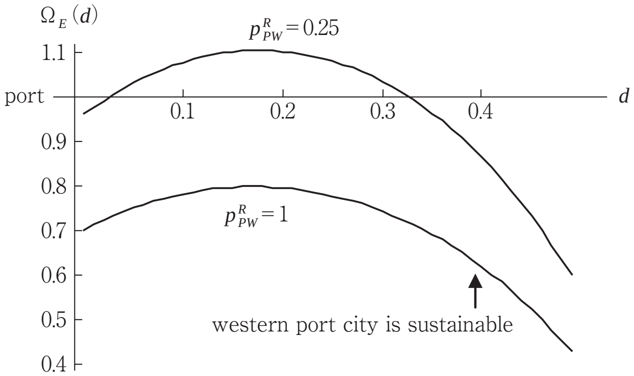
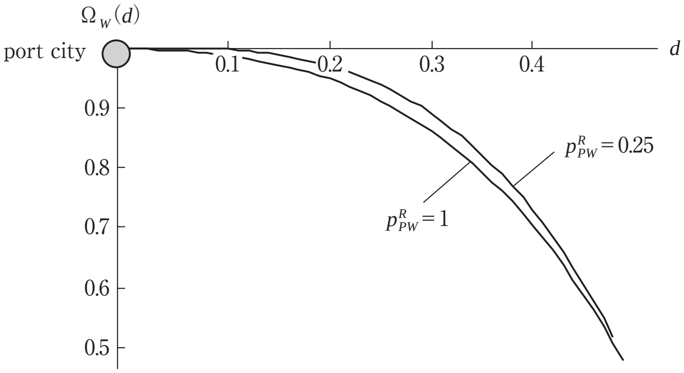


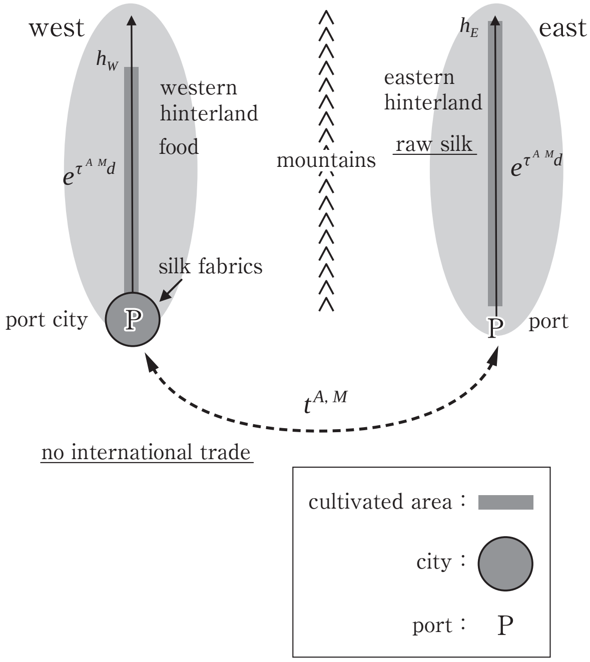
Figure 6b: Market potential of the west in phase 1 (f_E=3)



3. The impact of the port closures in the late 17th century on the phase 1 geography

The port closures in the late 17th century implied a total loss of raw silk supply. Following the closure, domestic production of raw silk started in the east, which had a comparative advantage in raw silk production due to the differences in the natural conditions. This section considers the impact of the port closure and the resulting domestic raw material production on the phase 1 geography with a single western port city. It investigates whether the single city in the western port is still sustainable under the change in the environment (Figure 7).

Figure 7: The phase 1 geography after the port closure (late 17c)



3.1 Modifications of the model to account for port closure and domestic raw material production

Geography and transport cost

There is no international trade due to the port closure. The same domestic transport cost assumptions are maintained.

Goods, production technology, and market structure (introduction of raw silk production)

It is assumed that food productivity in eastern Japan is so low that the eastern agricultural sector specializes in raw silk production after the port closure.[9] The production technology of raw silk is that a unit of unskilled labour combined with a unit of land produces a unit of raw silk. Perfect competition prevails for raw silk production as well as for food in the west.[10]

3.2 Sustainability analysis of the phase 1 geography with port closure

Numerical solution

The model is first solved numerically, assuming the same exogenous parameters used in the

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[9] The necessary condition for eastern Japan to specialize in raw silk is $1/f_E t^A e^{\tau^A d} < p^R_{PE} / e^{\tau^A d}$ or $1 < p^R_{PE}\, t^A f_E$. f_E is assumed to be high enough so that this holds.

[10] Formal description of the model is available from the author upon request.

previous section, to obtain the equilibrium values of the endogenous variables (Table 2). They will then be used in evaluating the market potential functions.

Table 2: Solution of the phase 1 geography with port closure

w^S_{PW}	0.222
w^U_{PW}	0.858
p^R_{PE}	0.257
P^M_{PW} $(=G^M_{PW})$	0.409
h_W	0.489
ω^S_{PW}	0.0277

Note: Food at the western port city is chosen as the numeraire ($p^F_{PW}=1$).

The equilibrium price schedules of phase 1 with port closure based on the results in Table 2 are shown in Figures 8a, 8b and 8c. Figure 8a is the food price schedule. Since food is now only produced in the west, prices in the east are generally higher than in the west because of the transport costs. Figure 8b is the price schedule of raw silk. After the introduction of raw silk production in the east, its price is lowest in the eastern frontier. Silk fabric producers in the western port city bear the transport cost to purchase raw silk from the east. Figure 8c is the price schedule of silk fabrics. Silk fabric production is agglomerated in the western port city, where its price is lowest. Silk fabric prices are generally higher in the east because of the inter-regional transport cost. It can be foreseen from these results that the east is now potentially an attractive place for silk fabric production, given the low raw silk cost and the high current prices of silk fabrics, although food is expensive in the east.

Figure 8a: Equilibrium price schedules of food with port closure

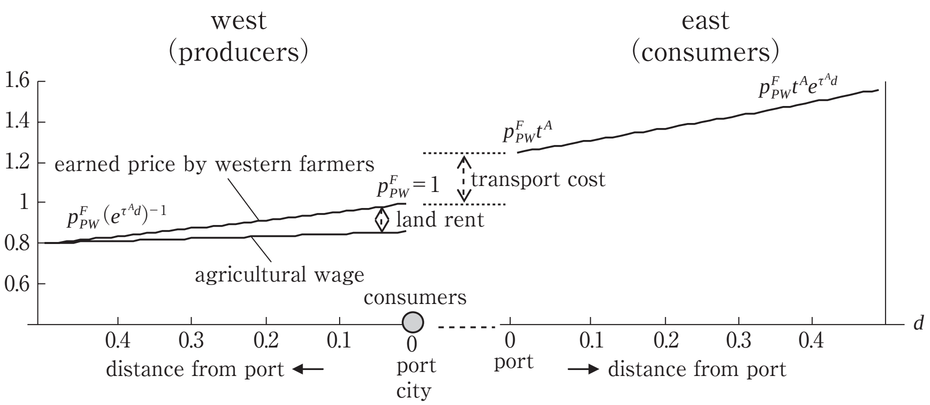


Figure 8b: Equilibrium price schedules of raw silk with port closure

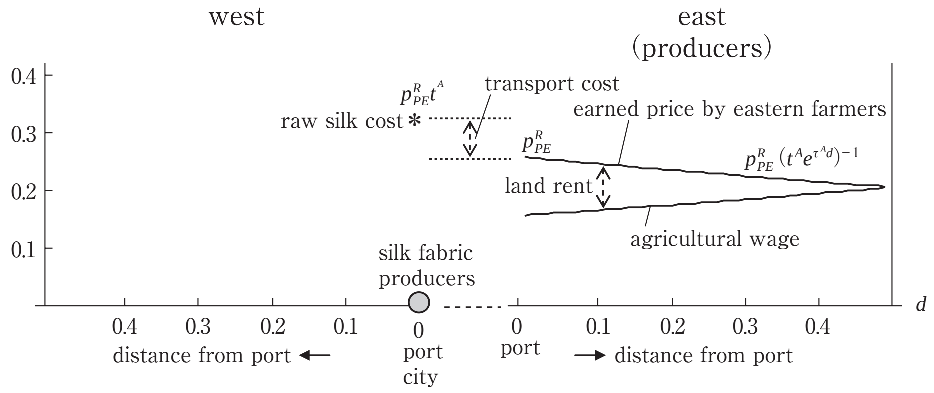
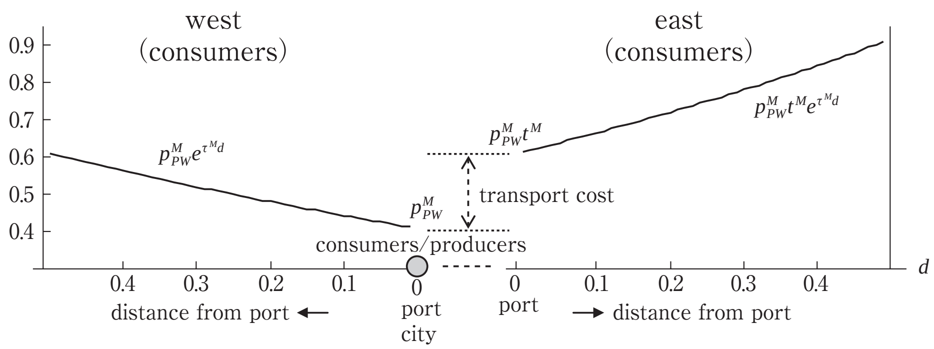


Figure 8c: Equilibrium price schedules of silk fabrics with port closure



Market potentials of the phase 1 geography with port closure

The market potentials of the phase 1 geography with port closure are shown in Figure 9a for the east and in Figure 9b for the west.[11] Figure 9a clearly indicates that every eastern location is more profitable than the western port city since the market potentials exceed unity. Therefore, with port closure, the phase 1 geography becomes unsustainable. This is because the advantage of the low raw silk price in the eastern hinterland outweighs the disadvantage of the inferior market access to the existing western port city and the western hinterland from the east. In particular, firms calculate that the inland location $d = 0.45$ in the east, indicated in Figure 9a, exhibits the highest market potential. It is likely then that the firms leave the western port city and a new manufacturing city emerges in the eastern inland sericulture region.

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[11] The market potential functions are available from the author upon request.

Figure: 9a: The eastern market potential of the phase 1 geography with port closure

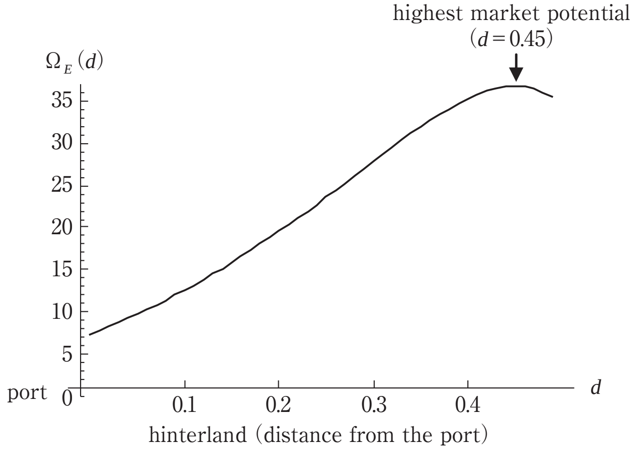
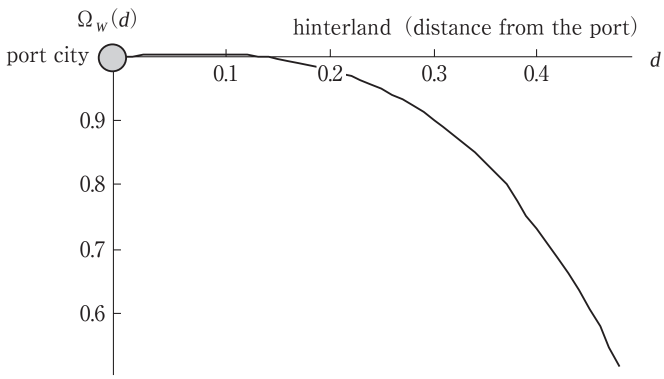


Figure: 9b: The western market potential of the phase 1 geography with port closure



4. A Possible dynamic process of the transition from the phase 1 to the phase 2 geography

The market potentials of the phase 1 geography with port closures shown in Figures 9a and 9b indicated that location $d = 0.45$ in the east is potentially most profitable from the viewpoint of silk fabric firms that are agglomerated in the western port city. It is likely that the profit maximizing firms with the skilled workers who are mobile between regions relocate to this eastern inland location to start production. This section considers a possible transition process from the phase 1 geography to the formation of a new geographic structure in phase 2, the economic isolation period of Japan.

4.1 The migration process

To take into account the changes in the market potentials over time, the market potential of region $R \in \{E, W\}$ at time t from the viewpoint of silk fabric firms in region $Z \in \{E, W\}$ is denoted as $\Omega^{Z}_{R\,t}(d)$. $\Omega^{W}_{E\,0}(d)$ and $\Omega^{W}_{W,0}(d)$ correspond to Figures 9a and 9b, respectively.

Skilled workers are mobile both inter-regionally and intra-regionally. On the other hand, unskilled workers are only mobile within the region they reside. In the hinterlands, they are food farmers in the west or raw silk farmers in the east. But if there is a city in the region, they can move to the city to be employed by the silk fabric firms. In order to account for inter-regional and intra-regional migration of the firms and skilled workers, a sequential migration process through which the firms with their skilled workers migrate away from the western port city to the (new) eastern city is introduced:

$$\dot{\lambda} = c\lambda(\pi_{CE} - \bar{\pi}), \tag{27}$$

where c is a positive constant denoting the adjustment speed, π_{CE} is the profit at the eastern city, and $\bar{\pi} = \lambda\pi_{CE} + (1-\lambda)\pi_{CW}$ is the average profit. This simply means that the rate of change in the regional share of firms and skilled workers is proportionate to the difference in the profits.[12]

Since there are no firms in the east initially, it is assumed that a fraction of firms and their skilled workers migrate from the western port city to location $d = 0.45$ in the east which is the most profitable location according to the market potential of the east at $t = 0$.[13] At $t = 1$ after the first wave of the inter-regional migration, production is newly set up at location $d = 0.45$ in the east, to which the eastern unskilled workers respond: some will be employed by the new silk fabric firms; those who remain in the agricultural sector can now ship their raw silk to the new (small) city to supply the new silk fabric firms, resulting in changes in the prices. Given the price changes, silk fabric firms, both in the east and in the west, re-evaluate their market potential functions. They will now have revised market potential functions, $\Omega^{E}_{E,1}(d)$ and $\Omega^{W}_{W,1}(d)$, respectively. According to the revised market potential functions, it is assumed that the firms with their skilled workers migrate intra-regionally, if there is a more profitable location within each region. That is, in the east, silk fabric firms and their skilled workers (or the city) moves to location d^* if it satisfies $\Omega^{E}_{E,1}(d^*) = \max \Omega^{E}_{E,1}(d) > \Omega^{E}_{E,1}(0.45)$. The same also occurs in the west if $\Omega^{W}_{W,1}(d^*) = \max \Omega^{W}_{W,1}(d) > \Omega^{W}_{W,1}(0)$. Unskilled workers respond again by changing the direction of their shipment of agricultural goods, if the city location changes.

Given the (new) location of the two cities and the profits of silk fabric firms in these cities, the

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12 One reason for introducing a gradual migration process is because 'all at once' migration to form a new single city does not result in a sustainable geography. The other reason is that there is a range of locations within which a sustainable two city geography exists.

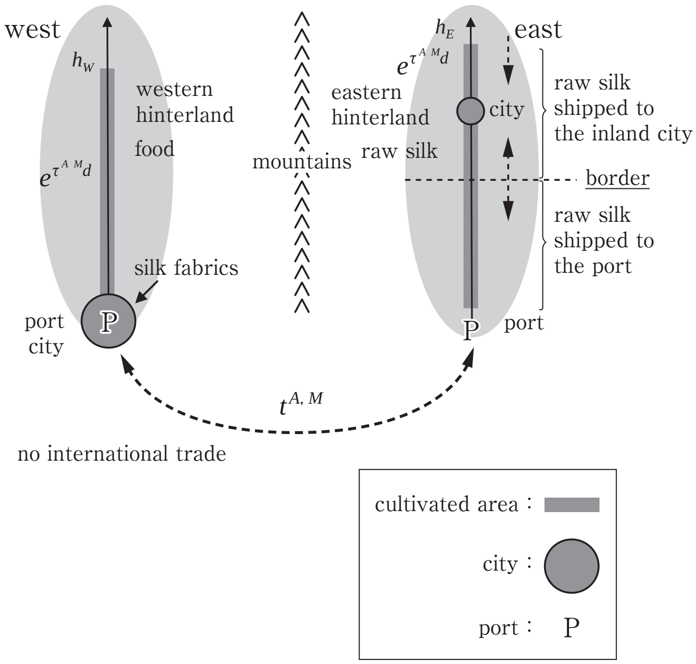
13 See Figures 9a and 9b.

next wave of inter-regional migration of firms and skilled workers occurs according to the inter-regional migration equation. The economy then proceeds to $t=2$ for the next intra-regional adjustment and migration. In this way, inter-regional and intra-regional migration occur sequentially until there is no further incentive for any migration.

4.2 A two city model

In addition to the migration process specified in the previous subsection, a model with two cities is necessary, in order to simulate the transition from the phase 1 to the phase 2 geography. A two city geography as in Figure 10 is modelled, allowing for a city in each region which can exist in locations other than the port. One complexity that arises from allowing for a non-port city is the direction of the agricultural goods shipment: as indicated in Figure 10, there exists a border that divides farms shipping products to the city or to the port.[14] Given the prices in the port and the city, farms can now choose where to send their products depending on their location.

Figure 10: A model of two cities



Solution

During the course of migration, the model is solved for a given level of λ to derive the silk

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[14] The example in Figure 10 shows the case of a border existing in the east. It can also occur in the west, if the western city is not located at the port.

fabric firms' profits in the two cities. Solving the model requires the market clearing of the goods and factors, the real wage equalization of unskilled workers within each region, and the real wage equalization of skilled workers in the two cities, together with the border condition described below to be satisfied in both regions.[15]

The borders and the agricultural incomes

The farm at the border location $d=b_E$ in the east should be indifferent between shipping raw silk to the port and to the eastern city in equilibrium, that is,

$$p_{PE}^{R}\left[\tau^{A}(b_E)\right]^{-1}=p_{CE}^{R}\left[\tau^{A}(|d_{CE}-b_E|)\right]^{-1}, \tag{28a}$$

where p_{CE}^{R} is the price of raw silk at the eastern city. Similarly, the farm at the border location $d=b_W$ in the west should be indifferent between shipping food to the port and to the western city in equilibrium, that is,

$$p_{PW}^{F}\left[\tau^{A}(b_W)\right]^{-1}=p_{CW}^{R}\left[\tau^{A}(|d_{CW}-b_W|)\right]^{-1}. \tag{28b}$$

The eastern farm income at location d is

$$Y_E(d)=\begin{cases} p_{PE}^{R}\left[\tau^{A}(d)\right]^{-1}, & 0\leq d\leq b_E \\ p_{CE}^{R}\left[\tau^{A}(|d_{CE}-d|)\right]^{-1}, & b_E< d\leq h_E \end{cases}, \tag{29a}$$

and the western farm income at location d is

$$Y_W(d)=\begin{cases} p_{PW}^{F}\left[\tau^{A}(d)\right]^{-1}, & 0\leq d\leq b_W \\ p_{CW}^{F}\left[\tau^{A}(|d_{CW}-d|)\right]^{-1}, & b_W< d\leq h_W \end{cases}, \tag{29b}$$

4.3 The formation of a sustainable geography in phase 2

The migration process described in subsection 4.1 is implemented, using the model of two cities and the market potential functions.[16] It is assumed that a fraction of the firms and skilled workers move to the east initially.[17] When production starts in the east, the prices change due to the responses by eastern unskilled workers. The price schedules at $t=0$ and $t=1$ for raw silk and silk fabrics are shown in Figures 11a and 11b. Figure 11a shows that the raw silk price rises (due to the congestion in the east that drives up local unskilled wages) but also that the direction of raw silk shipment changes: the raw silk farmers close to the new city ship to the new city instead of the port. There-

[15] Formal description of the model is available from the author upon request.
[16] The market potential functions are available from the author upon request.
[17] The analysis is implemented assuming that initially 1% relocates to the east.

fore, as can been seen in the $t=1$ price schedule, there will be a (small) peak of the raw silk price at the new city. Figure 11b shows that the silk fabric prices are reduced in the east (because there is now local production) and that there is a local minimum point at the new city.

Figure 11a: Price schedule of raw silk in the east at $t=1$ before the intra-regional migration of firms

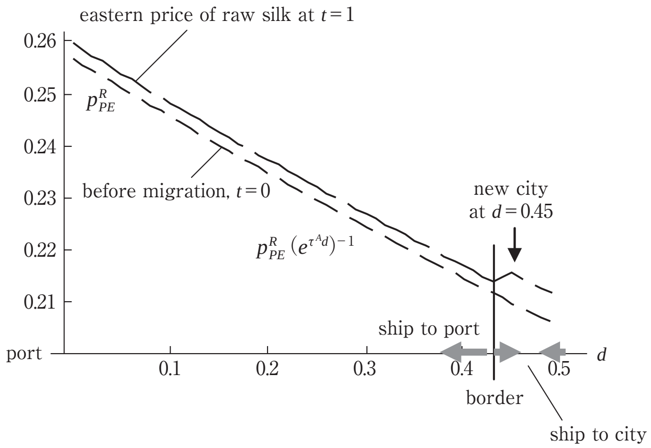
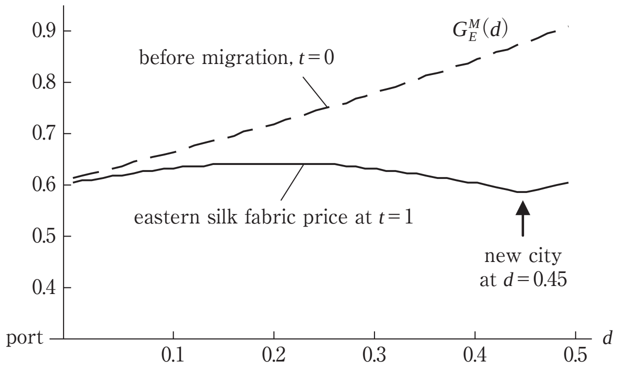


Figure 11b: Price schedule of silk fabrics in the east at $t=1$ before the intra-regional migration of firms



Given these price changes, silk fabric firms in the east and the west now have revised market potential functions of their regions, $\Omega^E_{E,1}(d)$ and $\Omega^W_{W,1}(d)$, which are shown in Figures 12a and Figure 12b, respectively. Figure 12a indicates that in the east, location $d=0.38$ is more profitable than the initial location $d=0.45$ that they migrated to. Therefore, given the change in the market potential, the eastern city moves to $d=0.38$, which is the intra-regional migration of firms and skilled workers. This overshooting of city location occurs because as seen in Figure 11a, raw silk price is lower to the 'left' of the initial city at location $d=0.45$, and because as seen in Figure 11b, silk fabric prices are higher to the 'left' of the city.

On the other hand, the western port city moves inland after the first wave of migration. Since a fraction of the firms and the skilled workers move out of the western port city, unskilled workers who were employed by them leave the city as well. This implies an expansion of the western agricultural sector. From a geographic point of view, it means an expansion of the (cultivated) western hinterland. The geographic expansion of the western market makes inland locations more profitable in terms of market access to the hinterland. This is the reason why the western city moves slightly inland.

Figure 12a: Revised market potential and intra-regional migration at $t=1$ in the east

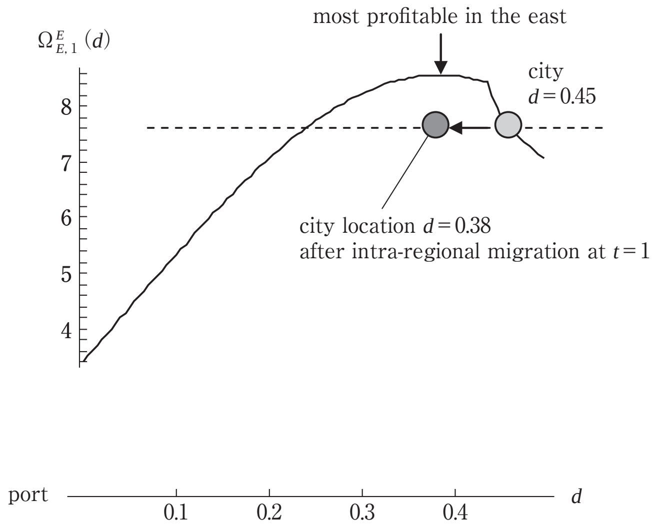
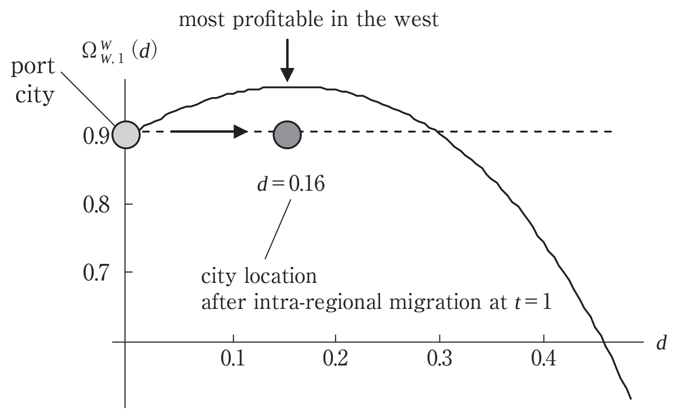


Figure 12b: Revised market potential and intra-regional migration at $t=1$ in the west



After some more rounds of migration, at $t=7$, the market potentials in the east and the west start showing cusps, suggesting a convergence of city locations as in Figures 13a and 13b, respectively. (Migration continues because the east is still profitable.) Then after thirty rounds the situation shown in Figures 14a and 14b is reached, which indicates a stable two city system: the eastern city locates at $d=0.35$ and the western city at $d=0.11$. The key result is that the new city in the east is found to locate in an inland area.[18]

Figure 13a: The eastern market potential at $t=7$

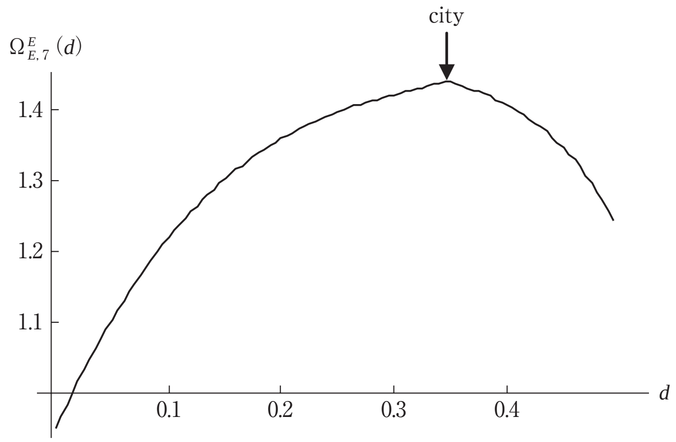
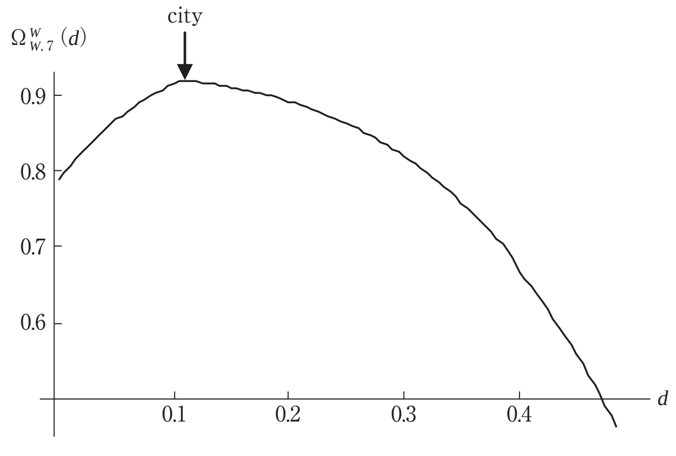


Figure 13b: The western market potential at $t=7$



18 Further details of the migration process in phase 2 are available from the author upon request.

Figure 14a: The eastern market potential in stable equilibrium at $t=30$

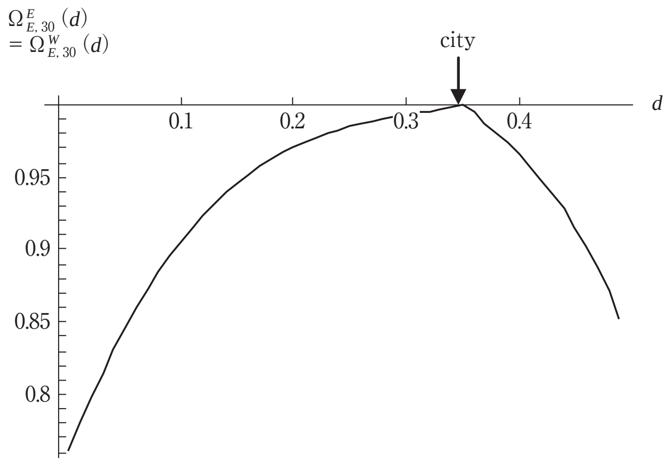
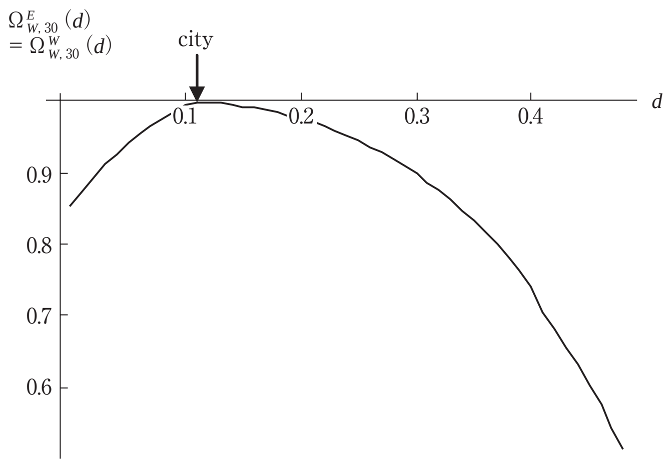


Figure 14b: The western market potential in stable equilibrium at $t=30$



The equilibrium price schedules of phase 2 in the two city geography after migration is completed are shown in Figures 15a and 15b. Figure 15a shows the price indices of silk fabrics. Now that silk fabric is also produced in the east, prices in the east are greatly reduced, particularly in places close to the new city. Figure 15b is the price schedule of the raw silk price. Raw silk prices have risen after the emergence of the new city in the east. This is due to the congestion in the east: production in the east involves hiring local unskilled workers by the silk fabric firms in the city. Competition for local unskilled workers, therefore, raises raw silk prices. This congestion is also the reason why not all firms move to the east from the west, despite the disadvantage of higher raw silk procurement cost in the west.

Figure 15a: Equilibrium price schedules of silk fabrics after migration in phase 2

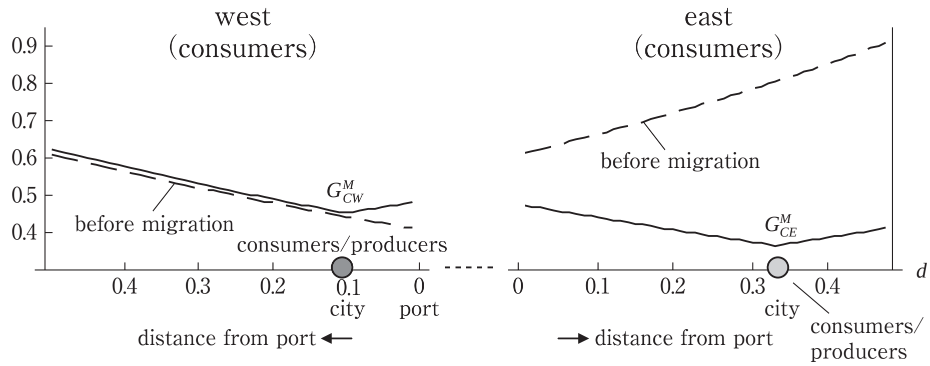
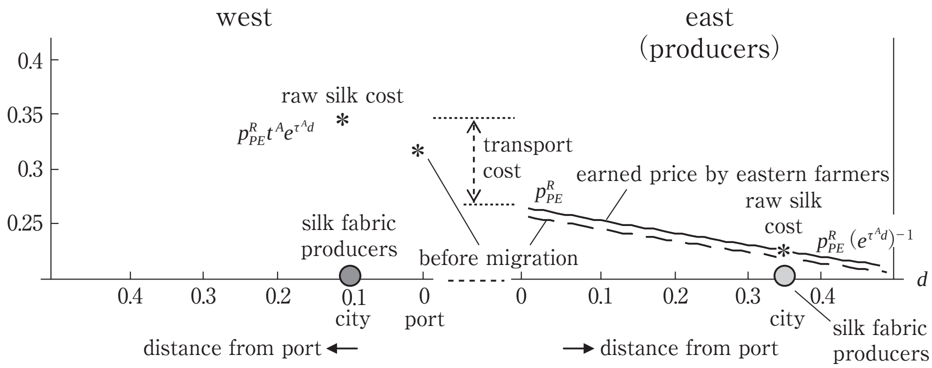
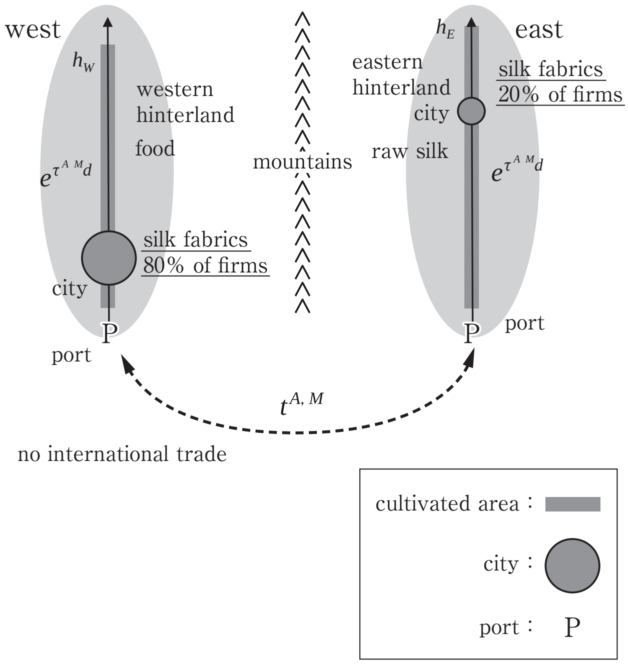


Figure 15b: Equilibrium price schedules of raw silk after migration in phase 2



The sustainable geography after the west-east migration in phase 2 can be summarized as in Figure 16: 20% of silk fabric firms with skilled workers have now moved to the eastern inland location. This explains the emergence of such cities as Kiryu, which grew rapidly in the 18th century after the port closures in an area which previously suffered from poor natural conditions for crop farming. The western city, now locating slightly inland, may correspond to the city of Kyoto which still remained as the silk fabric production centre during the economic isolation.

Figure 16: Sustainable geography in phase 2 after migration



5. Conclusion

The silk industry of Japan had shown several different geographic patterns: silk fabric production first evolved in the western port cities, but during the economic isolation period from the late 17th to the mid-19th century, commercial domestic raw silk production started in eastern Japan and silk fabric production dispersed toward the east, creating new cities in the eastern inland areas. This paper examined the relation between the changing geography of the silk fabric industry and the external shock, the port closures, or the *Sakoku*. Incorporating continuous space within each region allowed the modelling of economic geography at a finer level, distinguishing ports, cities and hinterlands.

The initial geography that the silk fabric industry is agglomerated in the western port city can be supported as a stable equilibrium if the eastern agricultural productivity is low and/or (imported) raw silk is sufficiently expensive relative to food, which are consistent with historical observations (phase 1).

The impact of the port closure that resulted in the introduction of raw silk production in the east was that the east, in particular the eastern inland location, becomes more profitable than the western port city, because of the low raw silk cost. This paper developed and applied a migration process (different to existing studies that focus on population increase) to find that a small new city will emerge in the eastern hinterland during the economic isolation era, while the west still remaining as the main production site. This may explain the coexistence of rival cities such as Kiryu in the east and Kyoto in the west during the isolation era (phase 2).

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