Testing the general validity of the Heckscher-Ohlin theorem: the natural experiment of Japan[1]

Daniel M. Bernhofen
University of Nottingham and GEP
and

John C. Brown
Clark University and GEP

February 19, 2010[2]

Abstract

We exploit Japan's 19th century move from autarky to free trade to test the general validity of the Heckscher-Ohlin theorem. The formulation used in this test employs Ohlin's measure of factor scarcity, where autarky factor prices impose a single refutable prediction on the economy's factor content of trade. Our test combines factor price data from Japan's late autarky period with commodity trade data and the economy's technology matrix from the early free trade period. The technology matrix is constructed from input requirements at the task level for Japan's tradable and key intermediate goods. It draws from a range of historical sources, including a major Japanese survey of agricultural techniques, accounts by European visitors and numerous studies by Japanese and western scholars that draw on village records and business accounts. For the early period of open trade, we evaluate Japan's factor content of trade at the corresponding autarky factor prices. We fail to reject the Heckscher-Ohlin hypothesis in each sample year.

JEL classifications: F11, F14, N10, N75.

[1] Addresses for Correspondence: Daniel Bernhofen, School of Economics, University of Nottingham, University Park, Nottingham, NG7 2 RD, UK. Tel: 44 115 846 7055, Fax: 44 115 951 4159, email: daniel.bernhofen@nottingham.ac.uk or John Brown, Department of Economics, Clark University and GEP, 950 Main Street, Worcester, MA 01610, USA; Tel: 011 508 793 7390, Fax: 508 793 8849, jbrown@clarku.edu.
[2] We acknowledge the generous support of the National Science Foundation Grant SES-0452991 and Leverhulme Trust Grant F/00 114/AM. Shoji Masahiro and Matsuura Miki provided excellent research assistance. Previous versions of the paper were presented at the 2009 NBER Summer Institute, Hitotsubashi University, University of Lausanne, Warwick University, University of Tokyo, University of Nottingham-Malaysia and Nanyang Technological University. We benefitted from discussions with Marius Bruelhart, Don Davis, Kozo Kyoto, Tanimoto Masayuki, Ayako Obashi, Peter Neary, Mathias Thoeng, David Weinstein, John Whalley and Sugita Yoichi. We are particularly indebted to Alan Deardorff's extensive comments on a previous version of this paper.

1. Introduction

The Heckscher-Ohlin theorem is one of the central general equilibrium propositions in economics. It predicts that the direction of trade is explained by differences in countries' relative factor scarcity. In Bertil Ohlin's original formulationBertil Gotthard Ohlin (1933), relative factor scarcity is measured by countries' autarky factor prices. However, since autarky factor prices are rarely observed, empirical investigations of the Heckscher-Ohlin theorem have focused on the Leontief, or quantity formulation of Heckscher-Ohlin, as developed by Jaroslav Vanek (1968). This approach, known as the Heckscher-Ohlin-Vanek (HOV) model, has dominated the empirical Heckscher-Ohlin literature for the last three decades. A shortcoming of the HOV formulation is that it is based on an integrated trading equilibrium characterized by the restrictive assumptions that all economies have identical technologies, identical factor prices and identical homothetic preferences.

This paper provides the first test of the general validity of the Heckscher-Ohlin theorem in its Ohlin, or price formulation. This formulation goes back to the seminal work by Alan V. Deardorff (1982), who has shown that a country's autarky factor price vector imposes a single restriction on the factor content of a country's trade with the rest of the world. Specifically, it predicts that the factor content of net imports valued at autarky factor prices is positive. This prediction can be interpreted as saying that a country will, on average, import its scarce and export its abundant factors. From an empirical point of view, this Heckscher-Ohlin formulation has the attractive feature of requiring no assumptions about the technologies or preferences of an economy's trading partners.

Since the first attempt of Wassily Leontief (1953) to confront Heckscher-Ohlin theory with data, the empirical Heckscher-Ohlin literature has focused exclusively on the quantitiy formulations of the theorem. Applying Vanek's (1968) formulation to Leontief's data, Edward E. Leamer (1980) launched an extensive research agenda on the empirical analysis of the factor content of trade in the HOV framework. Following the initital rejections of HOV by Keith E. Maskus (1985) and Harry P. Bowen et al. (1987), Daniel Trefler (1995, 1993) and Donald R. Davis and David E. Weinstein (2001)have made significant contributions in relaxing some of the restrictive assumptions of the HOV formulation. However, as a trade-off, the literature has moved away from testing the theorem to investigating how the individual assumptions affect the fit of modified versions of HOV (Davis and Weinstein 2001).

An alternative, indirect empirical approach to the quantity formulation of Heckscher-Ohlin is to focus solely on the production side of the model via the Rybczynski relationships. Using this approach, James Harrigan (1997) was able to estimate the joint effects of factor supply and technological differences on industry output. He found that technological differences are an important determinant of cross-industry variation in industry output even within the OECD.

There are several attractive features of the autarky price formulation of Heckscher-Ohlin. First, a test can be conducted for a single economy. An economy's endogenously determined factor prices in the autarky equilibrium impose a single restriction on its factor content of trade in the trading equilibrium. There are different ways of measuring an economy's factor content trade. However, as long as the economy's factor content of trade is measured using its own technology matrix, the existence of gains from trade is the only critical assumption for deriving this Heckscher-Ohlin prediction.[3] The intuition for this is that autarky factor prices embody more information about factor scarcity than endowments. While measured endowments embody only information about relative factor supplies, equilibrium factor prices embody information about both factor supply and factor demand.[4] For example, consider a two-country, two-factor world where country A has a higher land-labour ratio than country B. If consumers in A also have stronger preferences for land-intensive goods than consumers in B, country A could have a higher relative autarky price of land than country B and be a net importer of land-intensive goods. While the price formulation of Heckscher-Ohlin allows for this possibility, the quantity approach rules out such a scenario since it identifies trading patterns solely on differences in relative factor supplies.

A test of Heckscher-Ohlin with a formulation that measures factor scarcity as originally envisioned by Ohlin breaks new ground in a long and prominent literature. The challenge of testing this formulation is that it requires compatible data of a market economy under both autarky and free trade. Daniel M. Bernhofen and John C. Brown (2004, 2005) identified Japan's rapid integration into the international economy in the mid-19th century after over two centuries of nearly complete economic isolation as a natural experiment compatible with the autarky-free trade paradigm of neoclassical trade theory. Bernhofen and Brown (2004, 2005) evaluated Japan's trade flows during the early open trade period with

[3] Although the insight that the gains from trade is a sufficient condition for the Heckscher-Ohlin prediction is implicit in Deardorff (1982), it was explicitly stated in J. Peter Neary and Albert G. Schweinberger (1986).
[4] Friedrich A. von Hayek (1945) articulated the fundamental insight that prices embody all relevant information about relative scarcities in an economy.

commodity prices from the last years of autarky. They showed that Japan's commodity trading pattern behaved in accordance with the law of comparative advantage and provided upper bound estimates of the gains from trade.

For several reasons, the natural experiment of Japan is also well-suited for a test of the autarky price formulation of Heckscher-Ohlin. Since Japan was a market based economy with compatible data under autarky and free trade, it fits the empirical domain of the theory. The Japanese case also expands a test of Heckscher-Ohlin to include an example of a country that exhibited sharp differences with its main (western) trading partners in terms of technology, wages and preferences. At the same time, unlike today, imports into this low-income economy included goods that for the most part served as near or perfect substitutes for domestically-produced goods. This feature of Japanese imports ensures that this case meets the requirement of the theoretical framework that the resource usage of imports can be measured with the domestic technology matrix.[5] Finally, the high quality of historical trade and technological data offer distinct advantages. Measures of the factor content of trade from modern day economies are constructed from industry level input-output matrices in which thousands of products are grouped into broad industry aggregates. The available detailed technology data from historical sources in the case of Japan are disaggregated by each stage of production (or even task). Such detail allows for a closer assignment of factor usage to the quantity of each traded commodity. It also permits a ready correction for any trade in intermediate goods.

Our test combines factor price data from Japan's late autarky period with commodity trade data and the economy's technology matrix from the early free trade period. The construction of the technology matrix draws from a range of historical sources, including a major Japanese survey of agricultural techniques, accounts by European visitors and numerous studies by Japanese and western scholars that draw on village records, business accounts and other historical sources. A study of the production conditions has resulted in a five factor classification: skilled male labour, unskilled male labour, female labour, land and capital. The factor price data on wages, rental rates of capital and land rents stem from a range of historical studies of the late autarky period.

Our test evaluates the factor content of Japan's trade in each year of the early trading period 1865-1876 with the corresponding autarky factor price vector during the late autarky

[5] After the 1870s, Japan's growing imports of western technology, including steam engines and machinery, would make this a less tenable assertion. Contrast Japanese imports ca. 1870 with the imports of a country such as Ghana today, which imports both large amounts of oil and capital goods from developed countries.

period of the early 1850s. Since the inner product is positive in each single trading year, our results provide strong empirical support for the general Heckscher-Ohlin-Deardorff formulation. Our test results are robust to adjustments to potential productivity changes and to adjustments for trade imbalances.

In section 2 we employ a simple graphical framework that illustrates the interrelationship between the gains from trade and the price formulation of the Heckscher-Ohlin theorem. Our formulation builds on and exploits the concept of a factor trade utility function which was developed by Neary and Schweinberger (1986). Section 3 discusses the general formulation of the Heckscher-Ohlin theorem as formulated by Alan V. Deardorff (1982). Section 4 discusses the natural experiment of Japan, the empirical domain and the data sources for the construction of the technology matrix and the autarky factor prices. Section 5 contains the empirical results and investigates robustness. We conclude in section 6.

2. Gains from trade and the price formulation of Heckscher-Ohlin: the intuition

Consider a neoclassical distortion-free economy, called Home, that produces *n* goods using only two factors of production with the economy's endowment vector given by $\mathbf{V}^0 =(V_1^0,V_2^0)$. The allocation of factors to goods depends on the economy's technology and consumer preferences. The economy's technology matrix is given by the matrix **A** and consumer preferences are represented by a well-behaved utility function.[6] The economy's autarky equilibrium is characterized by the autarky factor price vector $\mathbf{w^a}=(w_1^a,w_2^a)$ and autarky utility u^a. Endowments and factor prices determine home's gross domestic product (GDP) under autarky: $GDP^a=w^a{}_1V_1{}^0+w^a{}_2V_2{}^0$. Geometrically, $\mathbf{V}^0$ and $\mathbf{w^a}$ can be thought of defining an *autarky GDP factor line*, as depicted in Figure 1, which goes through the endowment point $\mathbf{V}^0$ and has a slope of $(-w_1^a/w_2^a)$.

Home now has the opportunity to engage in international trade with the rest of the world. Assume that factor prices in the rest of the world prior to home's engagement in trade are given by $\mathbf{w^{ROW}}=(w_1^{ROW},w_2^{ROW})$. We can think of the rest of the world consisting of several countries already engaged in trade with each other prior to Home's entrance into world commerce. In the special—but restrictive—case where such a trade equilibrium is characterized by factor price equalization, $\mathbf{w^{ROW}}$ will be the same everywhere in the rest of

[6] For ease of exposition, we assume a fixed coefficient technology which implies that production techniques will not depend on factor prices and, therefore, be the same under autarky and trade. On the consumption side, utility can either pertain to a single representative consumer or community utility. Since we are not interested in the distributional implications of international trade, both interpretations are isomorph.

the world. More generally, we can think of $\mathbf{w}^{\mathbf{ROW}}$ as the average factor prices in the rest of the world.[7] Characterizing the rest of the world with a single factor price vector allows us to employ Ohlin's price definition of relative factor scarcity. Home is then relatively abundant in factor 1 if the autarky relative factor price at home is lower than in the rest of the world, or $w^a{}_1/w^a{}_2 < w_1^{ROW}/w_2^{ROW}$.

Consider now a trade equilibrium where Home is producing all goods that it produced under autarky.[8] Home's net import vector in the trading equilibrium is given by $\mathbf{T}=(T_1,\ldots,T_n)$, where $T_i>0$ if good *i* is imported and $T_i<0$ if good *i* is exported. Instead of focusing on actual trade in goods, we characterize the trade equilibrium by examining the direction of embodied trade in factor services. Given the domestic technology matrix **A,** the corresponding net factor import vector is given by $\mathbf{F}=\mathbf{AT}$, where $\mathbf{F}=(F_1,F_2)$. We assume that the trade equilibrium is such that one can exclude the cases where both factors are either imported (i.e. $F_i>0$) or exported ($F_i<0$). As a result, there must exist a vector $\mathbf{w^t}=(w_1^t,w_2^t)$ such that $w_1^tF_1+w_2^tF_2=0$. This vector can be thought of as defining a *factoral terms of trade* w_1^t/w_2^t.[9] In the case where the trade equilibrium is characterized by factor price equalization, w_1^t/w_2^t will coincide with w_1^{ROW}/w_2^{ROW}. In the absence of factor price equalization but under the assumption that utility and production functions are Cobb-Douglas, $\mathbf{w^t}$ will converge towards $\mathbf{w^{ROW}}$.[10] Since we assumed that home is relatively abundant in factor 1, the factoral terms of trade will be such that $w_1^a/w_2^a < w_1^t/w_2^t < w_1^{ROW}/w_2^{ROW}$.

Figure 1 illustrates that the economy's factor service trade must occur along its factoral terms of trade line, which is anchored at the economy's endowment point **V** and has, in absolute value, a slope of $w^t{}_1/w^t{}_2$. Since we are in a two-factor world, the factoral terms of trade line implies only two possible directions for trade: export factor 1 and import factor 2 ($F_1<0$ and $F_2>0$) or import factor 1 and export factor 2 ($F_1>0$ and $F_2<0$). The existence of gains from trade allows a prediction of (or at least restricts) the equilibrium pattern of factor trade. To see this we follow Neary and Schweinberger (1986) and consider the concept of a

[7] Alternatively, under the restrictive two-country assumption, $\mathbf{w^{ROW}}$ will be just the foreign autarky factor price vector.

[8] For ease of exposition, and without loss of generality, we assume away any natural or government imposed trade costs.

[9] Since we do not assume balanced trade in factor services, we allow for the possibility that Home's factor prices under trade differ from the factoral terms of trade.

[10] Building on A. H. Land (1959) and Douglas Stewart (1976), Alan. V. Deardorff (1986) presents an example that demonstrates that trade could lead to a divergence of factor prices. But he has also shown that Cobb-Douglas preferences and production functions imply indirect Cobb-Douglas preferences for factors which results into factor price convergence.

factor trade utility function.[11] A factor trade utility function is the maximum utility that the economy could attain if its endowments were augmented by **F** and Home's technology were applied to the augmented endowment vector $\mathbf{V}^{\mathbf{t}}=\mathbf{V}^0+\mathbf{F}$. Since the factor trade utility function can be shown to be quasiconcave and weakly increasing in endowments, the corresponding equal utility curves of 'factor trade augmented endowment points' will be bowed out as shown in figure 1.[12] Since $\mathbf{V}^0$ is the autarky endowment point, the corresponding utility level is the autarky utility u^a. International trade in factor services enables the economy to attain an augmented endowment point $\mathbf{V}^t$, defined as $\mathbf{V}^t=\mathbf{V}^{\mathbf{0}}+\mathbf{F}$. Now if we know that the free trade utility level u^t that corresponds to $\mathbf{V}^t$ exceeds the autarky level, i.e. $u^t>u^a$, then the free trade equal utility curve must lie to the right of the autarky GDP factor line. This implies that we can exclude the possibility that the economy will import factor 1 and export factor 2, which in turn implies that the economy must export its abundant factor 1 and import its scarce factor 2. We can state this result in the two-factor price formulation of the Heckscher-Ohlin theorem:

Two-factor price formulation of Heckscher-Ohlin:

Assume there are gains from trade. If the economy is abundant in a factor relative to the rest of the world, then the economy will export the services of its abundant factor and import the services of its scarce factor.

3. The general Heckscher-Ohlin Theorem

Consider now the more general case where *m* factors are potentially employed in the production of *n* goods. Technology can be characterized by a technology set Κ consisting of feasible pairs (**V**, **X**), where $\mathbf{X}=(X_1,\ldots,X_n)$ is a vector of production levels resulting from the factor employment vector $\mathbf{V}=(V_1,\ldots,V_m)$.[13] Since our framework is a single economy setting involving a comparison of this economy under autarky and trade, it does not require any assumptions about foreign technologies. This implies that we will define the economy's factor content of trade based on the economy's home technology. This set-up is less

[11] Neary and Schweinberger's (1986) formulation of direct and indirect factor trade utility functions builds on Alan D. Woodland's (1980) concepts of direct and indirect trade utility functions.

[12] See Neary and Schweinberger (1986, p. 426) for a discussion of the properties of the factor trade utility function and their reference to an unpublished Appendix B which contains proofs of these properties. Our analysis differs from Neary and Schweinberger by considering utility associated with $\mathbf{V}^0+\mathbf{F}$ rather than utility associated with **F**.

[13] We assume that the technology set fufills all the standard neoclassical assumptions, such as closedness and convexity, which are required to ensure the existence of the autarky and trade equilibrium.

restrictive than Deardorff (1982), who assumes identical technologies across trading partners.[14] The economy's fixed factor endowment vector is given by $\mathbf{V}^0$ and equilibrium factor prices are denoted by $\mathbf{w}=(w_1,\ldots,w_m)$.

Consumer demands are denoted by $\mathbf{C}=(C_1,\ldots,C_n)$. Consumers respond to domestic goods prices, denoted by $\mathbf{p}=(p_1,\ldots,p_n)$, and are assumed to conform in the aggregate to the weak axiom of revealed preference[15]:

$$\mathbf{p}^1\mathbf{C}^1 \geq \mathbf{p}^1\mathbf{C}^2 \;\; => \;\; \mathbf{p}^2\mathbf{C}^1 > \mathbf{p}^2\mathbf{C}^2. \qquad (1)$$

This has the standard interpretation that if the consumption point $\mathbf{C}^1$was chosen at the price regime $\mathbf{p}^1$ at which $\mathbf{C}^2$ could have been chosen, then if $\mathbf{C}^2$ was chosen at the price regime $\mathbf{p}^2$, then $\mathbf{C}^1$ could not have been affordable.

We consider two regimes, autarky and open trade. The superscripts *a* and *t* identify the variables associated with the two regimes. In autarky, production coincides with consumption, or $\mathbf{X}^a=\mathbf{C}^a$, and autarky goods and factor prices $\mathbf{p}^a$ and $\mathbf{w}^a$ are such that production is feasible, there is no excess demand and producers maximize profits. Profit-maximization implies that

$$\mathbf{p}^a\mathbf{X}^a-\mathbf{w}^a\mathbf{V}^0 \;\geq\; \mathbf{p}^a\mathbf{X}-\mathbf{w}^a\mathbf{V} \quad \text{for all } (\mathbf{V},\mathbf{X}) \text{ in K}. \qquad (2)$$

In the trade equilibrium, the consumption vector $\mathbf{C}^t$ will generally be different from the economy's production vector $\mathbf{X}^t$. The difference is the net import vector $\mathbf{T}=\mathbf{C}^t-\mathbf{X}^t$. The trade equilibrium is characterized by vectors of domestic goods and factor prices $\mathbf{p}^t$ and $\mathbf{w}^t$ such that production and trade are feasible, there is no excess demand and producers maximize profits. In the trade equilibrium, profit maximization implies that

$$\mathbf{p}^t\mathbf{X}^t-\mathbf{w}^t\mathbf{V}^0 \;\geq\; \mathbf{p}^t\mathbf{X}-\mathbf{w}^t\mathbf{V} \quad \text{for all } (\mathbf{V},\mathbf{X}) \text{ in K}. \qquad (3)$$

[14] In another respect, Deardorff 's (1982) formulation has greater generality since it allows for two additional definitions of the factor content of trade. The first is based on where the goods are actually produced in the world economy and the second is based on the actual content of consumption. However, this greater generality is bought at the cost of assuming identical technologies for trading partners, which is not a viable assumption for the case of Japan during the early years of open trade.

[15] This characterization of preferences, although strong, is a bit more general than the formulation in section 2, which requires the existence of community utility.

Since our focus is on the factor content of trade, we need to be more specific about technology. Under the assumption of constant returns to scale and the absence of joint production, technology can be represented by a l x m matrix $\mathbf{A}$ of unit input coefficients. Since least cost production techniques depend on factor prices, the technology matrix in the trade regime will be a function of $\mathbf{w}^t$, i.e. $\mathbf{A}=\mathbf{A}(\mathbf{w}^t)$. The factor content of trade based on the economy's technology matrix is then given by $\mathbf{F}=\mathbf{A}(\mathbf{w}^t)\mathbf{T}$. A further assumption is that if the economy's endowment vector $\mathbf{V}^0$ were augmented by $\mathbf{F}$, then it would be technologically feasible to produce the trade consumption vector $\mathbf{C^t}$ domestically. Formally,

$$(\mathbf{V}^0+\mathbf{F}, \mathbf{C}^t) \text{ is in } \mathrm{K}. \tag{4}$$

Assumption 4 is a plausible given that the factor content of trade is defined using domestic technologies.

Balanced trade occurs at the world price vector $\mathbf{p}^w$, i.e. $\mathbf{p}^w\mathbf{T}=0$, which can be different from the domestic price vector $\mathbf{p}^t$ because of trade restrictions. What needs to be assumed is that trade is, on average, more taxed than subsidized, which can be written as:

$$(\mathbf{p}^t-\mathbf{p}^w)\mathbf{T} \geq 0. \tag{5}$$

The intuition for this is that trade taxes, although reducing the volume of trade, do not interfere with the comparative advantage pattern of trade prediction. In contrast, trade subsidies can be so large that they prompt trading patterns that override underlying factor scarcity.[16] We are now in the position to state what we might call the Heckscher-Ohlin-Deardorff Theorem.

Heckscher-Ohlin-Deardorff Theorem:

Consider a single economy characterized by (1)-(5). The economy's autarky price vector $\mathbf{w^a}$ *imposes a single restriction on the factor content of trade, such that* $\mathbf{w}^a\mathbf{F}\geq 0$.

Proof: The balanced trade condition $\mathbf{p}^w\mathbf{T}$ and (5) imply $\mathbf{p}^t\mathbf{T} \geq 0$. Applying autarky production to the right-hand side of (3) yields $\mathbf{p}^t\mathbf{C^t} - \mathbf{p}^t\mathbf{T} - \mathbf{w}^t\mathbf{V}^0 \geq \mathbf{p}^t\mathbf{C^a} - \mathbf{w}^t\mathbf{V}^0$. Rearrangement gives rise to $\mathbf{p}^t\mathbf{C^t} \geq \mathbf{p}^t\mathbf{C^a}$. The weak axiom of revealed preference (1) implies then that $\mathbf{p}^a\mathbf{C^t} > \mathbf{p}^a\mathbf{C^a}$.

[16] Europe's common agricultural policy provides a classic example.

Employing (2) and (4), we obtain $\mathbf{p}^a\mathbf{C}^a$-$\mathbf{w}^a\mathbf{V}^0 \geq$ $\mathbf{p}^a\mathbf{C}^t$ -$\mathbf{w}^a$ ($\mathbf{V}^0$+$\mathbf{F}$), which implies that $\mathbf{w}^a\mathbf{F} \geq$ $\mathbf{p}^a\mathbf{C}^t$-$\mathbf{p}^a\mathbf{C}^a$ >0.

Several comments are in order. First, the proof shows that the existence of the gains from trade, as formulated by the weak axiom of revealed preference, is the key critical condition for the Heckscher-Ohlin theorem to hold in its price formulation. Second, $\mathbf{w}^a\mathbf{F}\geq 0$ generalizes the two-factor formulation from the previous section to higher dimensions. However, if there are more than two factors, it is not possible to pinpoint the direction of factor content trade to a precise measure of factor scarcity as we were able to do in section 2. The inequality can then be interpreted as saying that a country will, on average, import factor services with high autarky prices and export factor services where the autarky price is relatively low.

Third, in contrast to the HOV specification that yields sign predictions for each factor in each country in a single trade equilibrium, the Heckscher-Ohlin-Deardorff theorem yields a single refutable proposition based on two equilibria. The vector of autarky prices $\mathbf{w}^a$ acts as the predictor that imposes a restriction on the economy's vector of net imports **F** under trade.

Finally, the Heckscher-Ohlin-Deardorff price formulation has the attractive feature that it is not based on any assumptions about the technologies or preferences of the economy's trading partners. As a result, there is quite a bit at stake in testing this general Heckscher-Ohlin formulation. A refutation of the prediction could not be accounted for by unmet assumptions about technologies or preferences.

4. Empirical implementation

4.1 Experimental conditions and domain

The static trade model requires that the Japanese economy meets four basic conditions during the period of autarky from which data are collected (ca. 1845 to 1859) and the early trade period (1860 to 1876):

1) Markets for goods were competitive under autarky and trade.

2) Japan produced relatively homogeneous products in small scale production units, ruling out other explanations for Japan's trading patterns such as increasing returns to scale or imperfect competition.

3) After its opening up, the economy operated under a trade regime in which the country's exports did not receive substantial subsidies.

4) The factor prices observed during autarky were outcomes of competitive market conditions, including factor mobility and the absence of market power.

The recent historical literature on Japan summarized in Akira Hayami et al. (2004) and referenced in Bernhofen and Brown (2004 and 2005) provides evidence that the Japanese economy met conditions (1) and (2). A network of markets linked the three main economic regions of Japan: the Kinki (Ōsaka/Hyōgo/Kyoto), Nobi (Nagoya) and Kantō (Tokyo). Merchants could rely upon relatively inexpensive coastal shipping and sophisticated, if expensive, communication networks. Farmer households were responsible for the bulk of production on their own account, including processed products such as cotton and silk textiles. Merchants running small-scale operations often engaged directly in production; occasionally they put out production to area artisans in small-scale operations. Fishermen employing at the most a few workers produced maritime products such as seaweed or fertilizer. With the exception of a few coal and copper mines, traditional Japanese technologies ensured that metals and other processed raw materials would be produced in small workshops or firms. Bernhofen and Brown (2004, p. 58) discusses the absence of export subsidies (assumption (3)) during the early period of open trade.

The final assumption has been the subject of recent research on factor markets, particularly during the late Tokugawa era (roughly 1820 to 1868). This research has challenged the long-held view that feudal restrictions imposed by the Tokugawa regime on land and labor markets were fully binding until the Meiji era reforms of the 1870s and later. Osamu Saitō (2009, p. 179)notes that although the formal transfer of landholding rights remained difficult to carry out, leasing arrangements (and the related growth of tenancy) meant that "tenancy came to function as if there had existed a genuine lease market for land." On-the-farm employment of owner/tenant-operators dominated employment in Japan throughout the pre-open trade period, even as specialization in rice gave way to by-employment in activities in growth industries such as sericulture (raising silkworms and weaving), cotton (growing cotton, spinning and weaving), tea and fishing. The pace of economic change hollowed out the regulations from the 17th century that attempted to limit the movement of the population as well as the restrictions on entry imposed by urban guilds. As Saitō (2009, p. 186) notes, by the first half of the nineteenth century there was "a well-integrated labour market between the peasant farm household and non-farm sectors within a regional setting." Saitō argues that the integration of the two major regional markets appears to have been most effective at the level of white collar employment. At the same time, real wage series for unskilled workers in Kyoto (in the west) and skilled workers in a town outside of Tokyo (in the east) were highly correlated over the period 1820 to 1853 (before the first encounter with Perry) (see Osamu Saitō 1998a).

Osamu Saitō and Tokihiko Settsu (2006) and Ronald P. Toby (2004) provide recent summaries of historians' understanding of capital markets in Japan during this period. Although a sophisticated network of merchant lending linked the main cities of Edo (Tokyo), Ōsaka and Kyoto, Saitō argues that Japan lacked a banking system. Toby (2004) focuses instead on the actual activities of those involved in providing credit. He bases his findings on the detailed examination of the ledgers of the Nishimatsu house, a family engaged in lending in a small town well outside of the urban areas of Tokyo and Osaka during the late Tokugawa era. He concludes that bank-like activities took place. By 1840, the family was leveraging its own capital with three to four times that amount in funds borrowed (at favorable rates) from other lenders in a wholesale credit market. Based upon the levels and trends in quoted interest rates for interbank borrowing, the geographic reach of the family's borrowing and lending and evidence from other studies, he concludes that lending and deposits by this country lender located miles from well-known financial centers indicated that "a national credit market was in play" (Toby, 2004, p. 319).

The theoretical prediction is based on a static model combining data under autarky and trade, but without accounting for the passage of time. However, since autarky and free trade are observed at different points in time, a correct empirical inference requires that the economy's factor scarcity conditions were not affected in the transition from the autarky to the early free trade period. Furthermore, while the static theory necessarily assumes balanced trade, an actual economy will typically be characterized by imbalanced trade during particular time periods.

These considerations lead us to the following two identification conditions:

5) The observed sign of the inner product is caused by underlying factor scarcity and not by an underlying trade deficit.

6) During the transition from autarky to free trade the economy did not experience changes in preferences, technologies or in the composition of its endowments.

If the country is running a trade deficit, then the sign of the inner product might just reflect the trade deficit rather than Heckscher-Ohlin forces. This is most easily seen by considering the stark hypothetical case where the country only imports but does not export anything. In such a scenario the autarky value of net imports is positive, but this is not informative about Heckscher-Ohlin. Fortunately, Japan's trading pattern during the first years of trade included some years of surplus and other years of deficits so that we can investigate robustness regarding trade imbalances. We will discuss our strategies of how we deal with trade imbalances when we present our results in section 5. This brings us then to the second identification condition.

The transition period from autarky to free trade exposed the Japanese to encounters with western attitudes and technology, particularly in the four or five treaty ports where western merchants had complete freedom of movement. For the best test of the hypothesis, the analysis is restricted to those early years of open trade (1865 to 1876) for which trade data area available. It is likely that preferences were reasonably stable and technologies remained unchanged and during this period

Despite the enthusiasm of official and some cultural elites for western culture and institutions after the Meiji restoration of 1868, preferences for consumption remained largely unchanged during the first decades of open trade. Textiles, which dominated imports, reflected this fact Hoshimi Uchida (1988). Imported novelties such as woolen cloths were readily adapted to Japanese tastes in clothing, and the marketing strategies of western merchants assumed continued use of traditional clothing.[17] Population growth was modest in the years following the opening up, and Japanese historians do not report any notable changes in the age structure or sex composition of the population. There was no sizeable emigration or immigration, nor were there substantial imports or exports of capital goods.

It is plausible that rapid technological change in the production of tradable goods and in the infrastructure of the economy could have taken place in the years immediately following the opening up, which could have led to significant shifts in factor demands only indirectly related to the change from autarky to free trade. Because of the unique historical circumstances of the Japanese case, the adoption of the new technologies in Japan only began

[17] See *Preussisches Handelsarchi* (1873) and *Preussisches Handelsarchiv* (1874), which report that the use of woolen cloth for western dress was restricted to government uniforms of various kinds and the wealthiest classes.

in earnest after the mid-1870s.[18] Most important, as Erich Pauer (1987) notes, Japan's labor force lacked the technological know-how and skills to adopt the steam- and iron-based technologies of the western industrial revolution right after the opening up of trade. By the close of the test period (1876), the Meiji government and some western investors had made only limited progress in introducing western technologies in handful of coal, copper and gold and silver mines that employed at most a few thousand workers.[19] Transportation technologies, such as steamships or railroads, also required skills, organizational capabilities and capital that only became available during the second or third decade of the Meiji period.[20] Finally, even incremental changes in organization using existing technology such as the creation of large-scale cocoon reeling establishments with specialized female labor emerged only slowly, and these are well-documented in the historical literature. The development of the **A** matrix addresses one potential exception to this pattern, which was the adverse impact of open trade on productivity in sericulture.

Finally, Japan's trade during the early period can be characterized as that of a small open economy. Its exports were a miniscule share of global trade, and were smaller than Indonesia, the Philippines and virtually all of the Latin American countries Angus Maddison (2006, p. 360). Japan's share of the markets for silk of its main trading partners (France, Great Britain and the United States) was only about 15 to 20 percent Shin□ya Sugiyama (1988, ch. 4).

Overall, the Japanese economy exhibited substantial differences in preferences, technology and factor prices from its main trading partners. Consumer preferences posed significant challenges for western importers as they attempted to adapt to Japanese tastes in clothing and food. Japan used none of the technologies developed during the industrial revolution that dominated production of textiles, metals and transportation goods in the west. The wages (in silver) of its unskilled urban workers ca. 1870 were about one-half those in Amsterdam or Leipzig, and less than one-quarter of wages in London Robert Allen et al. (2007). Interest rates of 10 to 15 percent were significantly higher than interest rates of its western trading partners.

---

[18] The major exception to this rule would be limited application of new mining and metallurgy techniques starting in the early 1870s in some government-owned mines.

[19] British consuls in the treaty ports complained repeatedly that the government's hostility to foreign ownership prevented the much-needed modernization of the mining and metallurgy sectors. See the summary report by F. R. Plunkett (1875).

[20] Unlike in Latin America, the Anglo-Saxon regions of recent settlement or colonial Africa, foreign capital played no role in the establishment and construction of modern transportation systems in Japan.

4.2 Hypotheses and data sources

We exploit the circumstances of Japan's opening up to trade to test the following hypothesis about the sign of Japan's vector of net factor imports valued at autarky factor prices:

$$H_0:\ \mathbf{w^a F^i}=\mathbf{w^a}\ (\mathbf{A^{1870}}\ \mathbf{T^i}) \geq 0, \qquad (6)$$

where $\mathbf{A^{1870}}$ is the domestic technology matrix during the early free trade period and $\mathbf{T^i}$ is the vector of net imports in each test year i (i=1865,…,1876). To our knowledge, no other theory exists that suggests an alternative restriction on the economy's factor content of net imports. For that reason, we postulate randomness as the alternative hypothesis:

$$H_1:\ \mathbf{w^a F^i} \text{ is random with } \Pr(\mathbf{w^a F^i}<0)=0.5 \qquad (7)$$

In order to make a probability statement about the alternative hypothesis, we assume that in the case of randomness it is equally likely to obtain a positive as a negative sign. Assuming further that the 'yearly drawings' are independent and stem from the same distribution, we can then calculate the smallest level of significance for which the data would allow us to reject the randomness hypothesis H_1.

Detailed historical sources on the Japanese economy from both the autarky and the early free trade periods provide data sufficient to calculate the vector of net imports, construct the technology matrix and calculate the autarky factor prices. The vector of net imports **T**, which was also used in Bernhofen and Brown (2004 and 2005), is readily available from publications of the Meiji government. For completeness, data available during 1865 and 1867 from British consular and other western sources are also used.[21] The year 1865 marks the *de facto* beginning of open trade; the Tokugawa regime only abandoned efforts to limit the export of silk and silkworm eggs in 1864 after western military action. The trading vector is given at the individual product level. For most relevant products, both the value and quantity are available. The amount of detail permits a close match between the technology matrix and imports. For example, the usage of cotton can be adjusted to reflect that fact that most imported cloths (shirtings) were relatively light-weight. Additional detail is available on the degree of refinement of products such as copper, iron, and sugar.

[21] See Shuzeikyoku, Japan. Ōkurashō (1893) for 1868-1876 and Great Britain**.** "Commercial Reports by Her Majesty's Consuls in Japan" die 1865 and 1867. A fire in the largest treaty port of Kanagawa (near Yokohama) destroyed the trade returns for 1866.

Construction of the **A** matrix took account of two features of the Japanese economy during the early period of open trade: the extensive use of female labor and the locus of production in vertically disintegrated and non-specialized units. Rural households produced most of the tradable goods during the early trade period. Similar to the rural proto-industrial households of pre-industrial Europe or the farm households of early frontier America, Japanese producers included women in a wide range of tasks. In other ways, Japan's rural production units differed from those in pre-industrial Europe or frontier America. The typical proto-industrial household of pre-industrial Europe had only a small plot of land; family members devoted most of their time to specialized production of goods such as cloth or yarn on the account of a putting-out merchant. In Japan and similar to frontier America, production of manufactures was by farmer-proprietors or tenant farmers who also produced sufficient food for sustenance. Unlike farmers on the frontier, Japanese farmers faced land scarcity. They took advantage of a dense network of markets and emerging regional specialization to smooth out peaks in the demand for labor with diversified production for both domestic use and the market. Over the agricultural year, one farm could grow rice and soybeans, produce cotton, spin yarn, weave cloth and perhaps harvest and then refine vegetable wax. Specialized craftsmen or small firms took on tasks at certain stages of the production, such as scutching cotton produced by households prior to being spun, or dyeing yarn or cloth.

Construction of the **A** matrix for this economy of myriad small multi-product firms requires the compilation of data for each stage of production and knowledge about the locus of production. The manufacturing and economic censuses that gather data about technologies for contemporary economies could not do justice to an economy organized in this way. Fortunately, the Japanese sources that describe production methods in use during the early trade period reflect this reality. They describe the resource usage of technologies by individual stages of production, rather than by final output. At times a closer examination of the detailed information available on tasks within each stage helps to fill out details about the allocation of labor. The **A** matrix that can be constructed using these sources also accommodates the diversity of Japan's trade during the test period, which involved raw materials, intermediate inputs such as yarn and finished products such as calico cloth.

Japanese historical sources, contemporary western accounts and the research of Japanese economic historians provide a wealth of information on production technologies.[22] These sources suggest that five fundamental factors of production can capture the technologies in use during this period: female labor, unskilled male labor, skilled male labor, land and capital. Virtually all sources measure labor inputs in terms of days of work. As noted above, female labor was ubiquitous in most household-based production processes, albeit with clearly-defined tasks. Female workers were used in the picking of tea and in the reeling of silk, for example, but not necessarily the planting or pruning of tea shrubs and rarely in the production of mulberry leaves. Most labor on the farm performed by either a male or female could be defined as unskilled labor, particularly given the myriad outputs produced by one family over the course of the year. Unskilled labor could also be used in mining and metallurgy and the processing of maritime products, such as seaweed or herring that was used for fish fertilizer. The category of skilled workers includes production workers with specialized skills (such as smelters or tea sorters), the small number of managers required in traditional Japanese business organizations of the time, owner-operators of specialized small firms such as fishermen and craftsmen such as dyers. Skilled workers were identified either by the description found in the sources or in some cases by the wage premium that they commanded.

Capital is measured in terms of the user cost of capital. The capital equipment in use during the late Tokugawa and early Meiji periods was almost invariably made of wood, so that long service lives would not be expected. Information available from the sources confirms that this is the case. In addition, rural producers faced high rates of interest, which must be included in the calculation of the user cost of capital. The measurement of land is in terms of area with three levels of productivity: arable paddy or dry land and forest and mining land.[23]

Bernhofen, Brown and Tanimoto (2009) details the individual sources for the nearly forty tradable and two intermediate goods that are included in the **A** matrix. For agricultural products, the primary source is the *Nōji Chosa* found inYukio Chō et al. (1979), which is the

[22] The sources and details of constructing the **A** matrix are presented in full detail in Daniel M. Bernhofen, John C. Brown and Masayuki Tanimoto (2009) .
[23] Hedonic regressions of data from Toshio Furushima and Keiji Nagahara (1954) suggest that dry land was at the most about three-quarters as productive as paddy land, and this adjustment was used in measuring land for tea shrubs, mulberry trees, cotton and soybeans. Based upon Meiji sources, land used in mining and forestry was adjusted to one-twentieth the amount of paddy land 1882. (See *Chiso Kaisei Houkokusho* 1882).

first detailed survey of the production conditions of Japanese agriculture and dates from the Meiji era. This source provides data on the labor requirements for individual production tasks, land, capital and other inputs for all agricultural crops. Although compiled in the 1880s, the data are reflective of conditions a decade earlier. The main change in Japanese agriculture after 1868 was the modernization of rice production known as the *Meiji Nōhō*, which was a regime of double-cropping that included planting faster-maturing strains of rice, plowing rice paddies with horses and applying more fertilizer. Penelope Francks (1984, pp. 55-63) reviews the literature and finds that the most significant diffusion of these methods took place well after the 1880s.[24] Other sources, mostly contemporary accounts, describe the input requirements for products such as vegetable wax, camphor, shiitake mushrooms and charcoal, which was the main source of fuel for production processes in Japan during the early years of trading.

The estimates of input requirements for silk also take account of the unique circumstances under which Japan opened up to international trade. By the early 1860s, Europe was struggling with the devastating consequences of pebrine disease, which could not be detected prior to hatching silkworm eggs and altered the ratio of cocoons successfully produced to eggs initially hatched in an entirely unpredictable manner Giovanni Federico (1997, pp. 38-39). After Japan opened up, French and Italian merchants sought out silkworm eggs from the isolated sericulture regions of Japan, which were free of the disease. The exportation of eggs had an adverse impact on the productivity of Japanese sericulture by the early 1870s. The highest-quality eggs were exported, and those remaining in Japan yielded fewer cocoons than would have been the case under normal conditions. The cocoons also yielded less raw silk. In addition, a disease known as udschi was spreading through the silk growing regions by the early 1870s. Although these negative productivity shocks were strongest only during the latter part of the test period, it is advisable to incorporate them in input requirements for silk for the entire period. Fortunately, the comments found in Ernest de Bavier (1874), who was a leading exporter of silk and silkworm eggs to France, suggest plausible downward adjustments in productivity to account for these shocks.[25] A final

[24] Some areas of the most developed areas of the Kinki region, which were growing other commercial crops such as cotton, had adopted similar innovations as early as the late Tokugawa period.

[25] The upward adjustment in input requirements was 1.5 for raising cocoons from eggs and 1.25 for reeling silk from cocoons. The comments of S. Syrski (1872b) suggest that the de Bavier was overstating the low productivity of Japanese sericulture. It was also the case that by the time of the *Nōji Chosa*, pebrine disease was endemic to Japan. These adjustments overstate input requirements, since they do not take account of the higher

adjustment to input requirements takes account of the fact that the Japanese sericulture industry exported a small amount of joint products that were essentially by-products of the production first-quality raw silk. Input requirements for raw silk have been adjusted upward to take account of the potential impact of joint production.[26]

Among Japan's main maritime exports were products such as seaweed and seaweed gelatin (kanten) and processed cuttle fish (a form of squid), abalone and sea urchins. In addition, Japanese farming depended upon the use of fertilizer from herring caught off the coast of Hokkaido. The main source for technology data on these products are reports of the Hokkaido government.

Documentation for metals and metallurgy is particularly complete. From 1862 onwards, Japanese governments invited German, French, British and American mining engineers and geologists to analyze the mineral resources of the Empire (chiefly copper, iron, lead, oil, silver and gold) and suggest methods for upgrading mining methods and metallurgical techniques. The reports of these observers, along with historical accounts based on the extant business records of a few mines and smelting operations, provide rich detail on the labor- and charcoal- or wood-intensive Japanese technologies for mining and metallurgy.[27] These technologies relied upon human labor for virtually all mine operations, including excavation, transport, processing and drainage.

Finally, textiles were the most significant import during the early open trade period. These imports included yarn, gray and finished cotton cloth and woolen cloths. Local histories and contemporary studies provide significant details about the technologies in use for ginning cotton, processing it prior to spinning, weaving yarn and dyeing cloth. The continued use of these technologies into the twentieth century expanded the amount of documentation available for them.

Woolens accounted for a median of 18 percent of Japanese imports during the test period. In peak years such as 1865 or 1873, the share rose above 30 percent and up to 45 percent. At first glance, the imports of woolens would appear to be primarily for western-style dress, such as uniforms. The heaviest all-woolen cloths such as buckskins did serve this

---

labor productivity in reeling reported by both Syrski and de Bavier, which was 1.5 to 2.5 times the average compiled from the *Nōji Chosa*.

[26] The joint products included pierced cocoons that resulted from the raising of silkworm eggs, noshi silk, dupioni silk (also known as tama) and silk waste. Most of these joint products were retained for use in Japan as waste silk that was used either for wadding or as an input into low quality silk cloths.

[27] The main sources include Francisque Coignet (1957), Benjamin Smith Lyman (1879) and F. R. Plunkett (1875) .

purpose. In fact, most imports of woolens were used for traditional Japanese dress. Contemporary observers and historians of Japanese fashion such as Hitoshi Tamura (2004) note that most imports were of lighter cloths, such as camlets, *mousseline de laine* and mixed woolen and cotton cloths. Tamura's analysis of the accounts of cloth retailers and other evidence establish that woolens were a relatively inexpensive substitute for silks and were used as belts, linings, collars and outer wear (*haori*). The woolens substituted for silks such as *habutai* (a plain weave or figured weave fabric), *obi* (cloth for belts or sashes) and *chirimen* (a silk crepe fabric).[28] Japanese, English, German and French sources suffice to reconstruct the dimensions and weights of the imported woolens and the domestic silk fabrics for which they substituted; imports of woolens were then allocated to the silks of about the same weight. The factor requirements for those silks were then calculated. The average weight of imported woolens fell until the middle of the test period. Thereafter, printed *mousseline de laine*, which often substituted for silk crepe, dominated imports. The minimums of the implicit usage for every factor across all test years were chosen as the lower-bound estimate of the per-unit resource cost of these imports.

The main source of disagreement in the literature on silk weaving technologies is over the extent to which women were weaving these cloths by the early open trade period. This study follows the approach of the contemporary French silk trader, de Bavier, who argued that women wove most habutai and chirimen; men and women would have been both involved in the weaving of belts.[29]

Table One provides the **A** matrix for Japanese exports and imports during the early period of open trade. Depending upon the mix of imports and exports in any one year, the available information on production technologies covers 94 to 99 percent of exports and 70 to 90 percent of imports.[30] Construction of the matrix included information on three important intermediate inputs: firewood, charcoal and fertilizer. Charcoal and wood were the primary sources of energy in Japan during this period. The Japanese economy was unusual in the extent to which it relied upon fish fertilizer from sardines and herring to supplement the human waste and composted plant material commonly used throughout East Asia.

[28] See the accounts of a cloth merchant analyzed by Tamura (2004) and the more general discussion in D. T. Jenkins (1988). The reports of Prussian and German consuls in the treaty ports are also rich sources of documentation of the woolen textile market in Japan.
[29] See de Bavier (1974), Robert P. Porter (1898) and Takamusa Ichikawa (1996).
[30] Military goods, imports with insufficient detail on quantity and western goods such as shoes or opera glasses account for another ten percent. Two exports are gold and silver. Section 5.3 examines the implications of exports of these two products for the hypothesis test.

Table Two illustrates the process of constructing the **A** matrix in the case of striped cotton cloth known as *shima-momen*, which was a staple of the Tokugawa textile industry. This cloth consisted of white yarn in the weft and colored yarn (most often dyed blue with native indigo) in the warp. The disaggregated sources used to construct the **A** matrix provide sufficient information to tailor the input requirements to match the lightweight unfinished and finished cloths that dominated imports of cotton cloth during the early open trade period. The table also summarizes the most important feature of Japanese industrial organization during the period; depending upon the process, the location of production was either on the farm, in the hands of a master craftsman or in specialized firms. Table Two shows the four component sources of factor requirements for producing ten meters of *shima-momen*: growing cotton, preparing it and then spinning it; producing indigo dye and dyeing the warp yarn; and preparing and then weaving the yarn into finished cloth.[31] Cotton was grown throughout western Japan, particularly in the vicinity of Osaka. Domestically-grown indigo (*polygonum tincturum*) was the source of indigo dye. Both crops relied heavily upon the use of fertilizer, much of which was produced on the northern island of Hokkaido on a seasonal basis from herring Satoru Nakanishi (1998).[32] The factor requirements for fertilizer include the resources required to catch the herring using a gill net; the labor, charcoal and other equipment needed to convert the herring into processed fertilizer and the cost of transport by junk to Osaka. Production of raw cotton was relatively intensive in female labor, since picking the cotton was a task reserved for women. Ginning of cotton was carried out on the farm, most often by women using small, hand-held roller gins. The farm family would typically hire a male "scutcher" to card the ginned cotton, which would then be spun by family labor (almost always women) into yarn Masayuki Tanimoto (1992).

Production of indigo dye required fermentation of the *polygonum tincturum* leaves for up to 80 days to extract the dyestuff. Fermentation could take place on the farm or at a separate small firm that purchased dried indigo leaves from farmers Masatoshi Amano (1992). The resulting dyestuff was much lower in pure indigo (*indigotin*) than indigo produced from tropical plants in India or elsewhere Shinjori Sato (1915). Hence, much more dye was required in the vat fermentation dyeing methods used in Japan. Carried out by a specialized dyer, the methods were also time-consuming; up to twenty or thirty immersions of the yarn or

[31] The cloth illustrated here weighed 100 momme per tan, or 0.184 lbs. per square yard and is typical for the cloth that was imported.
[32] Price and input data from the Nōji Chosa allowed conversion of the several types of Japanese fertilizer into a herring fertilizer equivalent.

cloth in the dye vat was required for the darkest colors Uchida (1988). Female members of the family would preparing the warp for weaving and then weave the cloth. This task was usually on the family's account, although there was some putting out by local merchants. As the last row of the table demonstrates, female labor dominated in the labor processes associated with spinning and weaving. Skilled and unskilled male labor played an important role in providing the raw materials (fertilizer, cotton and indigo).

4.3 Sources for the autarky factor price vector $\mathbf{w^a}$

The autarky price vector includes prices for three kinds of labor, capital and land. Japanese and western economic historians have drawn upon account books, village records and surveys of domains to document the rates of pay of skilled, unskilled and female labor. The vector uses wage data from the last years of autarky (roughly the mid-1850s). Osamu Saitō (1998b) summarizes his development of long-term wage series for all three kinds of workers based upon evidence from western Japan, which includes the economic heartland of the Kinki region around Osaka, and eastern Japan (including the Kantō region around Tokyo). The most abundant evidence on the pay of unskilled workers is from the Kinki region. Saitō finds that throughout the 1850s, the rate of pay for rural unskilled male day labor was about 0.027 ryō for a farm near Osaka.[33] The wage for females was 0.018 ryō. The wage rates from this farm are about the same as other observations for male and female day laborers in western Japan from the 1830s and 1840s in agriculture and in other pursuits such as salt manufacture and rapeseed oil processing.[34] Evidence from eastern Japan is less well-developed than from the west, since economic growth in Japan shifted to the Kantō region only with the opening up to trade. The data that are available suggest that the daily wage for unskilled workers was also about 0.027 to 0.03 ryō in industrial occupations.[35] The limited data on day wages for females in eastern Japan suggest that they are similar to those in western Japan, or about 60 to 67 percent of male day wages.[36] Overall, the data suggest a day

[33] The ryō was a gold-based currency of the Tokugawa era. The yen replaced the ryō at a ratio of one to one in 1871.

[34] Wage observations are available from the more isolated han of Chōshū in far western Japan from the early 1840s for male and female day laborers in salt manufacture were 84 and 68 percent of the Osaka rates. The wage rate from the Osaka region for an unskilled day laborer for a rapeseed oil refiner was 90 percent of the Osaka rate in the 1830s.

[35]KYuriko Suzuki (1990) suggests that unskilled lads (*wakamono*) hired on annual contracts at a soy brewery north of Tokyo earned a daily wage of about 0.027 if we assume a 300 day work year and a daily payment in rice of 1 sho. Also in the Kanto region, a worker tending a water wheel earned about 0.031 ryō at a western-style blast charcoal furnace in 1857 Kinsei Rekishishiryo Shusei **(**1992. A young weaver in the Kanto region would have received the same cash payment as the *wakamono* under the terms of a two-year contract for weaving silk *obi* (kimono belt) in 1854 (see Waseda Daigaku Keizaishi Gak**kai** 1960). .

[36] The wage rates for women are similar to rates for women in the Lake Suwa region of the Nagano prefecture in eastern Japan in 1850 and 1854, but comparable rates for men are not available.

wage for unskilled males on the order of 0.0285 ryō and a day wage for female workers of about 0.0185 ryō.[37]

Skilled workers included production workers who were urban craftsmen, such as carpenters, tatami mat manufacturers, or stone masons; rural craftsmen such as dyers or smiths; and workers in the highest supervisory positions. The ratio of urban to unskilled day wages in the countryside could be on the order of 4:1 or 5:1 during the 1850s Osamu Saitō (2005, p. 93), but this ratio overstates the actual skill premium in the countryside. Saito (2005, p. 93) suggests that the ratio in western Japan was about 2.6:1 ca. 1800. For the late autarky period, other evidence available from Chōshū in the west during the early 1840s suggests that skilled workers were earning about 0.052 ryō (or a ratio 2.5:1 skilled to unskilled), while during the 1850s in the east the range was 0.048 to 0.051 for skilled workers.[38] The day wage of 0.051 is used for skilled workers here implies a ratio of 1.76:1, which may reflect the higher productivity of farm labor in the highly-productive Kinki region.[39]

The user cost of capital is the relevant interest rate plus depreciation times the price of the capital employed. Two approaches were used to calculate the cost of capital per unit of output. For most of the agricultural-based industries (cane sugar, tobacco, cotton, rice, wheat, soybeans, indigo, mulberry leaf inputs into silk and tea) and a few others (copper production and refining) and many of the marine industries (seaweed and the processing of awabi, iriko and cuttle fish), the source of data provides a charge for depreciation of capital equipment. The sources provide these values in yen. Depreciation could range up to 8 to 10 percent for the export products such as silk and tea and higher for marine products (including fishing boats or nets). For most remaining products, estimates of capital (in yen or ryō) were available from census sources or the original documents or surveys that described the technologies.[40] Most of these sources also provide estimates of rates of depreciation.

The user cost of capital also includes interest charges. The results presented here assume that the rural producers of all of these commodities faced an annual interest rate of twelve percent. As Toby and Saitō note Osamu Saitō and Tokihiko Settsu (2006, Ronald P.

---

[37] The male/female ratio of 1.5 to 1 is consistent with the retrospective data for1860 on male and female day wages in rice growing from a Meiji-era survey of the early 1880s cited by Saito (1998, pp. 43 and 190).

[38] These day rates are based upon the most skilled workers in the Choshu records (craftsman and skilled worker at the salt works) and the master and two head workers (*tōji* and *kashira*) at the soy sauce brewery, which employed about 20 workers, and the "key worker" at the blast furnace in the Iwate prefecture. They represent the highest-skilled workers in rural industries. See Suzuki (1990), Yukihiko Tojo (1992) and Yamaguchi-ken Monjokan (1960).

[39] Setting the skilled wage at a value that maintains the 2.5:1 ratio does not affect the results.

[40] See the results of the 1874 census of production published in Meiji Bunken Shiryō Kankōkai (1959).

Toby (2004), actual interest rates paid by small-time producers varied according to a number of characteristics that the data at hand cannot identify. Saitō (2006, p. 10) cites the studies of Uemura and Nakamura for the 1850s that are consistent with Toby's finding of 12-15 percent in the 1840s for a village near Nagoya (in western Japan).[41] The resulting interest charges for capital used in this study were up to 15 or 16 percent for industries such as silk and tea, where the reported maintenance charges were relatively high. The user cost of capital per unit of output was calculated in yen converted to the buying power of ryō in the mid-1850s.

Detailed data on the valuation of agricultural land are available from two sources. Toshio Furushima and Keiji Nagahara (1954) provide a study of agricultural rents (in terms of koku of rice) in the most productive area of pre-1859 Japan, the Kinai region (near Osaka). Valued at the price of rice prevailing in Osaka at the time, these rents ranged from 1.20 to 1.55 ryō and exceed any other available estimates by a wide margin. Waseda Daigaku Keizaishi Gakkai (1960) provides data on the valuation of agricultural land for various legal purposes in the Ashikagi area of the present-day Tochigi prefecture. Hedonic regressions of these data found predicted land values of about 6 ryō for second-quality paddy land in 1854. The implied rents would be a maximum of 0.96 ryō.[42] Land *valuations* reported in Nagasaki and the tea-growing region of Shizuoka right at the beginning of the open trade period were in the range of 8 to 10 ryō, which implies rents in the range of 0.64 to 0.8 ryō at an 8 percent annual return.[43] This rent is well above the rents that Syrski (1872a) reported for the area around Nagasaki ca. 1860 and implies a valuation well in excess of what Dan Henderson (1975, pp. 64-65) reports for a paddy field in the Shiga Prefecture.[44] For the test of the Heckscher-Ohlin hypothesis, this study used the upper-bound of rents of 1.55 ryō.

5. Empirical results

5.1. Technology matrix

A brief review of the elements of the **A** matrix (presented in Table 1) illustrates the net resource requirements of virtually all of Japan's exports and three-quarters of its imports during the early open trade period. The relative importance of particular resources (such as

[41] All of these studies deal with provinces in western Japan. I am not aware of studies of rural interest rates that provide insight into rates in the rural Kantō.
[42] This estimated is based on a return of 6 percent for land commonly used at the time and the assumption that the valuation of land for legal purposes is about one-half the actual value of land.
[43] The productivity of land in the Izumi region that provided the rent data was 87 percent above the productivity in the area around Tokyo.
[44] See Henry Gribble (1883), Syrksi (1872a) and K. Scherzer (1872). The valuations are reported estimates for 1860, the first year of open trade.

land or female labor) could in the end depend upon substantial intensity in the production of an intermediate product. Each kilogram of silk, for example, required in turn almost 300 kilograms of mulberry leaves. In addition, individual tasks associated with the production of certain commodities were intensive in resource use. Many women required one week to reel one kilogram of silk. Silk and sugar production were also relatively capital intensive. Tea production required substantial investments in tea shrubs, which could take several years to mature. Skilled labor was used for sorting tea both on the farm and at tea-firing facilities located in the treaty ports where it was prepared for export.

5.2 Test results

The results of the test of the hypothesis resulting from the autarky price formulation of Heckscher-Ohlin theory (eq. 6) are found in Table 3 for each test year 1865 through 1876. The first section of Table 3 provides the calculation of $\mathbf{w^a A^{1870} X^i}$, which is the autarky valuation of the factor services embodied in exports for each sample year. The value of factor exports ranges between 2.1 and 4.4 million gold ryō. Most of the year-to-year fluctuations stem from the exports of silk products. Capital accounted for 30 to 40 percent of factor service exports. Unskilled male labor was next most important. Surprisingly, despite the importance of the sericulture industry, female labor has the lowest share in the total factor services embodied in Japan's exports.

The second section of Table Three gives $\mathbf{w^a A^{1870} M^i}$, which is the autarky value of the factor services of foreign imports calculated with Japan's technology matrix. During the years 1869 through 1871, when a poor harvest prompted large imports of rice, land was the most important factor import; from 1872 through 1875, female labor and capital were most important. The importance of cotton textiles and sugar in the import bundle helps account for the dominance of capital and female labor.

The lower section of Table Three provides the value of the net flow of factors used in calculating the test value $\mathbf{w^a F^i}$, the autarky valuation of Japan's net imports of factors. Note that Japan was actually a net exporter (a negative value of a row) of land during the first of the eleven test years and generally a net importer of all other factors. This is the only support for the insight of Yasukichi Yasuba (1996), who contends that the importance of primary

products such as silk and tea in Japan's exports reflects a comparative advantage in land-intensive exports. The results are also at variance with Jeffrey G. Williamson (2000), who argues that Japan's exports were labor-intensive and imports were land- and capital-intensive. Instead, labor (particularly female labor) constituted about two-thirds of Japan's net imports of factors.

The final row of Table Three contains the test value of $\mathbf{w^a F^i}$ for each year of the early free trade period and reveals a positive sign in each of the eleven sample years. Under the maintained hypothesis that the annual data are drawn independently from the same distribution, we can test the Heckscher-Ohlin hypothesis H_0 against the randomness hypothesis H_1. For eleven positive signs in a sample of eleven, the p-value, defined as the smallest level of significance for which we can reject H_1 in favor of H_0 is about 0.05 percent. These findings provide strong evidence for the Heckscher-Ohlin prediction.

5.3 Robustness exercises

Although the results appear to provide unambiguous support for the autarky-price version of the Heckscher-Ohlin hypothesis, an examination of one important complication is in order. For eight of the eleven test years, Japan's trade was not balanced. The trade imbalance violates the fifth constraint on the empirical domain of the test, which asserts balanced trade. Two approaches allow an assessment of whether the test results are robust to the absence of balanced trade. The first focuses on the resource outflows that were required to balance trade. The second adjusts consumption so that it meets the constraint of balanced trade. Neither adjustment materially alters the conclusion of the tests.

Substantial trade deficits emerged during 1869-1870 in the wake of poor harvests and again in 1874. Although two modest loans on the London market by the Meiji government may have offset some of the deficit on current account, Hugh Patrick (1966, p. 181) notes that the outflow of silver and gold in bullion and in coin covered most of it.[45] Fortunately, data are available for the test years 1872 through 1875 that allow for the inclusion of these resource flows in the calculation of an augmented factor value of trade measure, $\mathbf{w^a F^i}$ (aug).[46]

Data are available on resource usage in both a private gold and silver mine that used traditional technologies (the Seigano mine) and the government-owned Ikuno gold and silver mine. The estimated resource usage from these data should span the range of input requirements for gold and silver produced in Japan (see Benjamin Smith Lyman 1879). With only 80 workers, the Seigano mine was most likely still operational only because the charcoal

[45] See Toshiki Tomita (2005) for a discussion of the bond issues of 1870 and 1873. The first issue was used for financing railroad construction. The second issue was for the purchase gold and silver bullion in conjunction with the launching of the yen.
[46] It should be noted that the annual outflow of gold and silver from Japan was several times the actual annual production of the mining industry.

used for smelting could be produced from wood on the property of the mine and the older and loyal labor forced was paid relatively low wages. Investments in Western technologies at the large scale government-owned Ikuno mine included steam engines for pumping water, transporting ore (to allow access to deeper mining) and stamping ore. Reverberatory furnaces were also installed. These investments more than doubled labor productivity relative to the Seigano mine. The Ikuno mine was the largest producer of gold and the second-largest producer of silver in Japan during the period C. Netto (1879, Table II).

Data on the net outflows of gold and silver (in yen) are available for the years 1872 to 1875 (see Iazan (or Tanzan) Ishibashi and Shigeru Kinoshita 1935). If it is assumed that the exports of coin were of gold and silver yen pieces, the highest outflow (in 1875) was about 550 thousand ounces of gold and 3.2 million ounces of silver.[47] As Panel A of Table Four demonstrates, the valuation of the resource cost of this outflow depends only in a minor way on whether western or traditional technologies are assumed. The maximum resource value is a little over 2 million ryō of the mid-1850s. The calculation $\mathbf{w}^a\mathbf{F}^i$(augmented) in Panel B of Table Four assumes traditional technologies and results in positive values of the net resource flow, although the skill-intensity of the production of precious metals does lead to a net export of skilled labor.

An alternative test for robustness reduces the inputs embodied in imports to a level consistent with balanced trade. This approach requires us to assume that Japanese preferences are homothetic so that one can scale down imports to evaluate the factor content of trade at an adjusted import vector $\mathbf{M}^{adj}$, which corresponds to the balanced trade condition, $\mathbf{p}^t\mathbf{M}^{adj}=\mathbf{p}^t\mathbf{X}^t$. The adjusted import vector can then be written as $\mathbf{M}^{adj}= (\mathbf{p}^t\mathbf{X}/\mathbf{p}^t\mathbf{M})\mathbf{M}$ and the corresponding adjusted autarky valuation of resource flows is $\mathbf{w}^a\mathbf{F}$(adj), where $\mathbf{F}(adj)=\mathbf{A}(\mathbf{M}^{adj}-\mathbf{X})$. The first row Panel C of Table Four presents the adjustment factor $\mathbf{p}^t\mathbf{X}/\mathbf{p}^t\mathbf{M}$, which ranges from 0.42 (a consequence of widespread failures of the rice harvest in 1869) to 0.81. The lower section of Panel C presents the net imports of factors under the assertion of balanced trade. The imposition of balanced trade leads to net exports of capital, but it does not fundamentally change the sign of the inner product of autarky factor prices and the factor content of trade.

6. Concluding remarks

[47] Japanese production of gold was 13,000 ounces in 1874. The production of silver was 344,000 ounces (Plunkett 1875, p. 459). Data from 1874 confirm that most exports of gold and silver coin were of Japanese gold and silver yen pieces. The remainder was Mexican silver dollars and silver and gold gilt coins from the late Tokugawa period.

In his *Foundations of Economic Analysis*, Paul Samuelson put economic theory on a solid scientific grounding by developing comparative statics methods aimed at deriving operationally *meaningful theorems*. Paul Anthony Samuelson (1947, p.4) defines a meaningful theorem as “a hypothesis about empirical data which could conceivably be refuted, if only under ideal conditions… [and] it is meaningful because under ideal circumstances an experiment could be devised whereby one could hope to refute the hypothesis.” A long line of research that applies comparative statics methodology to international trade has shown that Ohlin’s (1933) hypothesis on the relationship between autarky factor prices and international trade can be formulated as an operationally meaningful theorem. This was initially accomplished for the two-country, two-factor, two-commodity world familiar from undergraduate textbooks in international trade. Subsequent research by Deardorff (1982) has formulated a refutable Heckscher-Ohlin proposition for a single economy that holds under general conditions regarding dimensionality and assumptions about the economy’s trading partners.

This paper argues that Japan’s economy before and after its 19th century move from autarky to free trade provides the ”ideal conditions” where the Heckscher-Ohlin theorem ”could conceivably be refuted.” The case of Japan conforms to all the critical assumptions of the autarky price formulation of the Heckscher-Ohlin theorem. The historical circumstances of its opening up to international trade ensure that it meets the identification conditions necessary to test the theorem. In addition, almost all commodities it imported in its early trading years could be produced using the pre-industrial technologies available to it. The historical sources allow us to construct a technology matrix based on disaggregated data of input requirements. Combining the data in this technology matrix with the corresponding commodity trade flows and autarky factor prices permits us to test the Heckscher-Ohlin hypothesis. We were not able to reject the hypothesis in any of the sample years. This is certainly good news for the neoclassical trade model and to those who have contributed to its formulation since Ohlin.

References

Allen, Robert; Jean-Pascal Bassino; Debin Ma; Christine Moll-Murata and Jan Juiten van Zanden. 2007. "Wages, Prices, and Living Standards in China, Japan, and Europe, 1738-1925." University of Oxford, Department of Economics, Economics Series Working Papers 316.

Amano, Masatoshi. 1992. "Development of the Awa Indigo Industry and Economic Modernization of Tokushima Prefecture." *Kobe University Economic Review*, 38, 71-82.

Bavier, Ernest de. 1874. *La Sériciculture : Le Commerce Des Soies Et Des Graines Et L'industrie De La Soie Au Japon*. Lyon, Milan: H. Georg ; Du Molard frères.

Bernhofen, Daniel M. and John C. Brown. 2004. "A Direct Test of the Theory of Comparative Advantage: The Case of Japan." *Journal of Political Economy*, 112(1), 48-67.

____. 2005. "An Empirical Assessment of the Comparative Advantage Gains from Trade: Evidence from Japan." *American Economic Review*, 95(1), 208-25.

Bernhofen, Daniel M.; John C. Brown and Masayuki Tanimoto. 2009. "Hard-Earned Rewards: A Technology Matrix for the Tradeable Sector of the Late Tokugawa Economy." Unpublished.

Bowen, Harry P.; Edward E. Leamer and Leo Sveikauskas. 1987. "Multicountry, Multifactor Tests of the Factor Abundance Theory." *American Economic Review*, 77(5), 791-809.

Chiso Kaisei Houkokusho. 1882. Tokyo.

Chō, Yukio, Ken'ichirō Shōda and Hiroshi Ōhashi. 1979. *Meiji Chūki Sangyō Undō Shiryō*. Tōkyō: Nihon Keizai Hyōronsha.

Coignet, Francisque and Junkichi Ishikawa. 1957. *Nihon Kōbutsu Shigen Ni Kansuru Oboegaki : Ikuno Ginzan Kensetsuki*. [Tōkyō]: Sangyō Keizai Shinbunsha.

Davis, Donald R. and David E. Weinstein. 2001. "An Account of Global Factor Trade." *American Economic Review*, 91(5), 1423-53.

Deardorff, Alan V. 1986. "Firless Firwoes: How Preferences Can Interfere with the Theorems of International Trade." *Journal of International Economics*, 20(1/2), 131-42.

____. 1982. "The General Validity of the Heckscher-Ohlin Theorem." *American Economic Review*, 72(4), 683-94.

Federico, Giovanni. 1997. *An Economic History of the Silk Industry, 1830-1930*. New York: Cambridge University Press.

Francks, Penelope. 1984. *Technology and Agricultural Development in Pre-War Japan*. New Haven: Yale University Press.

Furushima, Toshio and Keiji Nagahara. 1954. *Shōhin Seisan to Kisei Jinushisei : Kinsei Kinai Nōgyō Ni Okeru*. Tōkyō: Tōkyō Daigaku Shuppankai.

Great Britain. "Commercial Reports by Her Majesty's Consuls in Japan," *Parliament. Papers by command.* London: Printed by Harrison and Sons. (various years)

Gribble, Henry. 1883. "The Preparation of Japanese Tea." *Transactions of the Asiatic Society of Japan*, 12(1), 1-87.

Harrigan, James. 1997. "Technology, Factor Supplies, and International Specialization: Estimating the Neoclassical Model." *American Economic Review*, 87(4), 475-94.

Hayami, Akira; Osamu Saito and Ronald P. Toby. 2004. *The Economic History of Japan: 1600-1990 Volume 1 Emergence of Economic Society in Japan, 1600-1859*. Oxford and New York: Oxford University Press.

Hayek, Friedrich A. von and Institute for Humane Studies. 1945. *The Use of Knowledge in Society*. Menlo Park, CA: Institute for Humane Studies.

Henderson, Dan Fenno comp. 1975. *Village "Contracts" In Tokugawa Japan : Fifty Specimens with English Translations and Comments*. Seattle: University of Washington Press.
Ichikawa, Takamasa. 1996. *Nihon Nōson Kōgyōshi Kenkyū : Kiryū Ashikaga Orimonogyō No Bunseki*. Tōkyō: Bunshindō.
Ishibashi, Iazan (or Tanzan) and Shigeru. Kinoshita. 1935. *The Foreign Trade of Japan: A Statistical Review*. Tokyo: Oriental Economist.
Jenkins, D T. 1988. "The Response of the European Textile Manufacturers to the Opening of the Japanese Market." *Textile History*, 19(2), 255-78.
Land, A. H. and Harold W. Kuhn. 1959. "Factor Endowments and Factor Prices." *Economica*, 26(102), 137-44.
Leamer, Edward E. 1980. "The Leontief Paradox, Reconsidered." *Journal of Political Economy*, 88(3), 495-503.
Leontief, Wassily. 1953. "Domestic Production and Foreign Trade; the American Capital Position Re-Examined." *Proceedings of the American Philosophical Society*, 97(4), 332-49.
Lyman, Benjamin Smith. 1879. *Geological Survey of Japan: Reports of Progress for 1878 and 1879*. Tookei: Public Works Department.
Maddison, Angus. 2006. *The World Economy Volume 1: A Millennial Perspective Volume 2: Historical Statistics*. Development Centre Studies. Paris and Washington, D.C.: Organisation for Economic Co-operation and Development.
Maskus, Keith E. 1985. "A Test of the Heckscher-Ohlin-Vanek Theorem: The Leontief Commonplace." *Journal of International Economics*, 19(3-4), 201-12.
Meiji Bunken Shiryō Kankōkai. 1959. *Meiji 7-Nen Fuken Bussan Hyō*. Tōkyō: Meiji Bunken Shiryō Kankōkai.
Nakanishi, Satoru. 1998. *Kinsei Kindai Nihon No Shijō Kōzō : "Matsumae Nishin" Hiryō Torihiki No Kenkyū*. Tōkyō: Tōkyō Daigaku Shuppankai.
Neary, J. Peter and Albert G. Schweinberger. 1986. "Factor Content Functions and the Theory of International Trade." *Review of Economic Studies*, 53(3), 421-32.
Netto, C. 1879. *On Mining and Mines in Japan*. Tokyo, Japan: The University.
Ohlin, Bertil Gotthard. 1933. *Interregional and International Trade*. Cambridge,: Harvard University Press.
Patrick, Hugh. 1966. "Financial Development and Economic Growth in Underdeveloped Countries." *Economic Development and Cultural Change*, 14(2), 174-89.
Pauer, Erich. 1987. "Traditional Technology and Its Impact on Japan's Industry During the Early Period of the Industrial Revolution." *Economic Studies Quarterly*, 38(4), 354-71.
Plunkett, F. R. 1875. "Report by Mr. Plunkett on the Mines of Japan," *House of Commons Sessional Papers.* 465-519.
Porter, Robert P. and National Association of Manufacturers (U.S.). 1898. *Commerce and Industries of Japan : A Report of Investigations Conducted by Robert P. Porter*. Philadelphia: Bureau of Publicity National Association of Manufacturers.
Preussisches Handelsarchiv. 1873. "Handelsverkehr von Hiogo und Osaka Im 1. Halbjahr 1873," November 21, 550-54.
Preussisches Handelsarchiv.1873. "Jahresbericht Des Konsulats Zu Yedo Für 1872," December 21, 681-85.
Saitō, Osamu. 1998a. *Chingin to Rōdō to Seikatsu Suijun : Nihon Keizaishi Ni Okeru 18--20-Seiki*. Tōkyō: Iwanami Shoten.
____. 1998b. "Edo Shichyu Ni Okeru Service Gyo Chingin: 1775-1871 (Wage of Service Industry in Edo)." *Nihon Rekishi*, 430, 81-85.
____. 2009. "Land, Labour and Market Forces in Tokugawa Japan." *Continuity and Change*, 24 (1), 169-96.

____. 2005. "Wages, Inequality, and Pre-Industrial Growth in Japan, 1727-1894." In *Living standards in the past: new perspectives on well-being in Asia and Europe*, eds. R. C. Allen, T. Bengtsson and M. Dribe, 77-97. Oxford and New York: Oxford University Press.
Saitō, Osamu and Tokihiko Settsu. 2006. "Money, Credit and Smithian Growth in Tokugawa Japan," Institute of Economic Research, Hitotsubashi University Hi-Stat Discussion Paper Series d05-139.
Samuelson, Paul Anthony. 1947. *Foundations of Economic Analysis*. Cambridge,: Harvard University Press.
Sato, Shinjori. 1915. "Indigo Content of Some Japanese Indigos." *The Journal of Industrial and Engineering Chemistry*, 7(8), 675-76.
Scherzer, Karl. 1872. *Fachmännische Berichte Über Die Österreichisch-Ungarische Expedition Nach Siam, China Und Japan (1868-1871.)*. Stuttgart,: J. Maier.
Shusei, Kinsei Rekishishiryo. 1992. *Kinsei Rekishishiryo Shusei 2 Period*. Tokyo: Kasumigaseki Shuppansha.
Shuzeikyoku, Japan. Ōkurashō. 1893. *Dai Nihon Gaikoku Bōeki Nijūgonen Taishōhyō : Meiji Gannen Yori Dō Nijūgonen Ni Itaru*. Tōkyō: Koide Yoshifusa.
Stewart, Douglas B. 1976. "Can Trade Widen the Difference between Factor Rewards? Another Look at the More-Goods-Than-Factors Case." *The American Economic Review*, 66(4), 671-74.
Sugiyama, Shin'ya. 1988. *Japan's Industrialization in the World Economy, 1859-1899 : Export Trade and Overseas Competition*. London ; Atlantic Highlands, NJ: Athlone Press.
Suzuki, Yuriko. 1990. "Shōyu Seizōgyō Ni Okeru Kōyō Rōdō'," In *Shōyu Jōzōgyōshi No Kenkyū,* ed. R. Hayashi, 131-196, Tōkyō: Yoshikawa Kōbunkan.
Syrski, S. 1872a. "Landwirtschaft in Japan," In *Fachmännische Berichte Über Die Österreichisch-Ungarische Expedition Nach Siam, China Und Japan (1868-1871),* ed. K. Scherzer, 175-227. Stuttgart: Julius Maier.
____. 1872b. "Über Seidenkultur in Japan," In *Fachmännische Berichte Über Die Österreichisch-Ungarische Expedition Nach Siam, China Und Japan (1868-1871),* ed. K. Scherzer, 228-86. Stuttgart: Julius Maier.
Tamura, Hitoshi. 2004. *Fasshon No Shakai Keizaishi : Zairai Orimonogyō No Gijutsu Kakushin to Ryūkō Shijō*. Tōkyō: Nihon Keizai Hyōronsha.
Tanimoto, Masayuki. 1992. "The Evolution of Indigenous Cotton Textile Manufacture before and after the Opening of the Ports." *Japanese Yearbook of Business History*, 9, 30-56.
Toby, Ronald P. 2004. "Country Bankers in Proto-Industrial Japan: The Transformation of Credit," *In: The Economic History of Japan: 1600-1990. Volume 1. Emergence of Economic Society in Japan, 1600-1859,* ed. A. Hayami, O. Saito and R. P. Toby, 301-36. Oxford and New York: Oxford University Press.
Tojo, Yukihiko. 1992. "Shoki Seitetsugyo to Shokkou Shakai," In *Bokko Kigyo*, ed. N. Takamura, 207-08. Tokyo: Kigyo Bokko Mineruva Shobo.
Tomita, Toshiki. 2005. "Government Bonds in the Meiji Restoration Period," Tokyo: Nomura Research Institute,
Trefler, Daniel. 1995. "The Case of the Missing Trade and Other Mysteries." *American Economic Review*, 85(5), 1029-46.
____. 1993. "International Factor Price Differences: Leontief Was Right!" *Journal of Political Economy*, 101(6), 961-87.
Uchida, Hoshimi. 1988. "Narrow Cotton Stripes and Their Substitutes." *Textile History*, 19(2), 159-70.
Vanek, Jaroslav. 1968. "The Factor Proportions Theory: The N-Factor Case." *Kyklos*, 21(4), 749-56.

Waseda Daigaku Keizaishi Gakkai. 1960. *Ashikaga Orimono Shi*. Ashikaga: Ashikaga Sen'i Dōgyōkai.
Williamson, Jeffrey G. 2000. "Globalization, Factor Prices and Living Standards in Asia before 1940,"In *Asia Pacific Dynamism, 1550-2000*, eds. A. J. H. Latham and H. Kawakatsu, 13-46. London, New York: Routledge.
Woodland, Alan D. 1980. "Direct and Indirect Trade Utility Functions." *Review of Economic Studies*, 47(5), 907-26.
Yamaguchi-ken Monjokan. 1960. *Bōchō Fūdo Chūshi'an*. [Yamaguchi]: Yamaguchi-ken Monjokan.
Yasuba, Yasukichi. 1996. "Did Japan Ever Suffer from a Shortage of Natural Resources before World War II?" *Journal of Economic History*, 56(3), 543-60.

Figure 1: Heckscher-Ohlin price formulation

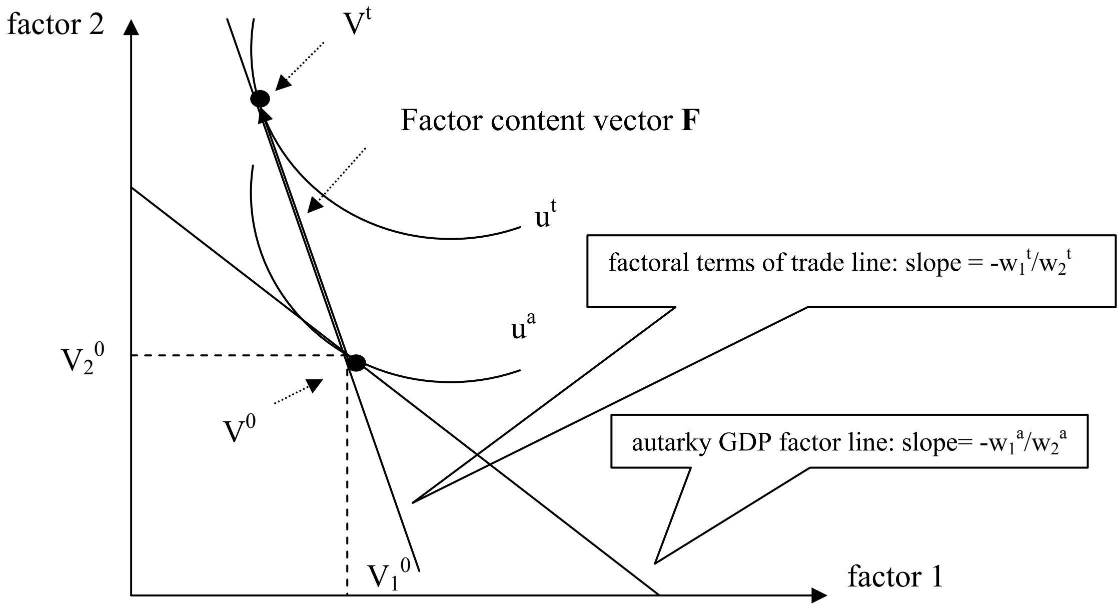

Table 1: The **A** matrix for Japan during the early trade period (1865-1876)

Export	Share	Male skilled labor (days)	Male unskilled labor (days)	Female labor (days)	Capital (ryō)	Land (tan)
Silkworm eggs	16.72	178	1532	341	199	17
Silk	33.77	3,250	29,527	15,930	4,717	396
Tea	27.49	453	585	208	151	17
Bancha tea	0.57	0	183	107	9	0
Wheat	0.11	17	181	28	12	8
Tobacco	0.84	38	475	27	18	10
Camphor	0.70	0	397	261	18	1
Vegetable wax	1.16	0	375	0	30	0
Mushrooms	1.11	0	968	0	0	25
Seaweed	1.99	9	18	26	3	0
Cut Seaweed	0.51	19	25	59	4	0
Kanten (Seaweed gelatin)	0.62	30	1,465	89	12	0
Copper	2.94	546	538	58	299	0
Charcoal	0.01	73	132	0	1	0
Coal	1.62	4.0	1.7	0.02	0.02	0
Sulphur	0.09	21	0	0	9	0
Cuttlefish	1.37	25	33	0	1	0
Iriko (sea cucumber)	0.77	11	232	0	0	0
Awabi (abalone)	0.73	0	0	616	2	0

Import	Share of Imports	Skilled	Unskilled	Female	Capital	Land
Rice	9.93	10	132	14	3	4
Soy	1.32	4	107	25	1	9
Wheat	0.02	17	181	28	12	8
Indigo	0.04	2,087	11,439	2,739	658	158
Kerosene	0.70	51	524	0	27	0
Lead	0.45	1201	890	1097	32	0
Tin	0.06	4152	414	0	1	0
Pig iron	0.11	319	161	0	1	0
Iron manufactures	2.56	514	221	0	3	0
Steel	0.07	466	228	0	0	0
Brown Sugar	6.65	68	420	44	123	4
White Sugar	2.84	162	901	88	265	9
Raw Cotton	2.07	161	1,154	993	89	24
Cotton Yarn	14.47	298	1,333	6,468	105	28
Unfinished Cotton Cloth (per1,000 meters)	10.73	22	100	881	8	2
Finished Cotton Cloth (per 1,000	8.63	85	118	885	9	2

meters)						
Woolens (per 1,000 meters)	60.3	302	295	367	45	4

Notes: All resource requirements are per metric ton unless otherwise specified. The ryō was the gold-based currency of Japan through 1871. One tan is about one-tenth of a hectare.
Sources: For a detailed discussion of the sources, see Bernhofen, Brown and Tanimoto (2009).

Table 2: Input Requirements for Ten Meters of Finished Cotton Cloth

	Production site	Skilled labor (days)	Unskilled labor (days)	Female labor (days)	Capital (Yen)	Land (Tan)
Cotton yarn						
Fertilizer	Hokkaido: fishing and on shore	0.68	2.79	0.16	0.27	0
Seed Cotton	Farm (Osaka)	0	2.22	2.67	0.12	0.10
Preparation: Ginning and “Bowing”	Farm and Specialized “Scutcher”	0.46	0	1.89	0.01	0
Spinning	Farm	0	0	20.00	0.09	0.00
Yarn subtotal		1.14	5.01	24.72	0.48	0.10
Dyeing of yarn						
Fertilizer	Hokkaido: fishing and on shore	0.11	0.44	0.03	0.04	0
Indigo Leaves	Farm (Awa or near Osaka)	0.0056	0.41	0.19	0.01	0.01
Indigo Dye making	Farm or specialized firms	0.047	0.05	0	NA	0
Dyeing	Specialized firm	3.02	0	0	NA	0
Dyeing subtotal		3.18	0.90	0.22	0.05	0.01
Preparing and Weaving	Farm	0	0	20.00	0.02	0
Total		4.33	5.91	44.94	0.56	0.11

Notes: Columns may not add up because of rounding.

Source. For the sources for individual row entries, please see the text.

Table 3: The Autarky Value of Japan's Factor Trade in the Early Years of Open Trade (in thousands of gold ryō ($\mathbf{w^aF}$))

	Factor Price ca. 1854-1857	1865	1867	1868	1869	1870	1871	1872	1873	1874	1875	1876
Exports												
Labor male skilled	0.051	279	300	247	206	278	446	455	358	498	474	553
Labor male unskilled	0.029	888	541	766	545	580	981	830	804	908	878	1458
Labor female	0.019	279	165	242	170	174	301	235	238	260	256	429
Capital	0.240	1228	757	1062	773	867	1567	1421	1199	1414	1326	1953
Land	1.500	699	435	599	429	487	769	655	641	819	768	1265
Total $\mathbf{w^aA^{1870}X^i}$		3373	2198	2916	2124	2385	4063	3597	2599	3080	2934	4392
Imports												
Labor male skilled	0.051	930	751	566	630	989	992	1015	1277	1354	1819	1650
Labor male unskilled	0.029	570	1053	757	1226	2532	2296	1324	1480	1701	1985	1890
Labor female	0.019	1117	1528	1422	1318	2162	2702	2836	3033	3573	3394	3641
Capital	0.240	600	1227	933	1135	2096	2170	1704	1912	2125	2650	2423
Land	1.500	425	1030	654	1595	3420	2751	1120	1232	1414	1541	1499
Total $\mathbf{w^aA^{1870}M^i}$		3643	5590	4331	5904	11199	10912	8000	8934	10167	11390	11103
Imports-Exports												
Labor male skilled	0.051	652	451	318	424	711	546	559	919	856	1345	1096
Labor male unskilled	0.029	-318	513	-9	681	1952	1315	494	676	793	1108	432
Labor female	0.019	837	1363	1180	1148	1987	2401	2601	2796	3313	3138	3213
Capital	0.240	-627	469	-129	361	1229	604	283	712	711	1325	471
Land	1.500	-275	595	55	1166	2934	1983	465	592	594	773	233
Total Net $\mathbf{w^aF^i}$		269	3392	1415	3780	8814	6848	4403	6335	7086	8456	6711

Notes: All values are in gold ryō. The value in each row is the net valuation of the trade in that factor at factor prices prevailing under autarky (1854-1857). For a discussion of the valuation of factors of production and the calculation, please see the text.

Table 4: Assessing the Impact of Imbalanced Trade

Panel A: Autarky Valuation of Net Factor Imports of Japanese Trade in Precious Metals (in thousands of gold ryō)

Factor	1872	1873	1874	1875
Gold and silver (traditional technology)	80	-392	-2073	-2158
Gold and Silver (Western technology)	84	-401	-2117	-2203

Panel B: The Autarky Value of Factor Trade Including Net Exports of Precious Metals (in thousands of gold ryō ($\mathbf{w^a F^i}$(augmented))

Factor	1872	1873	1874	1875
Labor male skilled	642	555	-1051	-883
Labor male unskilled	497	665	737	374
Labor female	2595	2783	3231	3121
Capital	283	712	711	470
Land	466	587	568	206
Total Net ($\mathbf{w^a F^i}$ augmented))	4483	5302	4194	3288

Panel C: The Autarky Value of Factor Trade after Adjusting for Trade Imbalances

	1865	1867	1868	1869	1870	1871	1872	1873	1874	1875	1876
$\mathbf{p^t X / p^t M}$	1.00	0.58	1.00	0.60	0.42	0.81	0.65	0.77	0.79	0.58	1.00
Factor											
Labor male skilled	652	133	318	169	133	361	205	625	570	587	1096
Labor male unskilled	-318	67	-9	186	472	888	31	335	434	281	432
Labor female	837	715	1180	615	724	1898	1610	2097	2558	1724	3213
Capital	-627	-51	-129	-97	4	200	-313	272	262	221	471
Land	-275	159	55	522	935	1471	74	308	296	131	233
Total Net ($\mathbf{w^a F^i}$(adjusted))	269	1023	1415	1395	2268	4818	1607	4278	4940	3712	6711

Notes: For a discussion of the calculations, please see the text. The calculations in Panel B assume the use of traditional technologies for mining and refining silver and gold. The ratio $\mathbf{p}^t\mathbf{X}/\mathbf{p}^t\mathbf{M}$ is set at 1 for the years (1865, 1868 and 1876) when Japan ran a trade surplus.
Source: Lyman (1879, pp. 43-45 and 160-162) provides the input requirements for gold and silver mining. Ishibashi (1935) provides the data on net exports of gold and silver coin and bullion. Sugiyama (1988, Table 3-4) provides consistent data on $\mathbf{p}^t\mathbf{X}$ and $\mathbf{p}^t\mathbf{M}$ in silver yen.