

Testing the general validity of the Heckscher-Ohlin theorem: the natural experiment of Japan¹

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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.

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1. Introduction

The Heckscher-Ohlin theorem is one of the central general equilibrium propositions of economics. It predicts that the direction of trade is explained by differences in countries'

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relative factor scarcity. In Bertil Ohlin's original formulation (Bertil 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 (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 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 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 factor. In an important follow-up paper to Deardorff, Peter Neary and Albert Schweinberger (1986) have shown that the existence of gains from trade is sufficient for Deardorff's Heckscher-Ohlin prediction to hold in a single economy setting. 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 Wassily Leontief's (1953) first attempt to confront the Heckscher-Ohlin theory with data, the empirical Heckscher-Ohlin literature has focused exclusively on the quantity 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 initial rejections of HOV by Keith E. Maskus (1985) and Harry P. Bowen et al. (1987), Daniel Trefler (1993 and 1995) 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 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 (1996) was able to estimate the joint effects of factor

supply and technological differences on industry output. He found the latter to be an important determinant of cross-industry variations 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 the 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 the domestic technology matrix, Neary and Schweinberger (1986) have shown that the existence of gains from trade is the only critical condition for deriving this Heckscher-Ohlin prediction. 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.³ For example, assume country A is more land abundant than country B. If its consumers also have stronger preferences for land-intensive goods than consumers in B, it 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 formulation of Heckscher-Ohlin rules out such a scenario in order to identify trading patterns solely on differences in factor endowments.

By testing Heckscher-Ohlin in a formulation where factor scarcity is measured as originally envisioned by Ohlin, this paper is breaking 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 Bernhofen and John 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. Employing commodity prices from the last years of autarky and trade flows during the early free trade period, Bernhofen and Brown (2004, 2005) showed that Japan's commodity trading pattern behaved in accordance with the law of comparative advantage and also established that Japan experienced positive gains from trade.

Since positive gains from trade are the main sufficient condition for the autarky price formulation of Heckscher-Ohlin, the stakes are high in testing the theorem. A possible rejection could not be explained by unmet assumptions. In addition, the Heckscher-Ohlin

³ Friedrich Hayek (1945) first articulated the fundamental insight that prices embody all relevant information about relative scarcities in an economy.

Theorem yields a sign prediction relating data on autarky factor prices to measures of the factor content of trade; the sign of this cannot be foreseen by the outcome of a comparative advantage test involving only data on autarky commodity prices and trade flows.

For several reasons, the natural experiment of Japan is also well-suited for a test of the autarky price formulation of Heckscher-Ohlin. As a small open economy during both autarky and the early years of free trade, Japan fits the empirical domain of the test. 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.⁴ 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.

The 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 using 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 imports in each year of the early trading period 1868-1875 with the corresponding autarky factor price vector during the late autarky period of the early 1850s. Since the inner product is positive in each single trading

⁴ We are grateful to Peter Neary for pointing this out to us. 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, which imports both large amounts of oil and capital goods from developed countries.

year, our results provide strong empirical support for the general Heckscher-Ohlin prediction in the Deardorff-Neary-Schweinberger formulation. Our test results are robust to the incorporation of trade in near substitute goods and to adjustments for trade imbalances.

In section 2 we employ a simple graphical framework to illustrate the inter-relationship between the gains from trade in factor content space and the price formulation of the Heckscher-Ohlin Theorem. Building on Neary and Schweinberger (1986), section 3 uses the concepts of factor trade utility and factor trade expenditure functions to derive the general Heckscher-Ohlin theorem. 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 small open economy, called home, which trades with the rest of the world (ROW). We assume initially that the economy produces n goods using only two factors of production with the endowment vector given by $\mathbf{V}=(V_1, V_2)$. The economy's autarky equilibrium is characterized by autarky factor prices given by $\mathbf{w}^a=(w_1^a, w_2^a)$. Endowments and factor prices determine home's gross domestic product (GDP) under autarky:

$GDP^a=w_1^a V_1+w_2^a V_2$. Geometrically, \mathbf{V} 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} and has a slope of $(-w_1^a/w_2^a)$. The horizontal intercept measures autarky GDP in units of factor 1 and the vertical intercept measures it in units of factor 2. Autarky factor prices in the rest of the world are given by $\mathbf{w}^{ROW}=(w_1^{ROW}, w_2^{ROW})$. Applying Ohlin's price definition of relative factor scarcity, home is relatively abundant in factor 1 if $w_1^a/w_2^a < w_1^{ROW}/w_2^{ROW}$.

Under free trade, the economy is able to engage in trade at the international goods prices $\mathbf{p}=(p_1, \dots, p_n)$.⁵ Denoting a net import vector with $\mathbf{T}=(t_1, \dots, t_n)$, any equilibrium trading vector needs to fulfil the balance of trade condition, i.e. $\mathbf{pT}=0$.⁶ Given the domestic technology matrix \mathbf{A} , the corresponding net factor import vector is given by $\mathbf{M}=\mathbf{AT}$, where $\mathbf{M}=(M_1, M_2)$.⁷ The balance of trade condition in commodity space defines a balance of trade condition in factor services, i.e. $w_1^f M_1 + w_2^f M_2 = 0$, where w_1^f and w_2^f denote the corresponding

⁵ For ease of exposition, and without loss of generality, we assume away any natural or government imposed trade costs.

⁶ The net import vector is defined such that $T_i > 0$ if good i is imported and $T_i < 0$ if it is exported.

⁷ For simplicity we assume a fixed coefficient technology which implies that \mathbf{A} is the same under autarky and free trade.

free trade factor prices. These factor prices can be thought of defining a *factoral terms of trade* w_1^f/w_2^f , which must lie between w_1^a/w_2^a and w_1^{ROW}/w_2^{ROW} . In the special case where the free trade equilibrium is characterized by factor price equalization, w_1^f/w_2^f will coincide with w_1^{ROW}/w_2^{ROW} .⁸

Figure 1 shows that the balance of trade condition implies that the economy's trade must then occur along its factoral terms of trade line, which is anchored at the economy's endowment point \mathbf{V} and has, in absolute value, a slope of w_1^f/w_2^f . Since home is assumed to be relatively abundant in factor 1, the figure is drawn such that $w_1^a/w_2^a < w_1^f/w_2^f$. In the two-factor case the factoral terms of trade line implies only two possible directions for trade: export factor 1 and import factor 2 (i.e. $M_1 < 0$ and $M_2 > 0$) or import factor 1 and export factor 2 (i.e. $M_1 > 0$ and $M_2 < 0$). But in which direction will the economy trade? As pointed out by Neary and Schweinberger (1986, p. 421) "the existence of gains from trade is sufficient for the Heckscher-Ohlin theorem to hold in...its factor content version". International trade in factor services enables the economy to attain an augmented endowment point \mathbf{V}^f , defined as $\mathbf{V}^f = \mathbf{V} + \mathbf{M}$. The economy will experience a gain from international trade, with the gain being measured by an increase in factor services evaluated at autarky factor prices, if the augmented endowment point \mathbf{V}^f lies outside the economy's autarky GDP factor line. But this implies that the economy must export factor 1, which is relatively abundant, and import factor 2. Intuitively, this is because the relative value of factor 1 is higher in international exchange than it is domestically. This leads us then to the following two-factor price formulation of the Heckscher-Ohlin theorem:

Two-factor formulation of Heckscher-Ohlin

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

3. Factor content functions and the general Heckscher-Ohlin Theorem

⁸ In moving from autarky to free trade, domestic factor prices are expected to converge to factor prices in the rest of the world. But only under the strict assumptions of identical technologies and zero trade costs will this lead to factor price equalization.

Consider now the more general case of a small open economy with n goods and m factors of production. The economy's vector of factor endowments is given by $\mathbf{V}=(V_1, \dots, V_m)$. On the production side, we assume a convex production possibilities set where the technology is characterized by the implicit constraint $F(\mathbf{y}, \mathbf{V}) \leq 0$, where $\mathbf{y}=(y_1, \dots, y_n)$ is a vector of net outputs. On the consumption side a single consumer is characterized by a real valued utility function $u(\mathbf{x})$ which is assumed to be continuous, weakly increasing and quasi-concave in the consumption vector $\mathbf{x}=(x_1, \dots, x_n)$. Following Alan D. Woodland (1980) a direct trade utility function is defined as the maximum utility attainable when domestic production is augmented by a net import vector $\mathbf{T}=(t_1, \dots, t_n)$. The direct trade utility function U^d can be written as:

$$U^d(\mathbf{T}, \mathbf{V}) = \max \{u(\mathbf{x}): F(\mathbf{x}-\mathbf{T}, \mathbf{V}) \leq 0\} \quad (1)$$

If the country engages in trade it faces an exogenous goods price vector $\mathbf{p}=(p_1, \dots, p_n)$. Its net import vector \mathbf{T} is then constrained to satisfy the balanced trade condition:

$$\mathbf{p}\mathbf{T}=0 \quad (2)$$

Markets (or the social planner) are then choosing a net import vector \mathbf{T} that maximizes the direct trade utility function (1) subject to the balanced trade condition (2). The equilibrium net import vector \mathbf{T} is then a function of \mathbf{p} and \mathbf{V} , i.e. $\mathbf{T}=\mathbf{T}(\mathbf{p}, \mathbf{V})$.

Alternatively, following the logic of Neary and Schweinberger (1986), we can look at the trading equilibrium from a factor endowment perspective. For this we consider the concept of a direct factor trade utility function. The direct factor trade utility function is defined as the maximum utility attainable when the domestic endowment vector \mathbf{V} is augmented by a net factor import vector $\mathbf{M}=(M_1, \dots, M_m)$. Domestic technology will then be applied to the augmented endowment vector $\mathbf{V}+\mathbf{M}$, which modifies the aggregate production possibilities constraint to $F(\mathbf{y}, \mathbf{V}+\mathbf{M}) \leq 0$. The direct factor trade utility function U^f is then defined as:

$$U^f(\mathbf{M}, \mathbf{V}) = \max \{u(\mathbf{x}): F(\mathbf{x}, \mathbf{V}+\mathbf{M}) \leq 0\} \quad (3)$$

We assume that the technology in each sector can be represented by a unit cost function which is increasing, concave and homogeneous of degree one in the economy's

factor prices $\mathbf{w}=(w_1, \dots, w_m)$. The vector of unit cost functions is denoted by $c(\mathbf{w})$ and the zero profit condition implies that $\mathbf{p}=c(\mathbf{w})$, which means that the equilibrium factor price vector \mathbf{w} is pinned down by the goods price vector \mathbf{p} . The balance of trade condition for trade in factor services can then be written as:

$$\mathbf{w}\mathbf{M}=0 \tag{4}$$

Similar to our discussion above, the market or social planner can now be thought of choosing a net factor import vector \mathbf{M} that maximizes the direct factor trade utility function (3) subject to the balanced trade condition (4). The equilibrium net factor import vector \mathbf{M} is then a function of \mathbf{w} and \mathbf{V} , i.e. $\mathbf{M}=\mathbf{M}(\mathbf{w}, \mathbf{V})$.

So far we have viewed trade in factor services as a way of augmenting the country's endowment vector to maximize consumer utility. Alternatively, we can fix the level of consumer utility u and solve for the net factor import vector \mathbf{M} that enables the economy to attain this utility level at a minimum expenditure. This logic leads to the concept of a factor trade expenditure function where the factor trade utility function (3) defines the constraint and the left-hand side of (4) becomes the objective. The factor trade expenditure function is then defined as the minimum expenditure on factor services necessary to obtain the utility level u . Formally, the factor trade expenditure function is given by:

$$e(\mathbf{w}, u, \mathbf{V})= \min \{ \mathbf{w}\mathbf{M}; U^f(\mathbf{M}, \mathbf{V}) \geq u \}. \tag{5}$$

Since the factor trade expenditure function embodies the equilibrium relationships between factor prices, the factor content of trade and utility, it is the central tool for deriving the autarky price formulation of the Heckscher-Ohlin Theorem. A key property of the factor trade expenditure function is that, similar to an expenditure function in consumer theory, it is increasing in utility, i.e. $e(\mathbf{w}, u^1) \geq e(\mathbf{w}, u^0)$ for $u^1 > u^0$.

Consider now a comparison of an economy under autarky and free trade. The autarky equilibrium is characterized by the autarky factor price vector \mathbf{w}^a and the autarky utility level u^a . In a free trade equilibrium the economy's factor price vector is given by \mathbf{w}^f and the free trade utility level is denoted by u^f .

General Heckscher-Ohlin Theorem:

Assume that the economy experiences gains from trade, i.e. $u^f > u^a$. The autarky price vector \mathbf{w}^a imposes a restriction on the factor content of net imports under free trade, such that $\mathbf{w}^a \mathbf{M}(\mathbf{w}^f, u^f, \mathbf{V}) \geq 0$.

Proof: Since $u^a < u^f$ and the factor trade expenditure function is increasing in utility, we obtain $\mathbf{w}^a \mathbf{M}(\mathbf{w}^a, u^a, \mathbf{V}) \leq \mathbf{w}^a \mathbf{M}(\mathbf{w}^a, u^f, \mathbf{V})$. Since $\mathbf{M}(\mathbf{w}^a, u^f, \mathbf{V})$ minimizes the expenditure of obtaining the free trade utility level u^f implies that $\mathbf{w}^a \mathbf{M}(\mathbf{w}^a, u^f, \mathbf{V}) \leq \mathbf{w}^a \mathbf{M}(\mathbf{w}^f, u^f, \mathbf{V})$. Under autarky, there is no trade and $\mathbf{M}(\mathbf{w}^a, u^a, \mathbf{V})$ is the zero vector, which implies that $\mathbf{w}^a \mathbf{M}(\mathbf{w}^a, u^a, \mathbf{V}) = 0$. But this implies that $\mathbf{w}^a \mathbf{M}(\mathbf{w}^f, u^f, \mathbf{V}) \geq 0$.

Several comments are in order. First, $\mathbf{w}^a \mathbf{M}(\mathbf{w}^f, u^f, \mathbf{V}) \geq 0$ 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 which particular factor is exported or imported. 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.

Second, in contrast to the Heckscher-Ohlin-Vanek specification that results in a sign prediction for each factor for each country in the world economy, the general Heckscher-Ohlin theorem yields only a single refutable general equilibrium proposition. The reason for this is that it combines data from two equilibria. The vector of autarky prices \mathbf{w}^a acts as the predictor that imposes a restriction on the corresponding vector of net imports \mathbf{M} under free trade.

Finally, the Heckscher-Ohlin 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 autarky (ca. 1850 to 1859) and the early free trade period (1860 to 1875):

- 1) Markets for goods were competitive under autarky and free 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 essentially under free trade. In particular, exports did not receive any 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 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 engaged directly in some production or occasionally put out production to area artisans in small-scale operations. Maritime products such as seaweed were produced by fishermen employing at the most a few workers. With the exception of a few coal and copper mines, existing 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 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 the land and labor markets remained economically significant until the Meiji era reforms of the 1870s and later. Saitō Osamu (2009) 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 a range of by-employment in activities in growth industries such as silk (raising

silkworms and weaving), cotton (growing cotton, spinning and weaving), tea and fishing. The pace of economic change hollowed out regulations from the 17th century that attempted to limit the movement of the population and the restrictions on entry imposed by urban guilds. As Saitō Osamu (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 Saitō Osamu, 1998).

Saitō Osamu and Settsu Tokihiko Settsu (2006) and Ronald 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), Osaka 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 “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 free trade, but with no element 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. This leads us to the following identification condition:

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

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 the early years of open trade (1868 to 1875) for which trade data of sufficient detail are available.

Despite the enthusiasm of official and cultural elites for western culture and institutions, 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.⁹ 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 in earnest after the mid-1870s.¹⁰ Most important, as Erich Pauer (1987) notes, Japan's labor force lacked the technological know-how and skills to readily adopt the steam- and iron-based technologies of the western industrial revolution. By the close of the test period (1875), the Meiji government and some western investors had made only limited progress in introducing western technologies in a few coal, copper and gold and silver mines that employed at most a few thousand workers.¹¹ Transportation technologies, such as steamships or railroads, also required skills, organizational capabilities and capital that only became

⁹ See "Handelsverkehr Von Hiogo und Oaska Im 1. Halbjahr 1873," *Preussisches Handelsarchiv*. Berlin, 1873a, 550-54.. The "Jahresbericht Des Konsulats Zu Yedo Für 1872," *Preussisches Handelsarchiv*. Berlin, 1873b, 681-85 reports that use of western woolen cloth for western dress was restricted to government uniforms of various kinds and some of the wealthiest classes.

¹⁰ 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.

¹¹ 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.

available during the second or third decade of the Meiji period.¹² 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.

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 market for silk was only about 15 to 20 percent in its principal export markets (Sugiyama Shin'ya, 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. It 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 the rates of its trading partners.

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:

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

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 ($i=1868, \dots, 1875$). Since there exist, to our knowledge, no other theory which suggests an alternative restriction on the economy's factor content of net imports, we postulate randomness as the alternative hypothesis:

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

¹² 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.

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 under autarky and the early free trade period allow us to construct the vector of net imports, the technology matrix and autarky factor prices. The vector of net imports \mathbf{T} , which was also used in Bernhofen and Brown (2004 and 2005), is readily available from published sources. Data available prior to the test period of 1868 to 1875 are either incomplete or subject to measurement error.¹³ 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, imported cotton cloths ranged in weight from heavy cloths such as taffachella (which were similar to domestic manufactures) that used over twice the amount of cotton per square yard of shirtings, the largest cotton cloth import. Additional detail is available on the degree of refinement of products such as copper, iron, sugar and so forth.

Construction of the \mathbf{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 vertically disintegrated and non-specialized organization of production. Most tradable goods were produced using household production in the countryside. Similar to pre-industrial Europe or frontier America, Japanese production processes would include women in a wide range of tasks. Unlike pre-industrial Europe, families involved in producing industrial goods were not specialized workers with limited access to land. Instead, similar to frontier America, virtually all production was by farmer-proprietors or tenant farmers who produced a wide range of products. Unlike on the American frontier, Japanese rural households produced both for home consumption and a dense network of markets. One farm could, over the agricultural year, grow rice and soybeans, produce cotton, spin yarn, weave cloth and perhaps harvest and then refine vegetable wax. Specialized craftsmen or small firms would sometimes take on

¹³ Japanese ports opened up to trade in July of 1859, but the open trading regime was not firmly established until western intervention in 1864. Data on trade from 1865 and 1867 are only available from the reports of the British consuls at the individual treaty reports. Unfortunately, the reports of the consuls do not record several key imports (particularly woolen and cotton cloth) in a consistent manner.

specialized tasks at various stages of the production process. Obviously, the manufacturing and economic censuses used to represent the technologies for contemporary economies could not do justice to an economy organized in this way. Fortunately, Japanese sources that describe technologies in use during the early trade period reflect the reality of an economy dominated by millions of small multi-product firms. They describe the resource usage of technologies by individual stages of production, rather than only by final output. Construction of the **A** matrix under these circumstances requires the compilation of such data for each stage of production and knowledge about the locus of production; at times the data are augmented by a closer examination of information on tasks within each stage. The outcome is a detailed **A** matrix that can accommodate the complex reality of both Japanese production conditions and its trade during the test period, which involved imports of 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.¹⁴ These sources suggest that five fundamental factors of production adequately capture technology 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, for example, but not necessarily the planting or pruning of tea shrubs. This approach of necessity abstracts from differentials in skill levels that may have existed among some female workers in areas such as silk production or weaving. Most agricultural labor could be defined as unskilled labor, particularly given the myriad tasks including by-employment 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 for fish fertilizer. The category of skilled workers includes production workers with specialized skills (such as smelters), the small number of managers required in traditional Japanese business organizations of the time, owner-operators of small firms such as fishermen and craftsmen such as dyers. Skilled workers were identified either by the description found in the sources or by the wage premium that they commanded.

¹⁴ The sources and details of constructing the **A** matrix are presented in full detail in **Bernhofen, Daniel M.; Brown, John C. and Tanimoto, Masayuki.** "Hard-Earned Rewards: A Technology Matrix for the Tradeable Sector of the Late Tokugawa Economy," Clark University, 2009.

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, although forest and mining land are distinguished from cropped land.

Daniel M. Bernhofen, et. al. (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 in Yukio Chō et al. (1979), which is the first detailed survey of Japanese agriculture 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 faster-maturing strains of rice, the use horses for plowing rice paddies and heavier use of fertilizers. 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.¹⁵ 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.

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

¹⁵ 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.

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.¹⁶ 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, which for the most part substituted for silks. Local histories and contemporary studies provide significant details about the technologies in use for ginning cotton, processing it prior to spinning, weaving and dyeing. The continued use of these technologies into the twentieth century expanded the amount of documentation available for them.

Table One provides the **A** matrix for Japanese exports and imports during the early period of open trade. Information on production technologies is available for 95 percent of exports and 60 percent of imports.¹⁷ Construction of the matrix included information on two important intermediate factors, 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.

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 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,

¹⁶ The main sources include **Coignet, Francisque and Ishikawa, Junkichi**. *Nihon Kōbutsu Shigen Ni Kansuru Oboegaki : Ikuno Ginzan Kensetsuki*. [Tōkyō]: Sangyō Keizai Shinbunsha, 1957, **Lyman, Benjamin Smith**. *Geological Survey of Japan: Reports of Progress for 1878 and 1879*. Tookei: Public Works Department, 1879, **Plunkett, F. R.** "Report by Mr. Plunkett on the Mines of Japan," *House of Commons Sessional Papers*. 1875, 465-519..

¹⁷ Woolens accounted for another 20 percent of imports by value and mostly substituted for domestic silks. Military goods, imports with insufficient detail on quantity and western goods such as shoes or opera glasses accounted for another ten percent. Two exports are gold and silver. Section 5.3 examines these three products.

preparing it and then spinning it; producing indigo dye and dyeing the warp yarn; and preparing and then weaving the yarn into finished cloth.¹⁸ Cotton was grown throughout western Japan, particularly in the vicinity of Osaka. Domestically-grown indigo (*polygonum tinctorum*) 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 (Nakanishi Satoru, 1998).¹⁹ 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 “bower” to card the ginned cotton, which would then be spun by family labor (almost always women) into yarn (Tanimoto Masayuki, 1992).

Production of indigo dye required fermentation of the *polygonum tinctorum* 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 cloth in the dye vat was required for the darkest colors (Hoshimi 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 w^a

The autarky price vector includes prices for three kinds of labor, land and capital. 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.

¹⁸ 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.

¹⁹ Price and input data from the Nōji Chosa allowed conversion of the several types of Japanese fertilizer into a herring fertilizer equivalent.

The vector uses wage data from the last years of autarky (roughly the mid-1850s). Osamu Saitō (1998) 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.²⁰ The wage for females was 0.018 ryō. The wage rates from this farm are also consistent with other observations for male and female day laborers in western Japan in agricultural and in other pursuits, such as salt manufacture and rapeseed oil processing, from the preceding two decades.²¹ 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.²² 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.²³ Overall, the data suggest a day wage for unskilled males on the order of 0.0285 ryō and a day wage for female workers of about 0.0185 ryō.²⁴

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 6:1 during the 1850s (Saitō Osamu, 2005, p. 93), but this ratio overstates the actual skill premium in the countryside. Saitō Osamu

²⁰ 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.

²¹ Wage observations are available from the more isolated han of Chōshū in 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.

²² **Suzuki, Yuriko.** "Shōyu Seizōgyō Ni Okeru Kōyō Rōdō'," R. Hayashi, *Shōyu Jōzōgyōshi No Kenkyū*. Tōkyō: Yoshikawa Kōbunkan, 1990, 131-96. suggests that unskilled lads (*wakamono*) hired on annual contracts at a soy brewery north of Tokyo earned a daily wage of about .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 at a water wheel earned about .031 ryō at a western-style blast charcoal furnace **Shusei, Kinsei Rekishishiryō.** *Kinsei Rekishishiryō Shusei 2 Period*. Tokyo: Kasumigaseki Shuppansha, 1992. in 1857. A young weaver would have received the same cash payment as the *wakamono* under the terms of a two-year contract for weaving silk *obi* (kimono belt) **Waseda Daigaku Keizaishi Gakkai.** *Ashikaga Orimono Shi*. Ashikaga: Ashikaga Sen-i Dōgyōkai, 1960. in 1854.

²³ 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.

²⁴ The male/female ratio of 1.5 to 1 is consistent with the retrospective data for 1860 on male and female day wages in rice growing from a Meiji-era survey of the early 1880s cited by Saitō, **Osamu.** "Edo Shichyu Ni Okeru Service Gyo Chingin: 1775-1871 (Wage of Service Industry in Edo)." *Nihon Rekishi*, 1998, 430, pp. 81-85..

(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.²⁵ A day wage of 0.051 is used for skilled workers here.

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.²⁶ 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 and Ronald P. Toby, 2004), actual interest rates paid by small-time producers varied according to a number of characteristics that the data at hand can not identify. Saitō (2006, p. 10) cites the studies of Uemura and Nakamura that, despite showing diverging trends in the 1860s and later, are consistent with Toby's finding of 12-15 percent in the 1840s for a village near Nagoya (in western Japan).²⁷ 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 the mid-1850s.

²⁵ 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, Yuriko**. "Shōyu Seizōgyō Ni Okeru Kōyō Rōdō", R. Hayashi, *Shōyu Jōzōgyōshi No Kenkyū*. Tōkyō: Yoshikawa Kōbunkan, 1990, 131-96, **Tojo, Yukihiro**. "Shoki Seitetsugyo to Shokkou Shakai," N. Takamura, *Kigyo Bokko Kigyo Bokko Mineruva Shobo*, 1992, 207-08, **Yamaguchi-ken Monjokan**. *Bōchō Fūdo Chūshin*□an. [Yamaguchi]: Yamaguchi-ken Monjokan, 1960..

²⁶ See the results of the 1874 census of production published in **Meiji Bunken Shiryō Kankōkai**. *Meiji 7-Nen Fuken Bussan Hyō*. Tōkyō: Meiji Bunken Shiryō Kankōkai, 1959..

²⁷ 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.

The valuation of land used several sources. Japanese farmland was assessed as rice tax based upon whether the land was dry or paddy land and on the rated quality. Shōji Uemura (1986) and Waseda Daigaku Keizaishi Gakkai (1960) provide detailed data on land valuations on Shikoku (a southern island also known for growing sugar) and in the area around Ashikagi, which is 80 kilometers from Tokyo, for 74 groups of parcels over the period 1809 to 1858. Regression analysis of these data suggests that paddy land was valued at a slight premium over dryland; the main determinant of value was quality. In 1853, a tan of land would be valued at about 9 ryō. These data are roughly consistent with the report of Syrski on the valuation of land around Nagasaki ca. 1860 and a bit under the valuation Dan Henderson (1975, pp. 64-65) provides for a paddy field in the Shiga Prefecture.²⁸ The implicit rent charged on a property of a given value depended upon the use of the land. Syrski cites about 2 percent for rice fields and the data in the Nōji Chosa Chō, et al.(1979) imply up to 8 to 10 percent for mulberry and tea. The estimates here assumed 8 percent, so that the annual implicit rent was 0.72 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-fifths of its imports during the early open trade period. The relative importance of particular resources (such as land or female labor) could in the end depend upon substantial intensity in the production of an intermediate product. Each kilogram of silk 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. Almost three days were needed for a woman to reel one kilogram of silk. Silk production also required large amounts of working capital given that many families would have purchased the two inputs to cocoons, mulberry leaves and silkworm eggs, from specialized producers. 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, where it was prepared for export.

²⁸ See **Gribble, Henry**. "The Preparation of Japanese Tea." *Transactions of the Asiatic Society of Japan*, 1883, 12(1), pp. 1-87, **Syrski, S.** "Landwirtschaft in Japan," K. Scherzer, *Fachmännische Berichte Über Die Österreichisch-Ungarische Expedition Nach Siam, China Und Japan (1868-1871.)*. Stuttgart: Julius Maier, 1872, 175-227.. The valuations are reported estimates for 1860, the first year of open trade.

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 year 1868 through 1875. The first section of Table 3 provides the calculation of $\mathbf{w}^a \mathbf{A}^{1870} \mathbf{X}^i$, which is the autarky valuation of the factor services embodied in exports each sample year. The value of factor exports ranges between 1.5 and 3.0 million gold ryō. Most of the fluctuation 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 silk industry, female labor has the lowest share in the total factor services embodied in Japan's exports.

The second section of Table Three gives $\mathbf{w}^a \mathbf{A}^{1870} \mathbf{IM}^i$, 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, unskilled male labor was the most important implicit 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 $\mathbf{w}^a \mathbf{AT}^i$: 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 four of the eight test years and generally a net importer of all other factors. Despite the paucity of arable land in Japan, this finding provides support for the insight of Yasuba Yasukichi (1996), who contends that the dominance of primary products such as silk and tea in Japan's exports reflects a comparative advantage in land-intensive exports. This also is contrary to the suggestion of Jeffrey Williamson (2000), who argues that Japan's imports were both land- and capital-intensive and its exports were labor-intensive.

The final row of Table Three contains the test value of $\mathbf{w}^a \mathbf{AT}^i$ for each year of the early free trade period and reveals a positive sign in each of the eight 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 eight positive signs in a sample of eight, the p-value, defined as the smallest level of significance for which we can reject H_1 in favor of H_0 is about 0.4 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 two complications is in order. First, the trading vector \mathbf{X}^i used in the analysis includes about 95 percent of exports, but the vector of imports (\mathbf{IM}^i) includes only 60 percent of the imports by value. Of the excluded imports, about 2.5 percent were military items for which comparable information on Japanese technologies is not currently available. Another 6.3 percent were western goods not produced in Japan or lacked detail on the quantity imported.²⁹ One-half of the missing imports (20 percent) were woolens, which recent research (D T Jenkins, 1988, Shinya Sugiyama, 1988, Hitoshi Tamura, 2004, 2001) suggests substituted primarily for domestically-produced silks. The other complication is that for most of the test years (1869-1875), Japan balanced a deficit in its trade in goods with the outflow of silver and gold in bullion and in coin. Fortunately, data are available for the last four test years that allow for the inclusion of these resource flows in the calculation of $\mathbf{w}^a \mathbf{AT}^i$.

Aside from heavier all-woolen cloths such as buckskins that were used for military or government uniforms of a western design, most Japanese imports consisted of worsted cloths such as camlets or mousseline de laine, mixed woolen and cotton cloths and light woolen cloths such as flannel or Spanish stripes. The worsted and mixed cloths substituted for Japanese silks in traditional Japanese dress and were used for belts, linings for sleeves, collars and outer wear (*haori*). The imports substituted for silks such as *habutai* (a plain weave fabric), *obi* (cloth for belts or sashes) and *chirimen* (a silk crepe fabric).³⁰ As it turns out, many imports of cotton cloth, which were for the most part lighter than Japanese cotton cloths, served this purpose as well. The woolen cloths that were clearly identifiable as substitutes for Japanese silks accounted for about 75 to 80 percent of the yardage and about 55 percent of the value of imported woolens.³¹ Japanese, German and French sources provide enough information to reconstruct the dimensions of the imported and domestic fabrics and

²⁹ The top three in this category were machines and instruments, leather and leather goods (boots and shoes) and glass. Most of the machinery imports were on behalf of the Meiji government during this period.

³⁰ See the accounts of a cloth merchant analyzed by **Tamura, Hitoshi**. *Fasshon No Shakai Keizaishi : Zairai Orimonogyō No Gijutsu Kakushin to Ryūkō Shijō*. Tōkyō: Nihon Keizai Hyōronsha, 2004. and the more general discussion in **Jenkins, D T**. "The Response of the European Textile Manufacturers to the Opening of the Japanese Market." *Textile History*, 1988, 19(2), pp. 255-78.. The reports of Prussian and German consuls in the treaty ports are also rich sources of documentation of the woolen textile market in Japan.

³¹ United States and German consular reports from the treaty ports in 1870 and 1875 provide more detail on imports than the published Meiji trade statistics. They confirmed that virtually all goods classified as mixed woolen and cotton goods were actually cloths such as orleans, mousseline de laines, lustres and fancies. The calculation excludes woolen blankets, which were substitutes for traditional Japanese comforters (stuffed with cotton wadding and a silk cover). It also excludes the import category unenumerated woolen piece goods, which could have also included substitutes for domestically-produced silks.

the factor requirements for them. The main source of disagreement in the literature 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.³²

Panel A of Table Four includes imputed input requirements for woolen imports for which clear substitutes in the silk sector were identifiable. The final row of Panel B provides the autarky valuation of factor imports for woolens that substituted for Japanese silks. It ranged from 200 thousand to over one million gold ryō, which is from five to fifteen percent of the estimates of $wAIM^i$ found in Table Three.

The second robustness check is required because during some of the 1870s, the Japanese economy experienced a trade deficit. The deficit could lead to a violation of the balanced trade condition required by the theoretical model. Since Japan prohibited direct foreign investment, private capital flows could not fill the gap in the merchandise trade balance. The government's recourse to international credit markets was limited to a few modest loans in the early 1870s. Instead, exports of gold and silver primarily as coin covered the deficit in goods trade (Hugh Patrick, 1966, p. 181). One approach to ascertaining whether the exports of gold and silver were sufficient to offset the estimated value of wAT^i is to construct estimates of the domestic resources embodied in the outflow of specie. Lyman's study tour of Japanese mining in the late 1870s included several private gold and silver mines that used traditional technologies (the Seigano mine) and the government-owned Ikuno gold and silver mine. The Ikuno mine used some western technologies for mining and smelting starting about 1869. Lyman argued that the Seigano gold and silver mine was most likely still operational only because the mine included tracts of land that provided wood for the charcoal used for smelting and because the owner was able to retain his older and loyal labor force of 81 workers for relatively low wages. Investments in Western technologies at the government-owned Ikuno mine, which employed 925, included steam engines for pumping out water, transporting ore (to allow access to deeper mining) and stamping the ore as well as reverberatory furnaces. These investments increased the efficiency of the mining and

³² See **Bavier, Ernest de**. *La Sériciculture : Le Commerce Des Soies Et Des Graines Et L'industrie De La Soie Au Japon*. Lyon Milan: H. Georg Du Molard frères, 1874, **Ichikawa, Takamasa**. *Nihon Nōson Kōgyōshi Kenkyū* : Kiryū Ashikaga Orimonogyō No Bunseki. Tōkyō: Bunshindō, 1996. for more information. **Porter, Robert P. and National Association of Manufacturers (U.S.)**. *Commerce and Industries of Japan : A Report of Investigations Conducted by Robert P. Porter*. Philadelphia: Bureau of Publicity National Association of Manufacturers, 1898. provides details on habutai production, which by the 1890s became important as a source for silk used in the manufacture of umbrellas.

recovery of precious metals from ore. The input requirements per ounce for gold and silver produced at the Seigano and Ikuno mines are found in panel A of Table 4. The low productivity of the Seigano mine's ores, the use of charcoal for smelting and the small batches for each charge of the smelters meant that almost 50 days of labor were required to produce one ounce of refined gold and 5 days were required for one ounce of silver. The application of capital-intensive western mining and smelting techniques could boost labor productivity at mines such as the Ikuno mine by two and one-half times over traditional techniques. 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 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.³³ The valuation of the resource cost of this outflow depends only in a minor way on whether western or traditional technologies are assumed. The calculation in Panel C of Table Four assumes traditional technologies. The value of wAT^i for the four test years (1872-1875) that incorporate information on the importation of woolen goods and on the exportation of gold and silver ranges from 2.4 million to almost 3 million gold ryō. All of these strongly positive values suggest that the sign predictions are preserved and that the pattern of Japan's trade was in accordance with the Heckscher-Ohlin theorem.

6. Concluding remarks

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 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

³³ Japanese production of gold was 13,000 ounces in 1874. The production of silver was 344,000 ounces. See 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 were Mexican silver dollars and silver and gold gilt coin from the late Tokugawa period.

accomplished for the two-country, two-factor, two-commodity world familiar from undergraduate textbooks in international trade. Subsequent research by Deardorff (1982) and Neary and Schweinberger (1986) has formulated a refutable Heckscher-Ohlin proposition for a single economy which 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 allowed us to construct a technology matrix based on disaggregated data of input requirements at the task level. Combining the data in this technology matrix with the corresponding commodity trade flows and autarky factor prices permit 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 contributed to its formulation since Ohlin.

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Figure 1: Heckscher-Ohlin prediction in the two-factor case

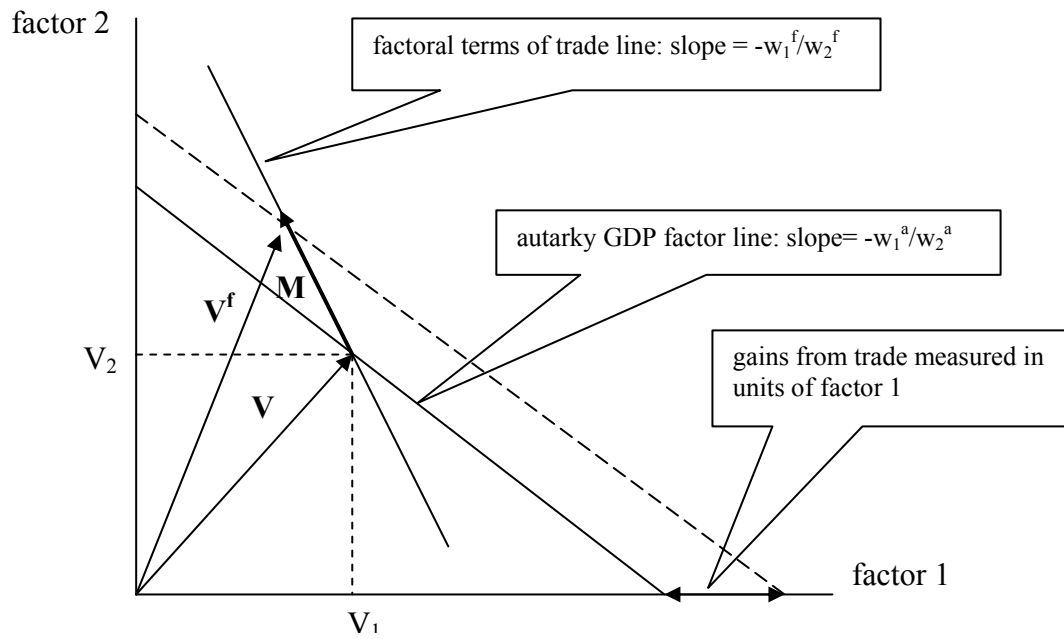


Table 1: The A matrix for Japan during the early trade period (1868-1875)

Export	Share	Male skilled labor (days)	Male unskilled labor (days)	Female labor (days)	Capital (ryō)	Land (tan)
Silkworm eggs and pierced cocoons	16.72	66.9	997.9	500.6	151.9	22.7
Silk	33.77	676.6	12,777.2	16,564.0	2,813.5	390.7
Silk waste	1.50	135.3	25,55.4	3,312.8	562.7	78.1
Tea	27.49	452.7	584.7	208.4	151.0	22.9
Bancha tea	0.57	0.0	183.0	107.4	8.8	0.0
Wheat	0.11	16.7	181.3	28.0	12.0	8.1
Tobacco	0.84	38.4	474.9	27.4	17.7	10.3
Camphor	0.70	0.0	397.0	261.4	18.4	33.0
Vegetable wax	1.16	0.0	375.2	0.0	30.1	0.0
Mushrooms	1.11	0.0	967.7	0.0	0.0	24.8
Seaweed	1.99	8.8	17.6	26.5	3.4	0.1
Cut Seaweed	0.51	19.4	24.8	58.5	3.8	0.1
Kanten (Seaweed gelatin)	0.62	29.7	1,465.5	89.2	11.5	0.4
Copper	2.94	546.0	537.7	58.4	299.4	0.3
Charcoal	0.01	73.2	132.3	0.0	0.8	0.1
Coal	1.62	4.0	1.7	0.0	0.0	0.2
Sulphur	0.09	21.5	0.0	0.0	8.8	0.3
Cuttlefish	1.37	24.8	33.1	0.0	0.6	0.0
Iriko (sea cucumber)	0.77	10.9	231.6	0.0	0.1	0.1
Awabi (abalone)	0.73	615.6	0.0	0.0	2.4	0.0
Share of total exports	94.6					
Import	Share of Imports	Skilled	Unskilled	Female	Capital	Land
Rice	9.93	10.0	132.3	14.0	3.1	4.1
Soy	1.32	3.6	106.7	24.7	1.4	8.8
Wheat	0.02	16.7	181.3	28.0	12.0	8.1
Indigo	0.04	139.1	762.6	182.6	43.9	10.5
Kerosene	0.70	51.0	523.6	0.0	27.3	0.3
Lead	0.45	1,200.8	889.6	1,097.3	31.5	0.0
Tin	0.06	4,151.7	414.3	0.0	0.6	0.2
Pig iron	0.11	319.0	160.6	0.0	1.1	0.1
Iron manufactures	2.56	514.0	221.2	0.0	3.4	0.1
Steel	0.07	466.2	228.5	0.0	0.0	0.2
Brown Sugar	6.65	67.7	419.6	44.2	123.4	4.2
White Sugar	2.84	162.1	900.6	88.4	265.1	8.7
Raw Cotton	2.07	64.4	461.8	261.2	35.7	9.6
Cotton Yarn	14.47	297.6	1333.4	6,578.5	104.5	27.7
Unfinished Cotton Cloth (per1,000 meters)	10.73	11.2	50.1	447.3	4.0	1.0

Finished Cotton Cloth (per 1,000 meters)	8.63	43.3	59.1	449.4	5.6	1.1
Share of Total Imports	60.3					

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, please see the 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 "Bower"	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 (w^aAT))

	Factor Price ca. 1854- 1857	1868	1869	1870	1871	1872	1873	1874	1875
Exports									
Labor male skilled	0.051	213	183	256	408	424	328	466	444
Labor male unskilled	0.029	509	374	418	681	598	570	667	642
Labor female	0.019	247	174	178	305	232	238	256	254
Capital	0.240	743	561	667	1190	1129	904	1109	1027
Land	0.720	302	227	282	403	343	337	451	435
Total $w^aA^{1870}X^i$:		2014	1518	1801	2988	2725	2040	2499	2367
Imports									
Labor male skilled	0.051	295	446	669	616	502	571	796	993
Labor male unskilled	0.029	495	1025	2240	1923	879	856	1094	1312
Labor female	0.019	823	896	1490	1651	1837	1772	2095	2084
Capital	0.240	675	947	1806	1807	1243	1283	1581	1934
Land	0.720	192	652	1466	1118	339	306	377	446
Total $w^aA^{1870}IM^i$		2480	3965	7672	7116	4800	4788	5942	6769
Imports-Exports									
Labor male skilled	0.051	82	263	414	208	78	244	330	549
Labor male unskilled	0.029	-14	651	1822	1242	281	286	427	670
Labor female	0.019	576	722	1312	1346	1605	1533	1839	1830
Capital	0.240	-68	386	1140	617	115	379	471	907
Land	0.720	-110	425	1184	715	-4	-31	-74	10
Total Net (w^aAT^i)		466	2447	5871	4128	2075	2748	3443	4402

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, please see the text.

Table 4: The Impact of Woolen Imports and Exports of Gold and Silver on the Autarky value of Factor Trade

Panel A: Input Requirements for Woolen Cloths and Precious Metals

Product	Male skilled labor (days)	Male unskilled labor (days)	Female labor (days)	Capital (ryō)	Land (tan)
Woolen cloths (per 1,000 meters)	201.6	107.1	319.2	22.5	2.8
Gold (Traditional technology per 100 ounces)	4266	227	682	0	2
Gold (Western technology per 100 ounces)	474	25	0	0	0
Silver (Traditional technology per 100 ounces)	1880	0	38	610	0
Silver (Western technology per 100 ounces)	204	0	0	66	0

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

	1868	1869	1870	1871	1872	1873	1874	1875
Gold and Silver (Traditional Technology)					-151	-390	-1127	-2143
Gold and Silver (Western Technology)					-96	-401	-1367	-2203
Woolen Cloth	353	209	312	352	526	930	647	1156

Panel C: The Autarky Value of Factor Trade Including Precious Metals and Woolens (in thousands of gold ryō (w^aAT))

	1872	1873	1874	1875
Labor male skilled	198	233	-456	-991
Labor male unskilled	353	406	487	774
Labor female	1710	1713	1915	1976
Capital	175	568	602	1142
Land	32	32	-35	79
Total Net (w^aAT^i)	2449	2952	2513	2980

Notes: For a discussion of the calculations, please see the text. The calculations in Panel C assume the use of traditional technologies for mining and refining silver and gold. *Source:* Bavier(1874, pp. 126-127), Porter and National Association of Manufacturers (U.S.)(1898, p. 76) and Ichikawa(1996, pp. 108-110) for the input requirements for *chirimen, habutai and obi* silk cloths. Jenkins(1988), Sugiyama (1988), and Tamura(2001 and 2004) provided data on the equivalence between imported woolen cloths and

domestically produced silks. 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.