

**A Ricardian factor content characterization of the welfare effects from trade:
evidence from Japan's opening up¹**

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Abstract

Following Samuelson's seminal 1939 contribution, existing measures of the gains from trade are rooted in the theory of consumer demand. Their empirical implementation requires either aggregate consumption data, which are hardly available, or are based on specific functional forms on consumer utility. We suggest a factor content characterization of the gains from trade which is based on production theory and requires no assumptions on the demand side of the economy. We show that our measure can be viewed as a generalization of David Ricardo's 1817 labour value formulation of the gains from trade. An attractive feature of our characterization is that the gains from trade become empirically refutable. In addition, our measure allows inference about the sources of the benefits and costs from trade. We apply our measure to Japan's 19th century opening up to world commerce where we are able to observe a market economy under autarky and trade. Our analysis applies Japan's 19th century autarky technology matrix to Japan's early commodity trade flows. We provide causal evidence on positive gains from trade and show that Japan's early gains arose from its ability to import relatively scarce factors as well as Ricardian augmentation of labour.

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1. Introduction

The question about the gains from trade lies at the heart of neoclassical economics. The view that an economy open to international trade is better off than under no trade has been held since the days of Adam Smith and David Ricardo. However, our current neoclassical characterization of the gains from trade goes back to Paul Samuelson's classic 1939 paper (Samuelson, 1939), in which he formally showed that an economy is better off under trade than under autarky. Following Samuelson's seminal 1939 contribution, existing characterizations of the gains from trade are all rooted in the theory of consumer demand. Their empirical implementation invokes either the weak axiom of revealed preference (Bernhofen and Brown, 2005) or is based on special functional forms for consumer utility.³

We propose a factor content characterization of the gains from trade which focuses on the production side of the economy and imposes no restrictions on consumer demand. International trade is characterized as an exchange of factor services within a cost-benefit framework. The costs from trade are the resources embodied in a country's exports; the benefits are the counterfactual resources that would have been required to produce the foreign imports domestically. An advantage of this formulation is that it allows for the possibility that the costs exceed the benefits. The gains from trade become an empirically refutable proposition rather than a theoretical assumption. An advantage of the factor content characterization of the gains from trade is that it provides information about the underlying sources of the benefits and costs from trade and about the relative contributions of factor abundance and factor productivity differences in determining the overall gains from trade.

³ See McKenzie and Pearce (1982) and Grinols and Wong (1991) for good surveys of the welfare literature.

Although we deviate from Samuelson in characterizing the gains from trade in terms of consumer demand, we argue that our measure has a historical precedent in David Ricardo. In fact, we show that our measure generalizes Ricardo's famous 1817 labour value formulation of comparative advantage to the case of multiple factors of production. The comparison with Ricardo suggests that our measure is based on "classical economic thinking," since it does not impose any assumptions on the demand side of the economy.

We apply our measure to Japan's 19th century opening up to world commerce which provides an unusual opportunity to observe a market economy under both autarky and trade under the *ceteris paribus* assumption. This comparison allows us to make a causal statement about the effects of trade on aggregate economic welfare. Our empirical analysis combines trade data on Japan's early trading years with autarky factor prices and technology data that reflect Japan's technological conditions during the first years of open trade. The technology matrix has been constructed 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 drawing on village records and business accounts.

We apply our measure to the three trading years of 1865, 1868 and 1876 during which trade was either balanced or in surplus. We find that the benefits from trade exceeded the costs in all sample years. In addition, we find that for the year 1876, the Japanese economy experienced no factor trade-offs. This implies that in this trading year the gains can be expressed in physical endowment quantities without having to rely on estimates of factor prices. We provide lower bound per capita factor income estimates

that are comparable to the upper bound consumption based gains from trade estimates in Bernhofen and Brown (2005). This confirms the equivalence of these two measures in capturing the order of magnitude of the aggregate gains from trade and also implies causal evidence for positive gains from trade in the absence of any assumptions on consumer preferences.

Combined with the data on the technologies in use in Japan during autarky, data on the technologies in use in the source countries for Japan's imports allow us to quantify the relative importance of technological differences and factor exchange in Japan's overall gains from trade. We find both a role of technological differences and factor exchange in all trading years, with a larger role of technological differences in later years of the sample period.

2. A new characterization of the welfare effects of trade

To put our new characterization of the welfare effects of trade into perspective, we start out by briefly reviewing the existing welfare measures of the gains from trade for a small neoclassical economy without any distortions. We then derive an alternative measure of the gains from trade that is based on the gains from trade in factor services.

2.1 Existing welfare measures of the gains from trade

Our current understanding of what it means that a country gains from trade is rooted in Samuelson's seminal 1939 paper. In that paper Samuelson theoretically proved the existence of the gains from trade and also linked the gains from trade characterization to the weak axiom of revealed preference.⁴ Since then the standard characterization of the

⁴ Samuelson's 1939 paper on the gains from follows up on Samuelson (1938), where he introduced the concept of weak axiom of revealed preference. This axiom allowed for the formulation of the theory of demand without relying on the concept of utility. Subsequent papers by Samuelson (1962) and Kemp

gains from trade involves a welfare comparison of a representative consumer under autarky and trade. The different welfare measures distinguish themselves by taking either consumer utility (Hicksian characterization) or consumption (Slutsky characterization) as the primitive. In what follows, we focus on the Slutsky type consumption characterization of the gains from trade since its recent empirical implementation in Bernhofen and Brown (2005) is closely related to our empirical work in this paper.

Consider a single economy that produces n goods under autarky and trade. The autarky equilibrium is characterized by an autarky price vector $\mathbf{p}^a=(p_1^a, \dots, p_n^a)$ and a consumption vector $\mathbf{C}^a=(C_1^a, \dots, C_n^a)$. The free trade equilibrium is given by a price vector $\mathbf{p}^t=(p_1^t, \dots, p_n^t)$ and a consumption vector $\mathbf{C}^t=(C_1^t, \dots, C_n^t)$. In a friction-less world \mathbf{p}^t is both the terms of trade and the price that producers and consumers face. The analysis of the gains from trade analysis then compares the consumption choices of a representative consumer under autarky and trade. Applying the concepts of income equivalents, we obtain two welfare measures of the gains from trade based on whether one uses autarky or trade prices to evaluate the consumption vectors. Using \mathbf{p}^t as the evaluation criteria, we obtain the compensating measure of the gains from trade:

$$\Delta W^C = \mathbf{p}^t \mathbf{C}^t - \mathbf{p}^t \mathbf{C}^a, \quad (1)$$

where ΔW^C is interpreted as the change in income necessary to compensate the economy from having to move from trade to autarky. By showing that $\mathbf{p}^t \mathbf{C}^t \geq \mathbf{p}^t \mathbf{C}^a$ Samuelson

(1962) extended the gains from trade argument to the case where an economy is large enough to influence the terms of trade.

(1939) established non-negative gains from trade with regard to this welfare characterization.

Using \mathbf{p}^a as the evaluation criteria, the second measure of the gains from trade can be written as:

$$\Delta W^E = \mathbf{p}^a \mathbf{C}^t - \mathbf{p}^a \mathbf{C}^a, \quad (2)$$

where ΔW^E is interpreted as the additional income (equivalent variation) that would enable the economy to attain the free trade consumption bundle at autarky prices. While the sign of (1) follows from optimizing behaviour, the sign of (2) follows from (1) and the assumption that consumer behaviour, in the aggregate, follows the weak axiom of revealed preference.

A shortcoming of the welfare measures (1) and (2) is that they are based on consumption data, which are difficult to come by. Bernhofen and Brown (2005) show that data on commodity autarky prices and trade flows provide an upper bound for (2) and are able to provide some theory-based welfare estimates of the gains from trade. Furthermore, (1) and (2) are rooted in consumer theory and disregard the production side of the economy. A significant part of international trade, both in contemporary and past trading relationships, involves intermediate or producer goods where demand stems from the production side of the domestic economy. We can view international trade as a reallocation of domestic resources that then allows the transformation of the exported resources into imports. It is desirable to have a welfare characterization that makes this trade-off explicit.

2.2 A factor content characterization of the gains from trade

We suggest a new production based measure of the gains from trade that is able to address some of the issues mentioned above. The starting point of this measure is an economy's trading vector with the rest of the world. Let's denote the vector of exports as $\mathbf{X}=(X_1,\dots,X_n)$ and the vector of imports as $\mathbf{M}=(M_1,\dots,M_n)$. From a cost-benefit perspective, the import vector \mathbf{M} constitutes the benefits to the economy and the export vector \mathbf{X} constitutes the costs compared with no trade. The central idea is to measure the costs and benefits with the resources embodied in observed trade flows. To link goods flows to resources requires information on technology. Assume there are k factors of production and the economy's technology is characterized by an n by k matrix \mathbf{A} , where the entry a_{ij} denotes the number of units of factor i necessary to produce one unit of good j . For simplicity, we assume that all production is characterized by fixed input coefficients implying that production techniques do not depend on factor prices. The factor outflows associated with trade are given by the factor content of exports \mathbf{AX} . The evaluation of the import vector requires some reflection since the imports can come from different locations using production techniques that will, in general, be different from home. However, under the assumption that the import vector \mathbf{M} could be produced with domestic technologies, the benefit from trade are the counterfactual resources that would have been necessary to produce the imported goods domestically, which is \mathbf{AM} . Evaluating the resource flows embodied in trade at the economy's autarky factor price vector $\mathbf{w}^a=(w^a_1,\dots,w^a_k)$, we obtain a cost-benefit characterization of the gains from trade:

$$\Delta W^{\text{FC}} = \mathbf{w}^a(\mathbf{AM}) - \mathbf{w}^a(\mathbf{AX}), \quad (3)$$

where the superscript ‘FC’ pertains to factor content.

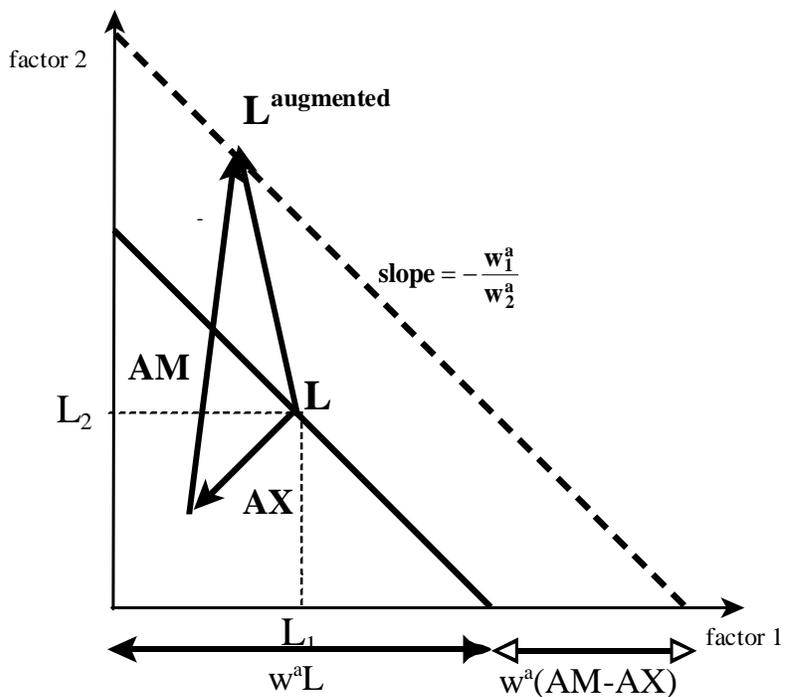
Figure 1 illustrates the factor content measure in the two-factor case. The economy’s endowment point is given by $\mathbf{L}=(L_1,L_2)$. Drawing a line through \mathbf{L} with the slope given by w_1^a/w_2^a , we obtain an “autarky factor income line.” The autarky factor income $\mathbf{w}^a\mathbf{L}$ measured in ‘real units’ of factor 1 is then given by the intercept of this autarky factor income line with the horizontal intercept. International trade can be thought of as enabling the economy to attain an augmented endowment point \mathbf{L}^{aug} defined as $\mathbf{L}^{\text{aug}}=\mathbf{L}+\mathbf{A}\mathbf{M}-\mathbf{A}\mathbf{X}$. By construction, this augmented endowment vector \mathbf{L}^{aug} would enable the economy to attain the trade consumption vector \mathbf{C}^t using domestic production techniques. From this viewpoint, the gains from trade can be characterized as the change in factor income, evaluated at autarky factor prices, which is equivalent to moving the economy from its actual endowment point \mathbf{L} to the augmented endowment point \mathbf{L}^{aug} , or

$$\Delta W^{\text{FC}} = \mathbf{w}^a\mathbf{L}^{\text{aug}} - \mathbf{w}^a\mathbf{L}. \quad (4)$$

This welfare characterization of trade has several attractive features. First, it imposes no restriction on the consumption side of the economy and requires only the standard assumptions such as competitive markets and constant returns to scale. An important implication of this cost-benefit characterization of trade is that the gains from trade are empirically refutable. The data could reveal that the resource costs associated with exports exceed the benefits from imports. A second attractive feature of (2) is that $\mathbf{A}\mathbf{M}-\mathbf{A}\mathbf{X}$ provides a physical characterization of the sources of the gains from trade. For

example, in Figure 1 a comparison of L and L^{aug} reveals that the economy is exporting factor 1 and importing factor 2. Hence, this trading pattern is compatible with the factor abundance explanation of trade which predicts that the country will export its abundant factor and import its scarce factor.

Figure 1: A factor content characterization of the welfare effects of trade



2.3 A special case: Ricardo's gains from trade formulation

In the previous section we offered a characterization of the gains from trade that is based on the factor content of trade. This cost-benefit characterization of the gains from trade has a historical precedent in David Ricardo's famous passage in chapter VII of the *Principles of Political Economy and Taxation*, where he discusses the trade in cloth and wine between Portugal and England. This passage employs what Samuelson (1969) so vividly labeled "Ricardo's four magic numbers" (where the numbers are given in bold):

“The quantity of wine which she [Portugal] shall give in exchange for the cloth of England, is not determined by the respective quantities of labour devoted to the production of each, as it would be, if both commodities were manufactured in England, or both in Portugal.

England may be so circumstanced, that to produce the cloth may require the labour of **100** men if she attempted to make the wine, it might require the labour of **120** men for the same time. England would therefore find it her interest to import wine, and to purchase it by the exportation of cloth.

To produce the wine in Portugal, might require only the labour of **80** men for one year, and to produce the cloth in the same country, might require the labour of **90** men for the same time, It would therefore be advantageous for her to export wine in exchange for cloth.

This exchange might even take place notwithstanding that the commodity imported by Portugal could be produced with less labour than in England.

Though she could make the cloth with the labour of **90** men, she would import it from a country where it required the labour of **100** men to produce it.” (Ricardo, 1817, p. 82)

Following John Stuart Mill, trade theorists have interpreted Ricardo’s four numbers as unit labour coefficients: the amount of labour required in each country to produce one unit of cloth or wine. More recent appraisals of this interpretation suggest that it suffers from a serious shortcoming: it is inconsistent with Ricardo’s explication. At the outset, Ricardo introduces the first two numbers and then uses them to predict England’s pattern of trade (that it exports cloth and imports wine) without reference to

the third and fourth numbers. If these were unit labour coefficients, the logic of the argument would require information on all four numbers before Ricardo could state a conclusion about the pattern of England's (and Portugal's) trade. The second flaw in the interpretation is that Ricardo also concludes that England benefits from trade prior to discussing the numbers for Portugal; he draws the same conclusions for Portugal based on its numbers. It is not clear how these conclusions about the gains from trade could be drawn from each country's unit labour coefficients.

Drawing on earlier work by Sraffa (1930), Ruffin (2002) and Maneschi (2004) suggest that Ricardo's four numbers pertain to the amount of labour embodied in each country's exports and imports rather than unit labour coefficients. Bernhofen (2009) further argues that this labour content interpretation yields a pattern of trade prediction which restores coherence to this famous passage and is compatible with Ricardo's labour theory of value.

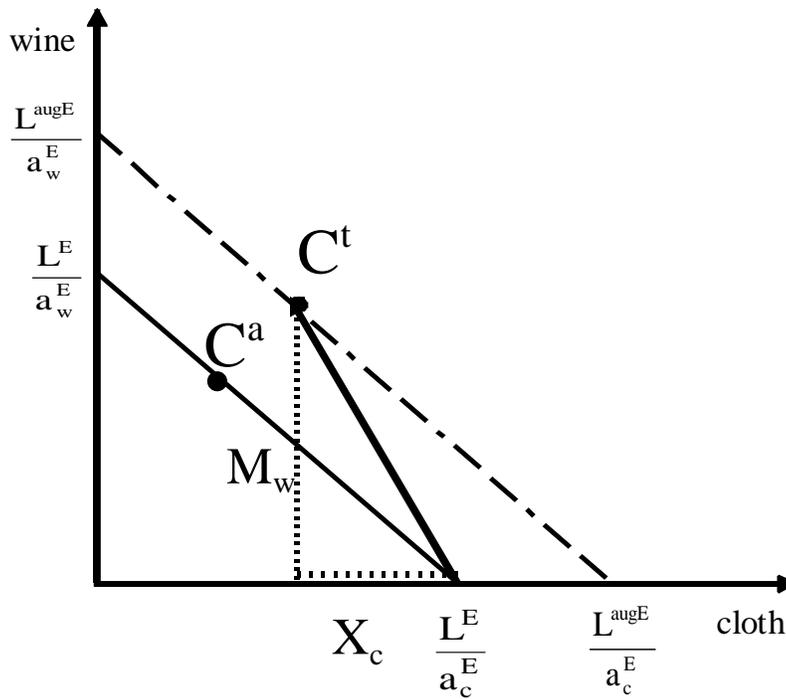
Ricardo's formulation can be viewed as a special case of (3). The first observation is that in the case of a single factor of production, the gains from trade can be measured in physical labour units; there is no need for autarky factor prices to evaluate any factor trade-offs. Using the notation from above, England's labour endowment is denoted by L^E and its technology matrix is given by $A=(a_c^E, a_w^E)$, where a_c^E is the unit labour requirement for cloth and a_w^E is the unit labour requirement for wine. Denote England's physical exports of cloth as X_c and physical imports of wine as M_w . Ricardo's assertion that "*the cloth may require the labour of 100 men*" implies then that $100=a_c^E X_c$ and his assertion that "*if she attempted to make the wine, it might require the labour of 120 men*" implies that $120=a_w^E M_w$. England's gains from trade can then be expressed as

$$\Delta L^E = a_w^E M_w - a_c^E X_c = 120 - 100 = 20, \quad (5)$$

which implies that “[*England*] gains the labour of 20 Englishmen”, as Sraffa (1930, p.54) put it. We can immediately see that (5) is a special case of (3) and that Ricardo’s choice of numbers imply positive gains from trade, since the labour embodied in imports exceeds the labour embodied in exports. Analogously, Portugal’s gains from trade can be written as $\Delta L^P = a_c^P M_c - a_w^P X_w = 90 - 80 = 10$ and “*Portugal gains the labour of 10 Portuguese*” (Sraffa 1930, p. 54).

Figure 2 depicts the gains from trade in the Ricardian model and helps with the comparison of the Ricardian factor content formulation (5) with the consumer-based welfare measures (1) and (2). The economy’s autarky consumption point is given by C^a and through trade the economy is able to afford a consumption point C^t outside its production possibility frontier. The consumer-based measures of welfare require data on both consumption points and commodity prices (under autarky or trade) to calculate the increase in income that is equivalent for the representative consumer to move between C^a and C^t . The Ricardian measure combines trade data (X_c, M_w) with domestic technology data (a_c^E, a_w^E) to construct a ‘labour augmentation equivalent to trade’, which is defined as $L^{augE} = L^E + \Delta L^E$. In this view, trade relaxes the economy’s resource constraint such that the trade consumption point C^t could be produced with domestic technology and L^{augE} . An advantage of the Ricardian measure is that it employs trade and technology data, which may be more readily available than consumption data.

Fig. 2: Gains from labour augmentation in the Ricardian model



2.4 Identifying the sources of the comparative advantage gains from trade

In the Ricardian model, the gains from trade stem from technological differences and the factor content measure provides a physical labour augmentation formulation of the gains from trade as illustrated in Figure 2. The Heckscher-Ohlin model abstracts from technological differences and the gains stem from the ability of countries to exploit their relative factor abundance. Two important questions arise. To our knowledge of the literature, neither has been addressed. How can we assess whether trade is caused by technological or endowment differences? Is it possible to measure the relative importance of each cause? We suggest an approach to answering both questions.

Assume now that “the” foreign technology matrix is also characterized by fixed input coefficients and is denoted by \mathbf{A}^* . The gains from trade can then be decomposed as follows:

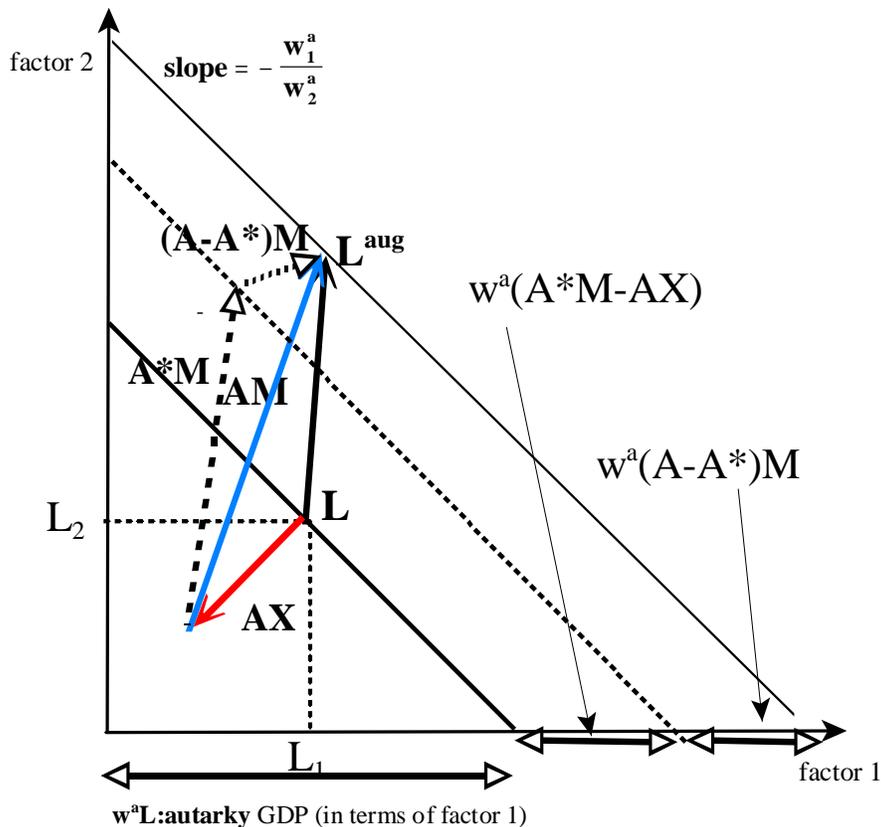
$$\Delta W^{FC} = \mathbf{w}^a(\mathbf{A}\mathbf{M}) - \mathbf{w}^a(\mathbf{A}\mathbf{X}) = \mathbf{w}^a(\mathbf{A} - \mathbf{A}^*)\mathbf{M} + \mathbf{w}^a\mathbf{A}^*\mathbf{M} - \mathbf{w}^a\mathbf{A}\mathbf{X}. \quad (6)$$

The rationale behind (6) is that the gross benefit from trade $\mathbf{w}^a\mathbf{A}\mathbf{M}$ can be decomposed into a factor exchange component ($\mathbf{w}^a\mathbf{A}^*\mathbf{M}$) and a technological difference component ($\mathbf{w}^a(\mathbf{A} - \mathbf{A}^*)\mathbf{M}$). The factor exchange component captures the ‘actual’ factor content of imports, since it evaluates imports using the technologies actually used to produce them. However, since foreign factors differ in their productivities, the technological difference component captures the contribution of factor productivity differences in the gross benefits from trade. In the special case where home and foreign technologies are identical, i.e. $\mathbf{A} = \mathbf{A}^*$, the technological difference component vanishes and all the gains stem from pure factor exchange. If trade is governed by Heckscher-Ohlin forces, some components in $\mathbf{L}^{aug} - \mathbf{L}$ must have a negative sign. Figure 1 depicts this scenario in the two-factor case. Here, an augmentation of the domestic factor endowment captures the gains from trade and the economy is exporting its abundant factor and importing its scarce factor.

In the presence of technological differences, it is possible that all components in $\mathbf{L}^{aug} - \mathbf{L}$ have a positive sign. This scenario is depicted in Figure 3, where $\mathbf{A}\mathbf{M}$ is decomposed into $\mathbf{A}^*\mathbf{M}$ and $(\mathbf{A} - \mathbf{A}^*)\mathbf{M}$. $\mathbf{A}^*\mathbf{M}$ reveals that the foreign economy uses a small amount of factor 1 and much more of factor 2 to produce the imported goods.

What may be termed “pure factor exchange” leads to an augmentation of the endowment of $L+A^*M-AX$ as the home economy trades away factor 1 for gains in factor 2. However, the vector $(A-A^*)M$ indicates the further augmentation of the domestic endowment from differences in the factor requirements of domestic and foreign technologies. Domestic technologies use factor 1 much more intensively than foreign technologies, so that imports ensure a realization of additional factor savings. In Figure 3, the technological differences are sufficiently large such that the domestic economy gains in both factors, i.e. both components in $L^{aug}-L$ are positive. The absence of factor trade-offs means that as in the Ricardian model, the gains from trade can be characterized without reference to autarky factor prices.

Figure 3: Decomposing the comparative advantage gains from trade.



An advantage of this decomposition is that it allows the trade data to reveal the relative importance of technological differences in the trading relationship. If we focus just on imports, or the gross gains from trade, we can consider the following definition:

Definition (share of gross gains from trade): Assuming that $\mathbf{w}^a \mathbf{A}^* \mathbf{M} \leq \mathbf{w}^a \mathbf{A} \mathbf{M}$, we can define $\lambda = \mathbf{w}^a \mathbf{A}^* \mathbf{M} / \mathbf{w}^a \mathbf{A} \mathbf{M}$ as the share of gross gains arising from pure factor exchange and $1 - \lambda = \mathbf{w}^a (\mathbf{A} - \mathbf{A}^*) \mathbf{M} / \mathbf{w}^a \mathbf{A} \mathbf{M}$, as the share arising from differences in technology ($0 < \lambda \leq 1$).

Note that λ is an aggregate measure that weighs factor productivities by import volumes and autarky factor prices. The data might reveal a value of λ close to 1 despite significant technological differences in some sectors if the import volumes in these sectors are comparatively small. In the boundary case of $\lambda = 1$, we can say that technological differences make no contributions to the overall gains from trade. A smaller value of λ indicates a larger role for technological differences. However, since $\lambda > 0$, this measure does not allow for a boundary case where the gains stem entirely from technological differences. In addition, we can examine the role of technological differences for a specific industry or subgroup of industries i by examining $\lambda_i = \mathbf{w}^a \mathbf{A}^* \mathbf{M}_i / \mathbf{w}^a \mathbf{A} \mathbf{M}_i$.

Alternatively, we can examine the role of technological differences in the net gains from trade. Figure 3 depicts a scenario where $\mathbf{w}^a \mathbf{A}^* \mathbf{M}$ is large enough to exceed $\mathbf{w}^a \mathbf{A}^* \mathbf{X}$. In such a case, the decomposition in (6) can be interpreted as follows. $\mathbf{w}^a (\mathbf{A}^* \mathbf{M} - \mathbf{A} \mathbf{X})$ captures the net gains from pure factor exchange and $\mathbf{w}^a (\mathbf{A} - \mathbf{A}^*) \mathbf{M}$ captures the gains arising from technological exchange.

3. Empirical Application: Japan's Factor Trade during the First Globalization

The opening up of Japan to international trade in 1859 after over two centuries of near autarky provides an unusual opportunity to apply the endowment measure of the gains from trade. Bernhofen and Brown (2004 and 2005) describe this episode in detail. Prior to the initiation of open trade through five treaty ports, Japan conducted only a miniscule amount of trade with the Dutch and the small community of Chinese merchants. Western military intervention in 1864 confirmed the open trade regime and put an end to the efforts of Japanese feudal lords and the Tokugawa ruler (the Bakufu) to restrict the export of silk and otherwise impede the activities of western merchants in the treaty ports. The Meiji restoration of 1868 cemented the country's commitment to following the terms of the trade treaties, which allowed for only modest export taxes and import tariffs at or below five percent ad valorem. The volume of trade grew rapidly through the 1870s.

The implementation of our measure of the Ricardian gains from trade requires data on trade flows, technologies in use during the early trade period and factor prices. We investigate the gains from trade using data for three years (1865, 1868 and 1876) during which the Japanese economy experienced either a balance in trade or surplus.

3.1 Data sources and the construction of variables

Two sources provide data on trade flows. For 1865, this study uses the reports of British consuls located in the treaty ports of Kanagawa, Nagasaki and Hakodate. Sugiyama (1988a) uses this source for his description of trade prior to 1868. In some cases, trade data are expressed in non-standard units (such as pieces of cloth).

Fortunately, Wagner (1862) provides a detailed listing of the common dimensions for the cloths produced and traded by Great Britain, which was Japan's main western trading partner during the period. The reports of the Swiss, Prussian and Austro-Hungarian trade missions during the 1860s provide additional information.⁵ For 1868 and later, the returns of the Meiji customs authorities are used (Japan. Department of Agriculture and Commerce. 1897). Although there are some discrepancies between this source and the British consular reports, they are not significant enough to affect the overall results. The Meiji data do have the advantage of reporting all commodities in consistent measures of weight or length. The evaluation of net factor flows includes three sample years (1865, 1868 and 1876) during which Sugiyama (1988a) argues that trade was about balanced. For comparison, the calculation for one other calendar year (1871) is included as well. This was a year of a trade deficit that was brought about by large imports of rice and soybeans after poor harvests in the northeast part of the country. The deficit was paid for by outflows of silver and gold (mostly in coin). Quantities of imports have been adjusted downward during 1871 to ensure that the merchandise trade for which technology data are available was balanced. Since the factor usage of most exports is accounted for, the lack of technological data for a share of imports implies that the estimates of AM-AX (or $L^{aug}-L$) are a lower bound of welfare gains for the years of balanced trade.

Japan had a sophisticated commercial economy by the time of opening up, which produced a wealth of data from account books and other primary sources. In addition, the Meiji and prefectural governments and western observers had a keen interest in recording data on technologies in use during the early trade period as part of an effort to modernize

⁵ See Jacob (1861), Switzerland. Eidgenössisches Handels- und Zolldepartment and Brennwald (1865), and Scherzer (1872).

the economy. For these reasons, a range of sources is available for constructing the **A** matrix for Japan during the early years of trade.

Bernhofen et al. (2009) provides the documentation for the over 35 Japanese and western sources used to compile the **A** matrix. The primary source for agricultural products is a detailed survey of agricultural productivity known as the *Nōji Chosa*, which was conducted in the late 1880s and was republished in a series of volumes in the 1970s (Chō et al., 1979).⁶ The data in this survey refer to the number of days required to perform different tasks involved in production, such as weeding, harvesting or plowing. The data also allow for assigning the tasks to male or female labour, either directly through the descriptive detail provided or indirectly through wage differentials. This source also provides estimates of land requirements and capital needs.⁷ A range of other sources, including studies by Japanese scholars of farm and business accounts and the observations of western visitors to Japan, supplement the *Nōji Chosa*. Particularly in activities such as processing tea, silk weaving, cotton dyeing and metallurgy, the sources specifically refer to skilled labour. For this reason, skilled labor was included as a fifth factor of production and all other male labour was described as unskilled labour. Overall,

⁶ Those familiar with the history of Japanese agrarian reform, including the introduction of early-maturing varieties of rice and draft animals, may be concerned that a source from the 1880s reflects the productivity improvements of the reforms. As Francks (1984) established in her study, these innovations were introduced primarily during the 1890s and later.

⁷ Land is measured in units of *tan*. One *tan* equals about one-tenth of a hectare. The *tan* were standardized in units of paddy land, which was the most productive (and valuable) agricultural land. Some crops such as soybeans, tea, cotton and mulberry trees were usually planted on upland dry land was used. For these crops, the quantity of land has been adjusted downward by 0.45 percent, which is the discount for non-paddy land from regression analysis of land value assessment data found in Waseda Daigaku Keizaishi Gakkai (1960, Table 23).

the evidence on technologies is available for virtually all of Japan's exports and 70 to 90 percent of its imports.⁸

For reasons discussed in detail in Bernhofen et al. (2009), the data from these mid- to late-nineteenth century sources provide reasonable estimates of the domestic resource requirements of these products for the early trade period. With the exception of copper, technological change in the export sector during the first years of open trade after 1859 was limited to some reorganization of production and relied upon the continued the use of pre-industrial techniques. The theoretical framework places one important restriction on Japan's imports in order to be able to assess the domestic factor requirements of them: all imports were feasible under autarky Japanese technology. For the most part, this condition holds during the early period of open trade. Most imports into Japan involved goods that could be produced using Japanese resources and technologies (sugar, rice, soybeans, cotton), were qualitative improvements on goods that could be produced but were not (English machine-spun yarn had a harder twist and was more consistent in quality than hand-spun Japanese yarn) or near-substitutes for goods that were produced in Japan, but were relatively expensive such as woolens and worsted cloth. Japan imported large quantities of woolens during the early period of open trade. The absence of suitable grazing land meant that Japan did not produce wool during the autarky period. For this reason, it may appear reasonable to describe woolens as new goods that may have been necessary for the tailoring of western-style garments. The research of Jenkins (1988), Sugiyama (1988b) and Tamura (2004) and the reports of German, British and American consuls during the period suggest that this most likely was

⁸ This share includes woolen, worsted and mixed cotton and wool cloths. These products, which were not produced in Japan under autarky, are discussed in more detail below.

not the case. Most of Japan's imports of woollens were of light worsted or mixed cotton and woolen cloths; these actually substituted for various kinds of silks. For example, the popular *mousseline de laine* took the place of the traditional Japanese silk crepes used for women's kimonos. Other cloths substituted for the narrow woven *obi*, or belt, worn by men around the kimono, and so forth. Truly new technologies or goods (steamships or steam engines, opera glasses, mechanical clocks) constituted a small share of imports during the period under consideration.

The valuation of the five basic inputs (w^a) is according to the factor prices prevailing in the mid-1850s. Capital is valued in ryō of the mid-1850s, which was replaced with the yen on a one-for-one basis in 1871. Wage rates for unskilled male labour and female labour are primarily from Saitō (1978). Since virtually all production of tradables took place in rural industries, only wage rates for skilled male labour in the countryside are used. Suzuki (1990) is one widely-quoted source that provides wages for skilled labour.

Data on rents on agricultural land are available from several sources. The main issue in providing a common rent for Japan is that rents varied substantially across regions according to the productivity of land, even when the focus is on paddy land. Generally, land in the east of Japan (including the core economic region of the Kantō around Tokyo) was not as productive as land in the West. A study of the area around Ashikaga in the Tochigi prefecture north of Tokyo provides data on the valuation of agricultural land for a silk-weaving district in eastern Japan (Waseda Daigaku Keizaishi

Gakkai, 1960).⁹ Hedonic regressions of these data found predicted land values of about 11 ryō for “standard” quality paddy land in 1854, with an implied rent of 0.67 ryō. Rents from the more isolated silk-producing region of the Gunma prefecture would have been somewhat lower, according to data provided by Iinkai (1988). Several studies provide estimates of rents from the Kansai. The booming cotton industry and the high quality of land pushed rents in that area to levels much higher than in the east. The study by Takeyasu (1968, Table I-27) provides consistent data on 43 plots of high quality dryfield land. The average is about 1.72 ryō per tan. Furushima and Nagahara (1954) provides a study of agricultural rents from Kawachi province. Valued at the price of rice prevailing in Osaka at the time, these rents were from 1.6 to almost 2 ryō. Since the average land value would be somewhat below the most productive region of Japan, an average value for rents was set at 1.08 ryō.¹⁰

3.2 Assessing the augmentation of factor endowments resulting from trade

Table 1 illustrates the calculation of the autarky valuation of net factor trade ($L^{\text{aug}}-L$) for the four sample years and the allocation of that trade across eight broadly defined sectors of the Japanese economy. Columns two through five include four main categories of imports. Both the relative importance of the imports in Japan’s trade and the resource intensity of domestic technologies play a role in the calculation of the estimates of factor trade found in column ten. The most important imports during the period of analysis were cotton and woolen textiles, which accounted for one-half to almost three-quarters of Japanese imports. These goods were intensive in the use of female (cotton)

⁹ The data are on contracts for the sale of land and for the short-term pawning of land. The value of the pawn contract rose about 6 percent per year that the land was pawned, which is close to the six percent used by other sources to convert land values to annual rents.

¹⁰ The productivity of land in the region that provided the rent data was 87 percent above the productivity in the area around Tokyo ca. 1874.

and skilled male (woolens) labour. Rice, sugar and agricultural raw materials were intensive in the use of unskilled farm labour and capital. Although less important than textiles, metals and minerals (petroleum) accounted for a large share of the imports of skilled male labor. The domestic technologies for minerals and metals were both skill-intensive and relatively unproductive. Columns 6 through 9 provide the value of traded factors embodied in Japan's exports, which were concentrated in sericulture (raw silk and silkworm eggs) and tea. At times exports of copper also provided significant export revenues. The factor content of these goods reflects the land intensity of Japan's exports during the early years of open trade, a point noted over a decade ago by Yasuba (1996).

Column 10 of Table 1 provides estimates of the net augmentations of Japan's endowments of labour, land and capital. During the early year of open trade such as 1865, trade provided an addition to Japan's skilled and female labour force of about 0.12 million person-years. With the increase in imports of woolens and cotton goods, the addition grew by the mid-1870s to about two-thirds million person-years. The results suggest that trade added up to four percent to Japan's labour force ca. 1853 under the assumption that the labour force participation rate for its population of about 30 million was three-fifths. By contrast, Japan was a net exporter of land during the early years of trade. As a rough approximation, the 210,000 *tan* of land (about 21,000 hectares) exported in 1865 would have accounted for about 0.5 percent of paddy and dry land. By 1871, massive imports of rice and soybean more than offset the exports of land embodied in tea and silk; the net addition to the country's arable acreage was about 2 percent.¹¹ Finally, as Japan imported more sugar, cotton and woolen textiles, it saved on capital.

¹¹ See Rein (1881) for the estimates of paddy and dryland fields in Japan ca. 1880.

4. Gains from Trade in Factors: A Lower-Bound Estimate

The theoretical framework provides an approach to accounting for the welfare effects of the international exchange of factors and technologies. The previous discussion suggested that during some years, the augmentation of Japan's endowment could be significant. Measuring the degree of significance requires setting up the appropriate counterfactual. Here, the counterfactual is the required addition to autarky factor income (by an augmentation of the domestic endowment) that would make the free trade consumption vector feasible. Once they are scaled to reflect the fact that domestic factor supplies may have grown over the period from the last years of autarky (1851-1853) to the early period of open trade (1865 to 1876), the estimates of the autarky value of domestic factor usage presented in Table 1 are viable candidates for the counterfactual factor income. Table 2 provides ranges of estimates of the per capita addition to autarky factor income for 1865, 1868 and 1876. The per capita estimates range from 0.003 to 0.23 ryō, with the lowest value in 1865.

Rows five and six of Table 2 provide estimates of the per capita gains to factor incomes as a share of two estimates of real GDP per capita ca. 1851-1853 from earlier research (Bernhofen and Brown, 2005). The backcast estimate assumes a growth rate of per capita real GDP of 0.4 percent obtained from 1851-1853 to the late 1870s, when the first estimates of Japan's real GDP are available. The forecast estimate also assumes a growth rate of 0.4 percent; it is based on the estimates of per capita GDP from the early 1840s for a domain in far western Japan (Chōshū) for which estimates of per capita GDP are available. Both approaches yield similar results. The first years of open trade accorded Japan modest gains to trade, as its comparative advantage in silk and tea

became apparent to potential exporters. As time went on, Japanese producers and consumers learned to take advantage of relatively inexpensive cotton yarn and cloth from England and substitute woolen cloths such as *mousseline de laine* for domestic silk crepe. The end of the distortions in the cotton market caused by the American Civil War and recovery from poor harvests after the early 1870s opened the way for the Japanese economy to realize substantial lower-bound gains of 5 to 9 percent of GDP by 1876. If the missing 25 percent of imports for which technological information is not available were similar to the included sectors, the gains to GDP could range from 7 to 11 percent. This estimate is broadly consistent with estimates obtained using consumption-based measures, which ranged between 5.4 and 9.1 percent for the trading years 1868-1875 (Bernhofen and Brown, 2005).

5. Productivity differences and the gains from trade

The recent economic history literature on the emergence of a global economy during the nineteenth century has emphasized the importance of transport innovations for creating conditions under which trading partners could take advantage of relative factor scarcities to realize benefits from trade.¹² Of course, the other major development of the late-eighteenth and nineteenth centuries was the development of technologies that could harness water power and then steam to increase productivity in a range of industries, including textiles. The availability of steam power enhanced productivity in mining, and a range of innovations in metallurgy increased the productivity of metals production several-fold. The development of these technologies opened up an immense gap between Northwest Europe and North America on the one hand, and the remainder of world, on the other. A growing literature on de-industrialization emphasizes the consequences of

¹² See Findlay and O'Rourke (2007) and O'Rourke and Williamson (1999) for two recent examples.

these changes for domestic production of textiles, for example, in lower-income economies such as the Ottoman Empire and India.

What so far has remained unexamined is the extent to which the technological gap of the industrial revolution made a positive contribution to the importing economies of the developing world. The case of Japan allows a closer look at estimating the relative importance of gains from trade arising from Heckscher-Ohlin forces of relative factor scarcity compared with the gains arising from emerging technological differences. This section presents preliminary estimates of the importance of differences in factor productivity for most of Japanese trade, which includes most of the products of the textile sector (woolen cloth, raw cotton, indigo, cotton yarn, unfinished cotton cloth), metals and minerals (pig iron, lead, kerosene) and key agricultural commodities (brown and white sugar, rice and soy beans).

As noted above, the gains from trade can emanate either from trading relatively abundant resources for relatively scarce resources or from differences in technology. In order to assess the importance of one or the other influence, we need to compute the autarky value of resources needed to produce imports using the domestic Japanese technology matrix (\mathbf{A}) and the autarky value of resources using the technologies of Japan's major importers (\mathbf{A}^*). As noted above, we can define $\lambda = \mathbf{w}^a \mathbf{A}^* \mathbf{M} / \mathbf{w}^a \mathbf{A} \mathbf{M}$ as the share of gains arising from factor exchange. Thus, $1 - \lambda$ is the share of gains arising from technological differences. This exploration of the gains focuses on industries that accounted for more than three-quarters of the factor imports shown in Table 1.

Although a net exporter of cotton at the height of the cotton famine ca. 1864-1865, Japan quickly went over to become a net importer. For the period under

consideration, China provided most of Japan's cotton imports. For the nineteenth century, Great Britain dominated the market for yarn imports into Japan. The most commonly imported yarns were in the high teens or 20s. They were often used as the warp in Japanese handlooms along with hand-spun weft. Great Britain also dominated the imports of unfinished cloth, which were primarily shirtings. These were either printed or dyed by Japanese finishers. Great Britain was also the source for Japanese imports of pig iron and other metal products (including lead). Finally, as a first approximation, most woolens imported into Japan came from Great Britain.¹³ India supplied world markets with indigo. China and the Chinese island of Formosa were the main source of Japanese imports of foodstuffs.¹⁴

Table 3 provides the domestic and foreign factor usage (a_{ij}) for the imports for which data on production technologies could be obtained. As the lower panel of Table 3 suggests, the technologies of source countries for imports used less labour for virtually all imports. White sugar and brown sugar provide the main exceptions; Formosan producers substituted unskilled male labour for the female labour used in Japan. Predictably, the western technologies used to produce woolens, cotton cloth, iron and kerosene were more capital-intensive than those used in Japan. The ability of the Chinese to use double-cropping decreased the land intensity of rice production relative to Japan. In general, most imports of agricultural raw materials were from countries using more land-intensive methods.

¹³ By the mid-1870s this was not the quite the case, as French-produced *mousseline de laine* accounted for a large share of Japanese imports of woolens. Future analysis of woolen imports will take this fact into account.

¹⁴ Buck (1930 and 1937), Wagner (1926), Tang (1924), Davidson (1903), Brooks (1898); and Manchester Chamber of Commerce (Manchester England), (1888) provide detail on production technologies for the countries providing major Japanese imports. (Clark, 1908) provides detail on production conditions in the English worsted industry. A complete accounting of sources is provided in an Appendix available from the authors.

The comparative data on technologies allow the calculation of λ for these twelve imports. As an indicator of the importance of Ricardian differences in the productivity of labour, $1 - \lambda$ ranged from almost one for pig iron and kerosene, down to a middle range of 0.4 to 0.6 for sugar and yarn, and to below 0.2 for indigo, soybeans, unfinished cloth and woolen cloth. Even within the terms of the mixed farming practiced in England, the land intensity of the production of the raw material overwhelmed the importance of technological differences.

For imports as a whole, Table 4 presents the results of calculations of λ and $1 - \lambda$ the three test years of 1865, 1868 and 1876 during which merchandise trade was either balanced or in surplus and for 1871. After 1865, the calculations of λ are relatively stable. They reflect the importance that woollens played in the volume of Japanese commodity trade and in trade in embodied inputs.¹⁵ In addition, they are driven by the rising imports of yarn, where the technological gap between Japan and Great Britain was very substantial.

About two-thirds of Japan's estimated gross gains from trade arose from the Heckscher-Ohlin forces emphasized in the economic historical literature. These differences can be reduced to differences in the relative availability of land. Up to one-third arose from differences in resource productivity. Japan's pattern of trade enabled it to take advantage of both emerging international markets in raw materials that were prompted by declines in transportation costs and of the technological innovations of the First Industrial Revolution.

¹⁵ These estimates hinge upon the degree to which woollens imported into Japan used wool from recently (re)-settled countries of the Antipodes rather than from European farms, which used fodder crops such as turnips as well as pastureland for grazing sheep.

6. Conclusions

International trade can be viewed as a transformation of exports into imports. To be welfare improving, the benefits from imports must exceed the costs of exports. Generalizing Ricardo's (1817) labour value formulation of comparative advantage to multiple factors and goods, this paper proposes a cost-benefit comparison in terms of the resources embodied in trade. An advantage of this cost-benefit formulation is that the gains from trade become an empirically testable hypothesis rather than a theoretical assumption. Furthermore, it allows for an examination of the underlying sources of the gains from trade.

We employed our Ricardian factor content characterization of the gains from trade to 19th century Japan, where we are in an unusual position to observe a market-based economy both under autarky and trade under the *ceteris paribus* assumption. We find evidence of positive gains from trade in all three sample years of balanced trade. In the final sample year of 1876, we can assert positive gains from trade without having to use autarky prices to value factor trade-offs. Furthermore, we find a strong role for factor productivity differences as a source of the gains from trade in some commodities.

Although we applied the Ricardian factor content measure to the case of Japan, this measure could be applied to other trading economies. For example, the role of technological differences as a cause of trade can be investigated in the absence of autarky price data. In cases where existing factor prices are reasonable proxies for autarky factor prices, the empirical application encompasses all the issues addressed in this paper.

Table 1 The Autarky Valuation of Japan's Factor Trade for Four Years of Trade (In Thousands of Ryō of 1851-1853)

Factor	Embodied in Imports (w^aAM)				Embodied in Exports (w^aAX)				Amount of Factor Trade $AM-AX$ (million)	Unit	Value (1,000 ryōs)
	Ag Raw	Mineral and Metal	Cot. Yarn & Cloth	Wool Cloth	Seri- culture	Tea	Other Raw and Marine	Fuel/ Mineral			
1865											
Labour male skilled	15	294	142	289	148	116	10	10	0.03	yrs	456
Labour male unskilled	47	61	186	116	604	84	26	6	-0.03	yrs	-311
Labour female	3	18	942	167	327	19	10	0	0.12	yrs	774
Capital	118	9	127	175	833	185	17	0	-2.53	ryō	-607
Land	17	1	143	67	351	91	13	0	-0.21	tan	-227
1868											
Labour male skilled	95	135	87	27	104	104	8	6	0.01	yrs	122
Labour male unskilled	313	43	175	11	417	82	30	3	0	yrs	10
Labour female	52	20	769	16	229	20	5	0	0.09	yrs	602
Capital	574	9	118	16	577	169	13	5	-0.19	ryō	-46
Land	178	0	137	6	241	82	8	0	-0.01	tan	-9
1871											
Labour male skilled	280	156	146	62	120	177	17	102	0.015	yrs	228
Labour male unskilled	1446	44	327	24	481	131	40	53	0.121	yrs	1136
Labour female	107	13	1421	36	270	31	9	4	0.221	yrs	1263
Capital	1475	8	222	38	671	284	19	241	2.20	ryō	528
Land	1326	0	257	14	279	139	13	1	1.07	tan	1165

1876												
Labour male skilled	189	564	394	880	166	248	37	59	0.09	yrs	1517	
Labour male unskilled	665	150	745	305	665	183	191	26	0.08	yrs	801	
Labour female	75	36	3314	412	381	43	20	1	0.51	yrs	3392	
Capital	1476	27	506	433	937	396	50	70	4.12	ryô	988	
Land	291	2	582	175	389	194	150	1	0.29	tan	316	

Source: Results of calculations involving the domestic technology matrix, trade flows during the four test periods and autarky factor prices.

Notes: One tan is equivalent to about one-tenth hectare. All factors are valued at factor prices prevailing ca. 1854.

Table 2: The Gains to Factor Trade for Japan in Three Years

	1865	1868	1876
Estimated addition to factor income in millions of ryō	>0.02	>1.44	>7.73
Estimated addition in ryō per capita	0.001	0.048	0.257
Addition scaled to 1851-1853 assuming 0.4 percent growth in per capita resources (Autarky to early free trade) in millions of ryō	0.001	0.046	0.212
Addition as a percent of "backcast" per capita GDP	0.02	1.19	5.50
Addition as a percent of "forecast" per capita GDP	0.04	1.81	8.60
Goods with data on technology as a percent of imports	89.2	69.3	75.5
Goods with data on technology as a percent of exports	97.7	97.9	93.7

Sources: Authors' calculations based upon Table 1 for the addition to factor income. See Bernhofen and Brown (2005) for the procedure and estimates of "forecast" and "backcast" per capita real GDP in ryō of 1851-1853.

Notes: The forecast and backcast estimates assume a growth rate of per capita GDP of about 0.4 percent. The backcast estimate of GDP per capita in 1851-1853 is 3.79 ryō and the forecast estimate is 2.47 ryō.

Table 3: The Resource Requirements for Imports into Japan

Import	Source of Imports	Skilled Male (days)	Unskilled Male (days)	Female (days)	Capital (yen)	Land (tan)
Japan(a_{ij})						
Iron products (per catty of 1.33 lbs.)		0.193	0.097	0.000	0.001	0.000
Lead (per catty)		0.726	0.538	0.663	0.019	0.000
Kerosene (per catty)		0.031	0.317	0.000	0.016	0.000
Rice (per picul of 133 lbs.)		0.606	7.996	0.844	0.185	0.251
Soy bean (per catty)		0.002	0.064	0.015	0.001	0.005
Brown Sugar (per catty)		0.041	0.254	0.027	0.075	0.003
White Sugar (per catty)		0.098	0.544	0.053	0.160	0.005
Indigo (per catty)		1.262	6.916	1.656	0.398	0.096
Cotton (per catty)		0.097	0.698	0.658	0.054	0.014
Yarn (per catty)		0.180	0.806	3.977	0.063	0.017
Unfinished Cloth (per yard)		0.010	0.046	0.410	0.004	0.001
Woolen Cloth (per yard)		0.291	0.185	0.391	0.031	0.003
Foreign(a_{ij}*)						
Iron products	Britain	0.002	0.001	0.000	0.001	0.000
Lead	Britain	0.001	0.004	0.001	0.001	0.000
Kerosene	U.S.A.	0.011	0.003	0.000	0.042	0.000
Rice	China	0.000	1.908	0.602	0.119	0.082
Soy bean	China	0.000	0.064	0.010	0.001	0.006
Brown Sugar	Formosa	0.000	0.038	0.065	0.004	0.010
White Sugar	Formosa	0.000	0.098	0.167	0.009	0.026
Indigo	India	0.106	3.141	0.731	0.126	0.266
Cotton	China	0.000	0.500	0.510	0.028	0.019
Yarn	Britain	0.010	0.423	0.583	0.027	0.044
Unfinished Cloth	Britain	0.003	0.046	0.091	0.006	0.005
Woolen Cloth	Britain	0.025	0.071	0.049	0.061	0.023
Difference (a_{ij}-a_{ij}*)						
Iron products		0.191	0.096	0.000	-0.001	0.000
Lead		0.725	0.534	0.662	0.018	0.000
Kerosene		0.020	0.314	0.000	-0.026	0.000
Rice		0.606	6.088	0.242	0.066	0.169
Soy bean		0.002	0.000	0.005	0.000	-0.001
Brown Sugar		0.041	0.216	-0.038	0.072	-0.007
White Sugar		0.098	0.446	-0.114	0.151	-0.021
Indigo		1.155	3.775	0.925	0.272	-0.170
Cotton		0.097	0.198	0.148	0.026	-0.005
Yarn		0.170	0.383	3.394	0.036	-0.027
Unfinished Cloth		0.007	0.000	0.319	-0.002	-0.004
Woolen Cloth		0.265	0.114	0.342	-0.030	-0.020

Source: The respective coefficients for foreign are from the input coefficients for the main importing country.

Table 4: The Calculation of λ for the Early Trade Period

Year	Component	Value
1865	$\lambda = w^a A^* M / w^a A M$ (relative factor scarcity)	0.86
1865	$1-\lambda = w^a (A-A^*) M / w^a A M$ (technological differences)	0.14
1868	$\lambda = w^a A^* M / w^a A M$ (relative factor scarcity)	0.57
1868	$1-\lambda = w^a (A-A^*) M / w^a A M$ (technological differences)	0.43
1871	$\lambda = w^a A^* M / w^a A M$ (relative factor scarcity)	0.62
1871	$1-\lambda = w^a (A-A^*) M / w^a A M$ (technological differences)	0.38
1876	$\lambda = w^a A^* M / w^a A M$ (relative factor scarcity)	0.67
1876	$1-\lambda = w^a (A-A^*) M / w^a A M$ (technological differences)	0.33

Source: Results of authors' calculations using the coefficients in Table 4, data on trade volumes and factor prices. For more information, please see the text.

Notes: The values in the final column are based upon the imports of the commodities in Table 3 evaluated for each trading year. The autarky wage for skilled male labour was 0.051 ryō. For unskilled male labour it was 0.0285 ryō. For female labour it was 0.0185 ryō. The price of capital was 0.24 ryō and the price of land was 1.08 ryō per tan of about one-quarter acre.

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