A Ricardian factor content characterization of the gains from trade: evidence from Japan's opening up[1]

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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 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

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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 , 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 have been rooted in the theory of consumer demand. Their empirical implementation requires either consumption data, which are rarely available, or the assumption of specific 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 the demand side of the economy. 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 the gains from trade become an empirically refutable proposition. The data could reveal that the costs from exports exceed the benefits from imports.[4] An additional feature of our approach 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 G. W. McKenzie and I. F. Pearce, "Welfare Measurement-a Synthesis," *American Economic Review* 72, no. 4 (1982) and Earl L. Grinols and Kar-yiu Wong, "An Exact Measure of Welfare Change," *Canadian Journal of Economics* 24, no. 2 (1991). for good surveys of the welfare literature.

[4] Since in Samuelson's formulation the gains are defined by the weak axiom of revealed preference, it is not clear what to refute.

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. This underlines that our measure is based on 'classical economic thinking' as 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 allows us to make causal statements on the effects of trade on aggregate economic welfare. Our empirical analysis combines trade data on Japan's early trading years with autarky factor prices data and technology data that reflect Japan's technological conditions in its late autarky period. 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 suggests a stronger role for Ricardian type technological differences than Heckscher-Ohlin type factor endowment differences as a cause of Japan's early trade. 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.

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 that technological differences played a stronger role than differences in relative factor abundance in explaining Japan's trade.

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.[5] Since then the standard characterization of the

[5] Samuelson's (1939) gains from trade piece is a follow-up of Paul A. Samuelson, "A Note on the Pure Theory of Consumer's Behavior," *Economica* 5, no. 17 (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 Paul A. Samuelson, "The Gains from Trade Once Again," *The*

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 $\mathbf{p^a}=(p_1^a,\ldots,p_n^a)$ and a consumption vector $\mathbf{C^a}=(C_1^a,\ldots,C_n^a)$. The free trade equilibrium is given by a price vector $\mathbf{p^t}=(p_1^a,\ldots,p_n^a)$ and a consumption vector $\mathbf{C^t}=(C_1^t,\ldots,C_n^t)$. In a friction-less world $\mathbf{p^t}$ is both the terms of trade and the price that producers and consumers face. The gains from trade analysis 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

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

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 $\mathbf{p^t C^t} \geq \mathbf{p^t C^a}$, Samuelson

Economic Journal 72, no. 288 (1962). and Murray Kemp, "The Gain from International Trade," *Economic Journal* 72, no. 288 (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:

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

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. Bernofen 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) is that they are rooted in consumer theory disregarding 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. Finally, since international trade is characterized by a reallocation of domestic resources where exports can be thought of being transformed into imports, it would be 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 which 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 $\mathbf{X}=(X_1,\ldots,X_n)$ and the vector of imports as $\mathbf{M}=(M_1,\ldots,M_n)$. From a cost-benefit perspective, the import vector **M** constitutes the benefits to the economy and the export vector **X** constitutes the costs compared to 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 a *n* by *k* matrix **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 **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 **M** could be produced with domestic technologies, the benefits from trade are the counterfactual resources that would have been necessary to produce the imported goods domestically, which is **AM**.

By evaluating the resource flows embodied in trade at the economy's autarky factor price vector $\mathbf{w^a}=(w^a_{1},\ldots w^a_{k})$, we obtain a cost-benefit characterization of the gains from trade:

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

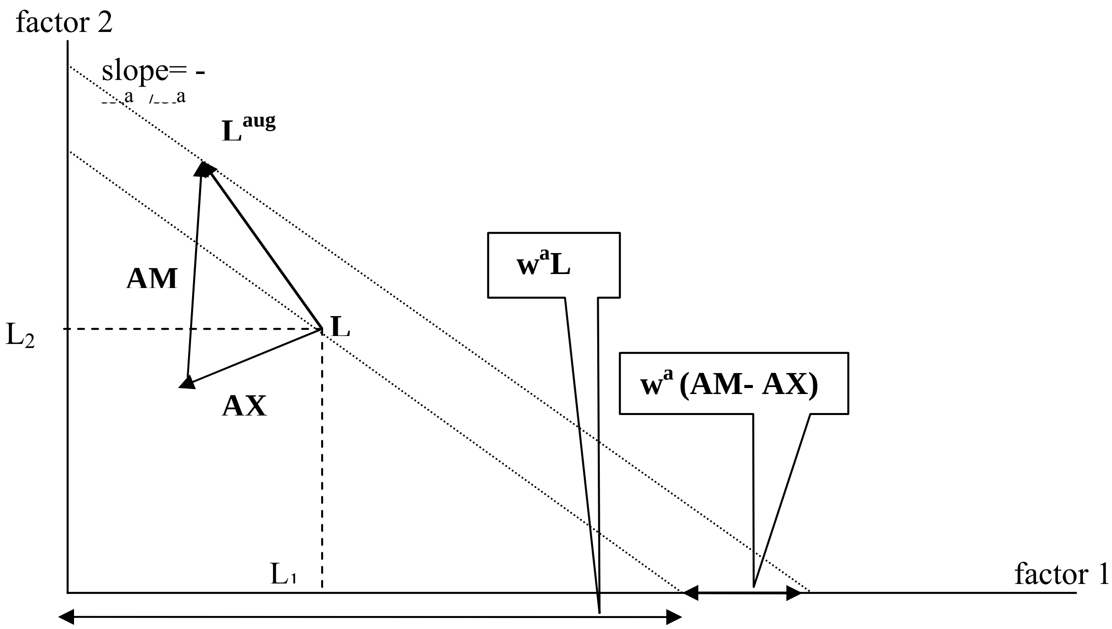
where the superscript 'FC' pertains to factor content.

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 **L** with the slope given by $-(w_1^a/w_2^a)$, we obtain an 'autarky factor income line'. Autarky factor income $\mathbf{w^aL}$ 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 $\mathbf{L^{aug}}=\mathbf{L}+\mathbf{AM}-\mathbf{AX}$. 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 **L** to the augmented endowment point $\mathbf{L^{aug}}$, or

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

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 (4) is that **AM-AX** provides a physical characterization of the sources of the gains from trade. For example, in Figure 1 a comparison of **L** and $\mathbf{L^{aug}}$ 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 have provided a characterization of the gains from trade that is based on the factor content of trade. We now show that this cost-benefit characterization of the gains from trade has a historical precedent in David Ricardo's famous passage in chapter VII of his *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 labelled "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."

Following John Stuart Mill's interpretation, 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 that restores coherence to this famous passage and is compatible with Ricardo's labour theory of value.

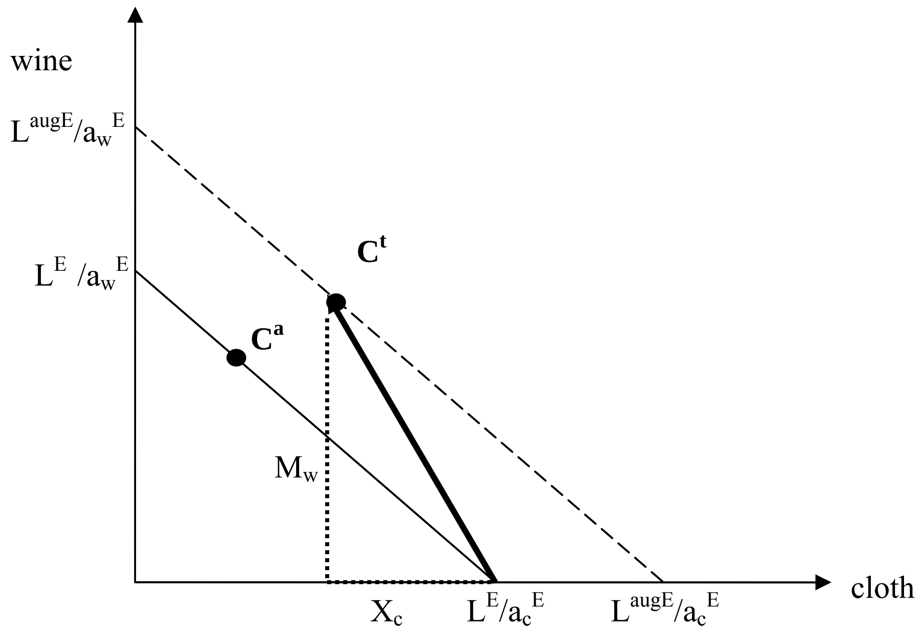
Let us illustrate that Ricardo's formulation can be viewed as a special case of (3). The first observation is that in the case of a single factor of production, the gains from trade can be measured in physical labour units; there is no need for autarky factor prices to evaluate any factor trade-off. 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 are the labour unit requirement for cloth and a_w^E are the labour unit requirements for wine. Let us 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 formulated as

$$\Delta L^E = a_w^E M_w - a_c^E X_c = 120-100 = 20, \tag{5}$$

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 to compare the Ricardian factor content formulation (5) with the consumer-based welfare measures (1) and (2). The economy's autarky consumption point is given by $\mathbf{C^a}$ and through trade the economy is able to afford a consumption point $\mathbf{C^t}$ 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 which is equivalent for the representative consumer to move between $\mathbf{C^a}$ and $\mathbf{C^t}$. 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 $\mathbf{C^t}$ could be produced with domestic technology and L^{augE}. An advantage of the Ricardian measure is that it employs trade and technology data, which are 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 countries exploiting their relative factor abundance. Two important questions arise. To our knowledge of the literature, neither has been addressed. How can we disentangle 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.

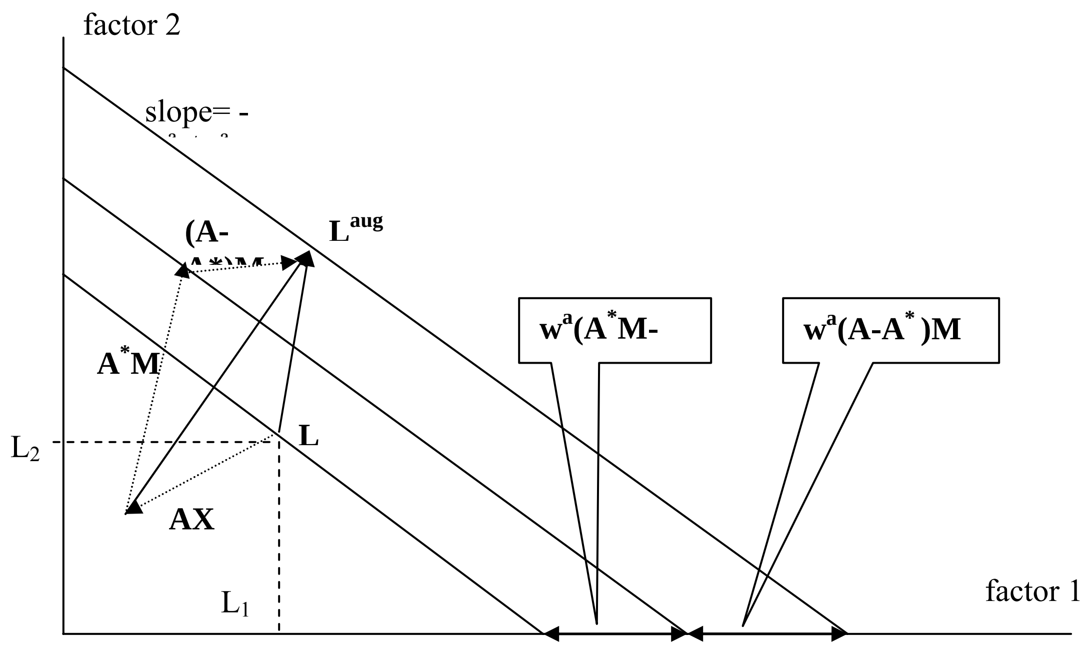
Assume now that "the" foreign technology matrix is also characterized by fixed input coefficients and is denoted by $\mathbf{A}^*$. The gains from trade can then be decomposed as follows:

$$\Delta W^{FC} = \mathbf{w^a(AM)\text{-}w^a(AX)} = \mathbf{w^a}\ (\mathbf{A} - \mathbf{A}^*)\mathbf{M} + \mathbf{w^a}\ \mathbf{A}^*\mathbf{M} - \mathbf{w^a AX}. \qquad (6)$$

The rationale behind (6) is that the gross benefit from trade $\mathbf{w^aAM}$ can be decomposed into a factor exchange component ($\mathbf{w^aA^*M}$) and a technological difference component ($\mathbf{w^a\,(A\text{-}A^*)M}$). 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 to 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 $\mathbf{L^{aug}\text{-}L}$ 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 $\mathbf{L^{aug}\text{-}L}$ have a positive sign. This scenario is depicted in Figure 3, where $\mathbf{AM}$ is decomposed into $\mathbf{A^*M}$ and $(\mathbf{A\text{-}A^*})\mathbf{M}$. $\mathbf{A^*M}$ 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 $\mathbf{L}+\mathbf{A^*M\text{-}AX}$ as the home economy trades away factor 1 for gains in factor 2. However, the vector $(\mathbf{A\text{-}A^*})\mathbf{M}$ 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 $\mathbf{L}^{aug}$-$\mathbf{L}$ are positive. The absence of factor trade-offs means that the gains from trade can, as in the Ricardian model, 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 $\mathbf{w^a A^* M} \leq \mathbf{w^a AM}$, we can define $\lambda = \mathbf{w^a A^* M / w^a AM}$ as the share of gross gains arising from pure factor exchange and $1-\lambda = \mathbf{w^a (A-A^*) M / w^a AM}$, as the share arising from differences in technology ($0<\lambda\leq 1$).

Note that λ is an aggregate measure which 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 λ=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

$\lambda>0$, a boundary case where the gains stem entirely from technological differences does not exist. In addition, we can examine the role of technological differences for a specific industry or subgroup of industries i by examining $\lambda_i = \mathbf{w^a A^* M_i} / \mathbf{w^a A M_i}$.

Alternatively, we can examine the role of technological differences in the net gains from trade. Figure 3 depicts a scenario where $\mathbf{w^a A^* M}$ is large enough to exceed $\mathbf{w^a A^* X}$. In such a case the decomposition in (6) can be interpreted as follows. $\mathbf{w^a(A^* M - AX)}$ captures the net gains from pure factor exchange and $\mathbf{w^a(A-A^*)M}$ **captures** the gains arising from pure 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, 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. The rapid opening up to trade was confirmed in 1864, when Japanese feudal lords and the Tokugawa ruler (the Bakufu) failed 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 late autarky 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 merchandise trade or a 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 (1988) 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.[6] For 1868 and later, the returns of the Meiji customs authorities are used (see Japan. Department of Agriculture and Commerce. (Noshomusho Nomukyoku), 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 (1988) argues that trade was about balanced. In addition, to illustrate the impact of the rice and soybean crop failures of 1870-1871, calculations for the calendar

[6] See C. Jacob, "Bericht Über Die Handels-Verhältnisse Von Japan," in *Die Hansastädte Und Japan, 1855-1867: Ausgewählte Dokumente*, ed. Erich Pauer and Regina Mathias-Pauer (Marburg: Förderverein Marburger Japan-Reihe, 1861)Karl Scherzer, *Fachmännische Berichte Über Die Österreichisch-Ungarische Expedition Nach Siam, China Und Japan (1868-1871.)* (Stuttgart,: J. Maier, 1872)Switzerland. Eidgenössisches Handels- und Zolldepartment. and C. Brennwald, *Rapport Général Sur La Partie Commerciale De La Mission Suisse Au Japon* (Berne,: J.A. Weingart, 1865).

year 1871 will be included as well. 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 are a lower bound.

Since Japan was a well-developed commercial economy by the time of opening up, data on technologies in use during the autarky period the **A** can be gleaned from a range of sources. Bernhofen, et. al. (2009) provides the documentation for the over 35 Japanese and western sources used to compile this information. 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, 1979).[7] 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.[8] 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

[7] 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 Penelope Francks, *Technology and Agricultural Development in Pre-War Japan* (New Haven: Yale University Press, 1984). established in her study, these innovations were introduced primarily during the 1890s and later.

[8] 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 and mulberry trees were never planted on paddy land. Instead, upland dry land was used. For these crops, the quantity of land has been adjusted downward by 25 percent, which is the discount for non-paddy land from regression analysis of land value assessment data found in Waseda Daigaku Keizaishi Gakkai, *Ashikaga Orimono Shi* (Ashikaga: Ashikaga Sen□i Dōgyōkai, 1960)., Table 23.

activities such as sorting 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, the evidence on technologies is available for virtually all of Japan's exports and 70 to 90 percent of its imports.[9]

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 late autarky 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), 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

[9] 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.

goods that may have been necessary for the tailoring of western-style garments. Jenkins (1988), Sugiyama (1988), Tamura (2004) and the reports of German, British and American consuls during the period suggest that this most likely was not the case. Most of Japan's imports of woolens 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 ($\mathbf{w^a}$) 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 (1973). Since virtually all production of tradeables took place in rural industries, only wage rates for skilled male labour are used. Suzuki (1990) is one widely-quoted source that provides wages for skilled labour. Data on rents on agricultural land are available from two sources. Waseda Daigaku Keizaishi Gakkai (1960) provides data on the valuation of agricultural land for various legal purposes. Hedonic regressions of these data found predicted land values of about 6 ryō for second-quality paddy land in 1854. The implied rents would be a maximum of 0.72 ryō.[10] Furushima and Nagahara (1954) provide a study of agricultural rents (in

[10] This estimated is based on a return of 6 percent for land commonly used at the time and the assumption that the valuation of land for legal purposes is about one-half the actual value of land.

terms of koku of rice) in the most productive area of pre-1859 Japan, the Kinai region (near Osaka). Valued at the price of rice prevailing in Osaka at the time, these rents were about 1.20 ryō. Since the average land value would be somewhat below the most productive region of Japan, a reasonable upper bound for rents was set at 1.08 ryō.[11]

3.2 Assessing the augmentation of factor endowments resulting from trade

Table 1 illustrates the calculation of the autarky valuation of the embodied resource flows **AM** and **AX** 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) 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

[11] The productivity of land in the Izumi region that provided the rent data was 87 percent above the productivity in the area around Tokyo.

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.[12] Finally, as Japan imported more sugar and cotton and woolen textiles, it saved on capital.

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

The theoretical framework provides an approach to accounting for the gains from trade that takes account of the role of trade in facilitating the international exchange of factors and technologies across international borders. 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.

[12] See Rein, (1881, p. 11) for the estimates of paddy and dryland fields in Japan ca. 1880.

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. The estimates of the autarky domestic factor usage presented in Table 1 offer one estimate that meets this condition, provided 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). 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 0.001 to 0.21 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 (Chōshu) for which estimates of per capita GDP are available. The estimates reveal a similar picture. 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.[13] 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 these changes for domestic production of textiles, for example.

[13] See Ronald Findlay and Kevin H. O'Rourke, *Power and Plenty : Trade, War, and the World Economy in the Second Millennium*, *The Princeton Economic History of the Western World* (Princeton, N.J.: Princeton University Press, 2007)Kevin H. O'Rourke and Jeffrey G. Williamson, *Globalization and History : The Evolution of a Nineteenth-Century Atlantic Economy* (Cambridge, Mass.: MIT Press, 1999). for two recent examples.

What so far has remained unexamined is the extent to which the technological gap of the industrial revolution made a positive contribution to 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 in the case of a subset 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).

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 ($\mathbf{A}(\mathbf{w}^{\mathbf{a}})$) and the autarky value of resources using the technologies of Japan's major importers ($\mathbf{A^*}$). As noted above, we can define $\lambda = \mathbf{w^a A^* M / w^a AM}$ as the share of gains arising from factor exchange. Thus, 1- λ 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 of cotton. 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). The United States provided kerosene. Finally, as a first approximation, most woolens imported into Japan came from Great Britain.[14] India supplied world markets with indigo. China and the Chinese island of Formosa were the main source of Japanese imports of foodstuffs.[15]

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[14] 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.

[15] Christopher Parkinson Brooks, *Cotton: Its Uses, Varieties, Fibre Structure, Cultivatinon and Preparation for the Market as an Ariticle of Commerce* (New York: Spon and Chamberlain, 1898); John Lossing Buck, *Chinese Farm Economy : A Study of 2866 Farms in Seventeen Localiaties and Seven Provinces in China* (Chicago: University of Chicago, 1930); John Lossing Buck, *Land Utilization in China : Statistics* (Nan-ching Shang-hai: Chin-ling ta hsüeh ; Tzu lin Hsi pao kuan, 1937)John Lossing Buck, Jinling da xue. Nong xue yuan., and Institute of Pacific Relations., *Land Utilization in China : A Study of 16,786 Farms in 168 Localities, and 38,256 Farm Families, in Twenty-Two Provinces in China, 1929-1933*, *International Research Series / Institute of Pacific Relations* (Chicago: University of Chicago Press, 1937); James Wheeler Davidson, *The Island of Formosa, Past and Present. History, People, Resources, and Commercial Prospects. Tea, Camphor, Sugar, Gold, Coal, Sulphur, Economical Plants, and Other Productions* (London and New York, Yokohama [etc.]: Macmillan & co.; Kelly & Walsh ld., 1903) ; Manchester Chamber of Commerce (Manchester England), *Bombay and Lancashire Cotton Spinning Inquiry; Minutes of Evidence and Reports* (Manchester,: [J.E.Cornish etc. etc., 1888)Qiyu Tang, "An Economic Study of Chinese Agriculture" (n.p., 1924); United States. Congress. Senate. Committee on Agriculture and Forestry., *Report of the Committee on Agriculture and Forestry on Condition of Cotton Growers in the United States, the Present Prices of Cotton, and the Remedy*, ed. States United, Cong d, and sess d, *53d Cong., 3d Sess. Senate. Rept. 986* (Govt. Print. Off., 1895) and Wilhelm Wagner, *Die Chinesische Landwirtschaft* (Berlin,: P. Parey, 1926) provide detail on production technologies for the countries providing major Japanese imports. W. A. Graham Clark, *Manufacture of Woolen, Worsted and Shoddy in France and England and Jute in Scotland*, *Special Agents Series* (Washington, D. C.: Government Printing Office, 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.

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. The main exceptions are in sugar and brown sugar, where Formosan producers substituted unskilled male labour for the female labour used in Japan. The differential for female labour is particularly striking. 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 lowered the land intensity of rice production relative to Japan. Otherwise, most imports of agricultural raw materials were from countries using more land-intensive methods.

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 wool overwhelmed the importance of technological differences.

For imports as a whole, Table 4 presents the results of calculations of λ and $1-\lambda$ for the three test years of 1865, 1868 and 1876 during which merchandise trade was either balanced or in surplus. The resulting calculations are relatively stable, and they reflect the importance that woolens played in the volume of Japanese commodity trade and in trade in embodied inputs.[16] From three-fifths to about two-thirds of Japan's estimated gross gains from trade arose from the Heckscher-Ohlin forces during the early Meiji period. These differences can be reduced to differences in the relative availability of land and capital (see Table 3). One-third or more arose from differences in resource productivity.

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. 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.

[16] These estimates hinge upon the degree to which woolens imported into Japan used wool from recently (re)-settled countries of the Antipodes rather than from European farms, which used food crops such as turnips along with relying upon pastureland.

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.

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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^a**AM**)				Embodied in Exports (w^a**AX**)				Amount of Factor Trade **AM-AX** (million)	Unit	Value (1,000 ryôs)
	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	ryô	-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	ryô	-46
Land	178	0	137	6	241	82	8	0	-0.01	tan	-9
1871											
Labour male skilled	298	166	155	66	120	177	17	102	0.02	yrs	268
Labour male unskilled	1538	47	348	26	481	131	40	53	0.13	yrs	1255
Labour female	114	14	1512	38	270	31	9	4	0.21	yrs	1364
Capital	1569	9	236	40	671	284	19	241	2.66	ryô	638
Land	1411	0	273	15	279	139	13	1	1.17	tan	1268
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
Gains 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
Gains as a percent of "backcast' per capita GDP	0.02	1.19	5.50
Gains 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. 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	0.001	0.002	0.000	0.001	0.000
Lead	Britain	0.001	0.003	0.000	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	0.848	0.532	0.004	0.018
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	0.066	0.049	0.061	0.019
				Difference (a_{ij}-a_{ij}^*)		
Iron products		0.192	0.096	0.000	-0.001	0.000
Lead		0.725	0.535	0.663	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	-0.150	0.126	0.050	-0.004
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		0.266	0.119	0.342	-0.030	-0.016

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)	0.82
1865	$1-\lambda = w^a (A-A^*) M / w^a A M$ (technological differences)	0.18
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
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.

Data Appendix: Constructing the A* Matrix

The elements of the A* matrix were constructed using the same basic procedure that was employed for constructing the A matrix. This discussion of sources focuses is organized according to the four categories of imports in Table 1. The range of sources for these estimates is disparate and reflects the rather stringent data requirements of the A matrix. Continental Europeans and Americans were focused on their relative competitive position vis-á-vis the British, and that resulted in numerous comparisons of costs. The inclusion of information on direct resource requirements, both in terms of raw materials such as coal or ore and in terms of labor occurs much less frequently in historical narratives or contemporary sources. Fortunately, this information is generally available.

Food and Agricultural Raw Materials

For the early trade period, the sources of food and agricultural raw materials were from other Asian countries.[17] The most important food imports were rice and soybeans. These imports were most important during the early 1870s, when Japan experienced a series of poor harvests. Sources indicate that most of these imports were from China, although there are some references in consular reports to imports from Indochina as well. Contemporary detailed evidence on resource used in rice and soybean production in China is relatively limited. Instead, this study relied upon the remarkably detailed surveys carried out by Buck (1930), Buck (1937) and Buck, et al. (1937) to arrive at an estimate of the use of resources. The first Buck survey covered 1,841 farms in 16 localities during the period 1921-1925; the second survey was conducted during 1929-1933 and covered 16,786 farms and 168 localities. The averages by localities were used to calculate the

[17] During the 1890s did Japan's mechanized spinning sector started to import large amounts of American cotton to be mixed with domestic and then Chinese cottons.

estimates of resource usage. As a first approximation, the average for China was used for both rice and soybeans commodities. The allocation between male and female/child labor relied upon the overall averages found in Buck (1937, Table VIII.2). The cost of capital included costs of repairs and the purchase of tools, depreciation, and the opportunity cost of capital.[18] The amount of capital per unit of rice or soybean was calculated as a weighted average of the 16 localities. The weights were the percentage of crop area devoted to the respective crop. The value of capital from the 1920s was deflated using the index for prices paid by wheat farmers found in Buck (1937, Table XI.3) and an index of industrial prices from Tang (1924).[19] The values in silver were then converted to yen of 1885. The estimates of land usage relied upon Buck's data on double-cropping found in Buck (1937, Table VII.1). Double-cropping was extensive throughout most of China.[20]

During the early trade period, China provided the main source of cotton imports into Japan. Cotton production took place across a large part of China, but most of what was produced was not marketed. This study used data only from villages where at least 14 percent of the crop was marketed. The cotton that was marketed was concentrated in three of the main regions as defined by Buck: the winter wheat-millet region, the Yangtze rice-wheat region and the winter wheat-kaoling region. A few localities from the rice-tea and double-cropping rice regions also marketed cotton, but it was much less prevalent than in the three northern regions. The Buck data from the early 1930s include the

[18] See Buck (1930, Tables III.20 and III.38) for the data on capital usage and the farming capital stock. Buck (1930, p. 20) uses an 8 percent interest rate as the opportunity cost of capital.

[19] The average of capital per unit of rice or soybean was a weighted average. The weights were the proportion of crop area devoted to the production of the commodity.

[20] The ratio of hectares in crops to hectares available for crops was 1.27 for soybean producing localities and 1.66 for rice-producing localities.

distribution of time spent for various tasks, the yield per hectare and the man hours per hectare on various crops. Although there are a few observations on lint cotton (i.e.,, ginned cotton) per hectare, most are for seed cotton per hectare. The weighted average and the median from Buck from the farms that marketed 14 percent or more were about 6.4 quintals per hectare. This is within the range of 4 to 8 quintals per hectare that (Wagner, 1926) reports based upon the pre-1914 conditions that were relayed to him by his students at the agricultural college in the German colony of Kiauchau. It is also reasonably close to the yields reported by the American consul in Ningpo during the mid-1890s (Fowler, 1895), who reported yields of lint cotton per hectare of the equivalent of 9 quintals of seed cotton per hectare.[21] Double-cropping was also extensively practiced in the regions growing cotton. Buck (1937, p. 291) notes that female labor played a smaller role in the agricultural tasks of the household than appears to be the case in Japan. The exception to this appears to be in the harvesting and ginning of cotton, which Fowler (1895, p. 243) argues was carried out by female and child labor. Buck (1937, Table VIII.10) provides the data on the allocation of time across different tasks of producing seed cotton. The average requirements of land and labor per catty of cotton were weighted by the marketed quantity per locality. Tang (1924) notes that traditional Chinese methods of ginning cotton yielded about 4.5 catties of lint cotton per day. The final total of resource requirements includes the labor expended in ginning, which was about 40 percent of the female labor required to produce one catty of cotton.

Japan imported relatively small quantities of indigo. At the opening of trade, most of this would have been from India although the importance of Central America grew by

[21] These estimates use the midpoint of the percentage of lint cotton to be obtained from seed cotton of 30 percent. See Wagner (1926).

the mid-1870s (see Simmonds, 1889, Section IV). Shortt (1862) provides a comprehensive review of the labor and land required to produce indigo in India. This information was supplemented with the estimates from McCulloch (1850) on the capital requirements for an indigo processing facility. Since the indigotin content of Japanese indigo was about one-fifteenth the content of Indian indigo, the resource requirements for Indian indigo were scaled accordingly. Sato (1915) provides the results of testing Japanese indigo, and Bloxam (1906) provides the results of tests for the indigotin content of Indian indigos.

Particularly after 1868, brown and white sugar were important imports into Japan. The main sources were apparently China. By 1875, southern Formosa accounted for almost one-half of imports. For this reason, the productivity information from the Formosan industry was used to represent the production conditions in the source country. Documentation of the Formosan industry is available from contemporary sources and recent historical research. Mazumdar (1998) provides a comprehensive review of the history of the Chinese industry. Isett (1995) summarizes most of the details of the industry, which can be supplemented by the account of Davidson (1903). Both an excellent climate and the ability to save on the costs of planting and cultivating by the process of rattooning, which involved trimming back existing plants to allow for a second and third year of growth, conferred the Formosan industry distinctive advantages in productivity.

Mineral Products and Metallurgy

Mineral products and pig iron and iron manufactures were not very important during the first years of Japan's open trade. Nevertheless, it was here that the contrast between Japanese and foreign technologies were potentially extreme. Japan used imported lead for both packaging tea for export and for military purposes. The main source of imported lead was Great Britain. Details on the labor and capital requirements for lead mining are available for two productive lead mines in Cornwall from Spargo (1865). Kerl, et al. (1868) provides a summary of the resource costs of smelting and refining lead ore.

Another mineral import was kerosene. The main source of kerosene was the nascent oil industry of the United States. The two steps of kerosene production are drilling an oil well and then refining the oil. Morris (1865) provides the detail on the costs of drilling an oil well in the Pennsylvania/West Virginia oil region in the mid-1860s and Gesner (1865) provides information on the investment and then running costs of an oil refinery.

Finally, Great Britain was the primary supplier of pig iron and iron manufactures to Japan during the early trade period. When more detail becomes available in the Meiji records in the early 1870s, it is apparent that a good share of the iron manufactures were nail or nail iron. At this juncture, only reasonable estimates of the resource cost for producing pig iron are available from contemporary sources. The sources used for pig iron include descriptions of mining iron ore, producing coal and coke and smelting the iron ore into pig iron. The main source for estimating resource requirements was Schoenhof (1886). Additional information on the breakdown of skill requirements is from the detail on firms provided by Wright (1891) for pig iron production. Schoenhof (1886) also provides evidence on the labor and other costs of mining coal and iron ore in Great Britain. These estimates can be compared with the material from Wright (1891).

The final sectors for imports were also some of the most important during the first few decades after Japan opened up to trade. The first sector is cotton textiles, where it rapidly became clear that Japan offered a market for yarn, unfinished cloth and finished cloth. The primary source for all of these goods was Great Britain. The typical yarn import was in relatively low counts, with an average of about 20s. This yarn was usually spun with either Indian cotton or a blend of Indian and American cotton. The most important imported unfinished cotton cloth was shirtings, which was usually made with a 30s or 40s yarn. Documentation for the resource costs of growing cotton in India is from many sources (see Baden-Powell, 1872; Barber, 1866;Mackay and Robertson, 1853; Medlicott, 1862; Powell, 1868 and Wheeler, 1862). Resource requirements were typically expressed in terms of the number of days of labor required to perform different tasks. As in China and Japan, it appears that women and children provided the main labor for picking cotton. Observers noted that Indian cotton ripened in an irregular manner, which meant that the same field was picked numerous times. It appears that the share of harvest labor in the overall labor requirements were higher than in China or Japan. Estimates of the ratio of seed to lint cotton were about 4:1 (see Medlicott, 1862). Ginning in India was with a hand-held churka. Although some sources suggest that only women and children were involved in ginning cotton, others mention the employment of men as well. The estimates for Indian cotton assume that the labor force was one-half male and one-half women (and children). For the United States, the estimates of the resource cost of producing cotton are from post-Civil War sources. These are particularly helpful in describing the capital required. The two main sources for this information were Barber (1866) and Lyman (1868). Additional detail on the technology used for ginning cotton prior to the introduction of the steam engine in the American south was provided by Brooks (1898).

The resource requirements of the British cotton and spinning weaving industry are available from several sources. A study of the Manchester Chamber of Commerce from the mid-1880s (Manchester Chamber of Commerce, 1888) provides detailed information on the resource requirements for spinning number 20s yarn (the main cotton yarn imported into Japan. The weaving industry is well-documented by Schulze-Gaevernitz (1892) and Shepard (1882). Another traditional source is Ellison (1886). Most British cotton (and woolen) spinning and manufacturing firms relied upon steam power. In the event the source did not provide information on the consumption of coal, the estimate of 10 pounds of coal per horsepower per hour found in Jevons and Flux (1906) was used.

Accounting for the foreign resource requirements for Japan's substantial imports of woolens pose an unusual set of challenges. By weight, wool was the most land-intensive resource embodied in Japanese imports. A pound of wool washed for final use in spinning woolen or worsted yarn required from an estimated 0.2 acres of land in England to 1.5 acres of land in Australia. A pound of ginned cotton ready for use in the mill required perhaps one-half acre for 100 lbs. if it were grown in the United States. For this reason, two characteristics of imported woolen cloths are critical for a reasonably accurate assessment of resources actually imported: the construction of the cloth (its weight and fiber content) and the source of the wool used in the cloth. At one extreme are all-woolen cloths. Heavy woolen cloth for uniforms, for example, could weigh up to 0.83 pounds per square yard. At the other extreme were light fabrics made a cotton warp and worsted yarn. A cloth such as an Orleans or lustre would weigh perhaps one-fifth pound per square yard, with only one-half of the weight in worsted yarn.[22] Cloths in- between included cloths made of a mixture of wool and cotton yarn and all-worsted cloths, such as *mousseline de laine* (“worsted muslin”), which made up a large share of woolen cloth imports into Japan by the mid-1870s.

As a first approximation, the main imports during the earliest period of open trade subject to analysis (1865) were camlets and some woolens. By the end of the period, *mousseline de laine* dominated imports. In the initial estimates presented in the paper, the resource requirements for all-worsted *mousseline de laine* were used. Detailed data on the British worsted industry is available from the account of the United States Special Agent, William Graham Clark (Clark, 1908). Clark provides information on labor, capital and other resources at all stages of production of worsted cloth. Additional information on cloth characteristics is available from Clark’s report, the study of the United States Tariff Commission from about the same time (United States. Tariff Board., et al., 1912), the detailed study of production conditions in the United States, Great Britain and continental Europe conducted by the United States Commissioner of Labor Carroll Wright (United States. Dept. of Labor., 1892) and the review of the impact of Russian tariff proposals on British exports of woolens (Mitchell, 1869, pp. 111-113) . Finally, Rondot (1847) provides the details on camlets, which were a staple of the east Asian woolen trade up through the late 1860s.

At the time of the Japanese opening up, about one-half of the wool used in British woolens was produced in Britain; the remainder was imported primarily from Australia.

[22] Woolen cloth is made with carded wool. After it is woven, it is subject to the process of fulling. Worsted cloth is made with combed wool. Unlike with woolens, the finishing process attempts to maintain the uneven texture of the yarn. If only because of the difference in yarn and finishing, worsted cloths are much lighter than woolens.

European producers of woolens relied upon a blend of domestic wools, wool from Argentina (and later Uruguay). The preliminary estimates presented in the paper assume that worsted cloth was produced in Britain using only British wool. The direct resource requirements for raising sheep for Britain are from Sinclair (1898) for a 500-acre farm. Even in the case presented by Sinclair, it is not straightforward to identify all of the resource requirements, since sheep raising also involved feeding with turnips and other crops. Additional labor was expended in washing sheep, shearing sheep and then packing the wool clip. Opinions were mixed on the labor required to perform these tasks. This study used the estimates provided by Stephens and Macdonald (1908, pages 440 and 446). The technology of raising sheep in Argentina and Australia was more straightforward, since the industries of both countries used only pasture land during the period in question. Carrow (1865) and Kenworthy (1865) provide the accounts of Argentinian and Australian sheep raising.

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