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Abstract

We propose a normative assessment of the value of international trade that is rooted in production theory and embeds Ricardo's 1817 formulation of the gains from trade into a multi-factor general equilibrium framework. Without imposing strong assumptions on consumer rationality or data from the economy's autarky equilibrium, our formulation reveals information about both the magnitude and the sources of the gains from trade. A high quality data set on product and task-specific factor employments in 19th-century Japan permits us to apply this approach to answer the following counterfactual: What factor augmentation would have been necessary to compensate the economy for an overnight suspension of trade in its early trade years of 1865-1876? Over the entire period, we find that trade was revealed to be equivalent to a 5.5% increase in Japan's female labour force, a 3.3% increase in its male labour force and a 3.9% increase in its arable land. Efficiency losses associated with a counterfactual suspension of trade averaged between 6.3 and 7.7 percent of the economy's productive capacity.

JEL-Code: F110, F140, N100, N750.

Keywords: gains from trade, factor augmentation equivalent to trade, natural experiment of Japan.

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1. Introduction

One of the oldest debates in economics is the existence and nature of the benefits of international trade. This debate is closely related to whether competitive market forces allocate resources in the “right direction”. Three fundamental questions. First, how does one value an economy’s international trade? Second, does international trade have a positive value to the economy? Finally, since we almost never observe a market economy in the absence of international trade, how can we empirically construct a counterfactual statement about the value of international trade? We use these three questions as an organizing principle to highlight the contributions of this paper.

We suggest a factor augmentation formulation of the gains from trade in which an economy’s factor content of trade -constructed by evaluating import and export flows with the economy’s domestic technologies- serves as a sufficient statistic for causal inference about the existence, magnitude and sources of the gains from trade.[3] The central idea is that an economy’s factor content of trade reveals information about the augmentation of resources that would be necessary for the economy to attain free trade consumption with domestic production techniques in a “trade-equivalent autarky equilibrium.”[4] An attractive feature of this formulation is that it imposes no restrictive assumptions on

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[3] Chetty (2009) provides an excellent survey of the “sufficient statistic approach” for welfare statements in the public economics literature. We are aware of two applications in the trade literature. Arkolakis, Costinot et al. (2009) identify two macro-level 'sufficient statistics' to estimate the gains from trade under different model specifications. However, these estimates are based on strong symmetry assumptions and functional forms on consumer utility and import demand systems. Bernhofen and Brown (2005) use autarky goods prices as a sufficient statistic for estimating comparative advantage gains from trade. Those estimates rely upon the assumption of a representative consumer who follows the weak axiom of revealed preferences.

[4] The concept of an ‘equivalent autarky equilibrium’ (denoted without the prefix ‘trade’) goes back to Deardorff and Staiger (1988), who show that the factor content of trade can be used to examine the effects of trade on factor prices. Deardorff (2000) provides a generalization. More recently, Burstein and Vogel (2011) extend this framework to imperfect competition and heterogeneous firms. However, none of these papers link the factor content of trade to the aggregate gains from trade.

consumer behaviour and does not necessarily require data from an economy's autarky equilibrium. Applying our framework to a unique historical data set on product and task-specific factor employments of 19th century Japan, we provide causal evidence of gains from trade that result from an augmentation of all factors of production. We are also able to answer the following counterfactual: What factor augmentation would have been necessary to compensate the economy for a sudden suspension of trade during the period 1865-1876? Calculation of the economy's factor content of trade reveals that the average annual benefit of trade was equivalent to a 5.5 percent increase in Japan's female labour force, a 3.3 percent increase in its male labour force and a 3.9 percent increase in its arable land.

Since the "real costs" of goods are the resources embodied in them, international trade can be viewed as an exchange of factor services within a cost-benefit framework. The costs of 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. A careful reading of Ricardo suggests that he used this cost-benefit perspective in his famous 1817 paragraph on comparative advantage. Our gains from trade characterization offers a generalization of Ricardo's labour value formulation to the case of multiple factors. This approach allows for the possibility that the costs of exports may exceed the benefits from imports. Rather than arising from a theoretical assumption, the gains from trade become an empirically refutable proposition.

Existing characterizations of the gains from trade are rooted in classical consumer utility or revealed preference theory. However recent research in behavioural economics has accumulated a large body of evidence questioning the conventional assumptions about preference satisfaction.[5] In light of this evidence, it is desirable to have a normative formulation of the gains from trade that does not depend on strong assumptions about the preferences of a representative consumer. We offer a normative assessment that casts the value of international trade as a change in the endowment constraints that the economy faces, rather than as a change in the extent to which preferences are satisfied.[6] The factor content of trade serves as a sufficient statistic for a precise welfare statement without imposing any restrictions on the demand side of the economy. From a formal general equilibrium perspective, the economy's factor content reveals information about a trade-equivalent autarky equilibrium: an equilibrium constructed by augmenting factor endowments such that free trade consumption can be obtained by domestic production.

Our formulation does not presuppose any particular mechanism generating international trade. Instead, the pattern of an economy's factor augmentation through trade can provide information on the main determinants of trade. If trade is governed primarily by endowment differences, as suggested by the Heckscher-Ohlin model, the factor content of trade should reveal a factor trade-off; the economy experiences an increase in some factors at the cost of giving up some others. If technological differences exert a dominant influence, it is possible that the all factors are augmented. The pattern of the factor augmentation will determine how the gains from trade can be measured. If trade implicitly augments all factors, the existence and magnitude of the gains can be uniquely determined without reference to any factor valuation and can instead be expressed in terms of the economy's endowment

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[5] See Sugden (2004) for a summary of the empirical evidence against rationality-based models and the problems it creates for welfare analysis. Three prominent issues are: (i) random variation of preferences, (ii) reference-dependent preferences and (iii) shaping effects in subjective valuations.

[6] On a fundamental level, our welfare criteria emphasizes the expansion of choices that result from relaxing the economy's aggregate endowment constraints. Our approach is reminiscent of Bernheim and Rangel (2007), who suggest normative frameworks that are rooted in the freedom of choice, but do not require coherence of preferences.

vector. In the case of a factor trade-off, information about the value of factors is required both to establish whether gains from trade exist and if they do, how large they are.

We introduce factor income equivalent and compensating measures of the gains from trade that can be thought of as duals to the well-known Slutsky expenditure measures of the gains from trade. We show that our factor income equivalent measure is an upper bound to the corresponding Slutsky equivalent variation measure and that our factor income compensating measure is a lower bound to the corresponding Slutsky compensating variation measure of the gains from trade. In addition, our factor augmentation formulation of the value of international trade can be expressed in terms of the resource inefficiency of the economy's autarky equilibrium relative to its trade-equivalent-autarky equilibrium. The degree of inefficiency can be quantified by Debreu's (1951) coefficient of resource utilization, where the loss of resource utilization stems from the inefficiency of economic organization resulting from the imposition of prohibitive import tariffs cutting off all international trade.[7]

Since our framework requires only data on factor prices, domestic technologies and trade flows, it has the potential for a broad domain of empirical applications. In this paper, we apply it to a high quality data set on product-specific factor employments in 19th century Japan. There are several attractive features of our empirical setting. Bernhofen and Brown (2004 and 2005) present evidence that during the decade of autarky and the first few decades of open trade, the Japanese economy falls in the domain of a neoclassical economy producing relatively homogeneous products characterized by perfect competition. Because of limited technological change during the first decades after the economy's opening up, we can calculate the factor content of virtually all of Japan's exports using a

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[7] Although Debreu (1951, p. 286) mentions a potential application of his resource utilization measure for an economy that applies a system of tariffs, we are not aware of any paper applying his measure to the gains from trade.

single factor employment matrix. In addition, since Japan by and large imported goods that were very close substitutes for domestically produced goods, we are able to calculate the vector of factors that would have been necessary to produce the imported goods with domestic production techniques.

The case of 19th-century Japan offers another advantage: we can observe factor prices under both autarky and free trade. This historical circumstance allows us to calculate both the compensating and equivalent variation measures of our factor income approach to the gains from trade. We can also make a direct comparison with the consumption equivalent variation measure of gains presented in Bernhofen and Brown (2005). Both empirical exercises are supportive of our alternative characterization of the gains from trade.

2. Conceptualizing the benefits from trade: from consumption to production approaches

To put our characterization of the welfare effects of trade into perspective, we start out by briefly reviewing the existing consumer based measures of the gains from trade. We then introduce our factor content characterization in two alternative settings.

2.1 Samuelson's gains from trade formulation

The current neoclassical characterization of the gains from trade is rooted in Samuelson's seminal 1939 contribution Samuelson (1939). In that paper, Samuelson theoretically proved the existence of the gains from trade and also linked his characterization of the gains from trade to the weak axiom of revealed preference.[8] Since then, the standard interpretation of the gains from trade involves a welfare comparison of the consumption level of a representative consumer under autarky and trade.[9]

[8] Samuelson (1939)'s gains from trade article follows up on Samuelson (1938), which introduces the concept of the weak axiom of revealed preference. This axiom allows for the formulation of the theory of demand without relying on the concept of utility. Subsequent papers by Samuelson (1962) and Kemp

Consider a small competitive economy that produces the same *n* goods under autarky and trade. The autarky equilibrium is characterized by an n-vector of autarky prices $\mathbf{p}^a$ and an n-vector of consumption $\mathbf{C}^a$. The free trade equilibrium is given by n-vectors of prices $\mathbf{p}^t$ and consumption $\mathbf{C}^t$. Samuelson (1939) showed that competitive producer behaviour and balanced trade imply that $\mathbf{p}^t\mathbf{C}^t \geq \mathbf{p}^t\mathbf{C}^a$. The consumption welfare measures of the gains from trade essentially capture "the distance" between $\mathbf{C}^a$ and $\mathbf{C}^t$ in expenditure equivalents. Using free trade prices $\mathbf{p}^t$ as the evaluation criterion gives the Slutsky compensating variation measure of the gains from trade:

$$\Delta I^{CV} = \mathbf{p}^t\mathbf{C}^t - \mathbf{p}^t\mathbf{C}^a. \qquad (1)$$

ΔI^{CV} is interpreted as the change in income necessary to compensate the representative consumer for the suspension of trade. Alternatively, using autarky prices $\mathbf{p}^a$ as the evaluation criteria, one obtains the Slutsky equivalent variation measure of the gains from trade:

$$\Delta I^{EV} = \mathbf{p}^a\mathbf{C}^t - \mathbf{p}^a\mathbf{C}^a. \qquad (2)$$

Taking autarky at the reference point, ΔI^{EV} is the change in income that would enable the representative consumer 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.

[insert Figure 1 here]

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

[9] By taking consumption as the primitive, we focus on the revealed preference approach to consumer demand that corresponds to the Slutsky income characterization of a welfare change. Alternatively, one could take utility as the primitive which corresponds to the Hicksian income characterization of a change in welfare.

Figure 1 illustrates both measures. Since (1) and (2) require aggregate consumption data under both autarky and trade, which are usually not available, they are difficult to implement empirically.[10] However, if data on autarky goods prices are available, Bernhofen and Brown (2005) have shown that the economy's net import vector evaluated at autarky prices provides an upper bound for the Slutsky equivalent variation measure (2). Applying this logic to autarky prices and data flows for 19th century Japan, they find an upper bound on the gains from trade of about 9 percent of GDP.

2.2 A factor augmentation equivalent to trade

As Figure 1 shows, the Slutsky compensation measures (1) and (2) use goods prices as metrics to capture the distance between the autarky and free trade consumption vectors $\mathbf{C}^a$ and $\mathbf{C}^t$. Alternatively, instead of focusing on the changes in income necessary to afford consumption levels in autarky and free trade, we can compare the amount of resources necessary to produce the autarky and free trade consumption vectors $\mathbf{C}^a$ and $\mathbf{C}^t$.

Assume the economy is able to produce *n* goods from *k* primary factors of production. Denote the k-vector of the economy's factor endowments by **L**. An *n x k* matrix **A** describes the economy's domestic technology under trade, where an entry a_{ij} denotes the number of units of factor *i* necessary to produce one unit of good *j*.[11] Full employment implies that $\mathbf{L}=\mathbf{AY}^t$, where $\mathbf{Y}^{\mathbf{t}}$ is the n-vector of production in the trade equilibrium. International trade enables the economy to separate consumption from

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[10] The general lack of output data also prevents one from inferring consumption from output and trade data.

[11] Unless technologies are characterized by fixed input coefficients, the unit input requirements will depend on factor prices. In our notation **A** includes the optimal techniques in the trade equilibrium and we suppress the dependence on factor prices. Of course, **A** includes both indirect and direct factors required to produce each good j. Note that this discussion of **A** refers to tradable goods.

production, with the difference being the economy's net import vector, defined as $\mathbf{T}$=$\mathbf{C}^t$-$\mathbf{Y}^t$. The *k*-vector of factor prices in the trade equilibrium is denoted by $\mathbf{w}^{\mathbf{t}}$.

Starting from the economy's trade equilibrium, we can consider the following counterfactual. Assuming trade were suspended, by how much would the economy's endowment vector have to be augmented for the economy to produce the consumption vector $\mathbf{C}^{\mathbf{t}}$ using domestic production techniques? Obviously, the augmented endowment vector $\mathbf{L}^{\mathbf{aug}}$ is given by $\mathbf{L}^{aug}$=$\mathbf{AC}^t$, which implies that the corresponding augmentation of resources must be $\Delta\mathbf{L}=\mathbf{L}^{aug}-\mathbf{L}$. A great advantage of this formulation is that the factor augmentation is revealed by the domestic factor content of the economy's net import vector, which follows from $\Delta\mathbf{L}=\mathbf{L}^{aug}-\mathbf{L}=\mathbf{AC}^{\mathbf{t}}-\mathbf{AY}^{\mathbf{t}}=\mathbf{AT}$.

Let us now split the economy's net import vector $\mathbf{T}$ into two components. $\mathbf{M}$ denotes the vector of imports and $\mathbf{X}$ denotes the vector of exports. Accordingly, the domestic technology matrix can then be written as $\mathbf{A}=(\mathbf{A}^m,\mathbf{A}^x)$, where $\mathbf{A}^m$ is the matrix of domestic total factor requirements of imports and $\mathbf{A}^x$ is the matrix of total factor requirements of exports. The "factor augmentation equivalent to trade" can then be written as:

$$\Delta\mathbf{L}=\mathbf{L}^{aug}-\mathbf{L}=\mathbf{A}^m\mathbf{M}-\mathbf{A}^x\mathbf{X} \tag{3}$$

Intuitively, (3) conceptualizes the gains from international trade in terms of a cost-benefit framework. Exports are the costs of international trade since they result in resource outflows that are captured by the factor content of exports, defined as $\mathbf{A}^x\mathbf{X}$. Imports are the gross benefits from trade. Under the assumption that the import vector $\mathbf{M}$ could have been produced with domestic technologies, the gross benefits from trade are the counterfactual resources that would have been necessary to produce the imported goods domestically, or the vector $\mathbf{A}^m\mathbf{M}$. The resulting *net benefit* from trade is then simply $\mathbf{A}^m\mathbf{M}-\mathbf{A}^x\mathbf{X}$. Trade is equivalent to augmenting the domestic endowment vector from $\mathbf{L}$ to $\mathbf{L}^{aug}=\mathbf{L}+\mathbf{A}^m\mathbf{M}-\mathbf{A}^x\mathbf{X}$.

[insert Figure 2 here]

So far we have only demonstrated that $\mathbf{C}^{\mathbf{t}}$ can be feasibly produced with the augmented endowment vector $\mathbf{L}^{\mathbf{aug}}$. We now establish that $\mathbf{C}^{\mathbf{t}}$ can be the production outcome of a competitive equilibrium. We proceed by introducing the concept of a trade-equivalent autarky equilibrium:

Definition: A trade-equivalent autarky equilibrium is an equilibrium that would arise if trade were suspended, but if the economy's endowment vector were augmented to $\mathbf{L}^{\mathrm{aug}} = \mathbf{L} + \mathbf{A}^{\mathrm{m}}\mathbf{M} - \mathbf{A}^{\mathrm{x}}\mathbf{X}$.

Given a trading equilibrium where the economy is incompletely specialized, Deardorff and Staiger (1988) have shown that a trade-equivalent autarky equilibrium exists such that the economy's augmented endowment vector $\mathbf{L}^{\mathrm{aug}}$ will produce the free trade consumption vector $\mathbf{C}^{\mathrm{t}}$ with domestic technologies and the same goods and factor prices $\mathbf{p}^{\mathrm{t}}$ and $\mathbf{w}^{\mathrm{t}}$ as in the trade equilibrium.[12] Figure 2 depicts the autarky equilibrium, the trade equilibrium and the trade-equivalent autarky equilibrium in a single diagram. Factor augmentation results in production possibilities that are associated with an augmented production possibilities frontier (PPF), denoted by PPF($\mathbf{L}^{\mathbf{aug}}$). In the trade-equivalent autarky equilibrium, consumption coincides with production $\mathbf{C}^{\mathbf{t}}$ and is tangent to $\mathbf{p}^{\mathbf{t}}$ on the augmented PPF($\mathbf{L}^{\mathbf{aug}}$). The resource augmentation formulation exploits the fact that the economy's trade vector (X_1 ,M_2) evaluated at the corresponding factor input requirements contains all the relevant information about the difference between the resources embodied in $\mathbf{C}^{\mathrm{t}}$ and $\mathbf{Y}^{\mathrm{t}}$. The factor content of trade described in this way can be thought of as a sufficient statistic for a factor augmentation equivalent to trade with the

[12] The proof requires two parts. We have already shown the first part, which is that $\mathbf{C}^{\mathrm{t}}$ is feasible to produce. Second, it requires that $\mathbf{C}^{\mathbf{t}}$ maximizes profits. For the proof of the second part we refer the reader to Deardorff and Staiger (1988, p. 96) equations (2.8) and (2.9), since a replication would require us to introduce additional notation.

added empirical virtue that the construction of this sufficient statistic requires only data that are observed in the trade equilibrium.

2.3 Ricardo's 1817 formulation of the gains from trade

Our factor augmentation equivalent to trade can be viewed as a formalization of the 18th century rule of the gains from trade: "[I]t pays to import commodities from abroad whenever they can be obtained in exchange for exports at a smaller real cost than their production at home would entail " Viner (1937, p. 440). In a recent paper, the historian of economic thought Andrea Maneschi (2004) has argued that David Ricardo followed this 18th century rule in his famous 1817 passage on the gains to be secured from 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 italics):

> "England may be so circumstanced, that to produce the cloth may require the labour of *100* men for one year; and 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. (Ricardo (1817, p. 82))"

Following John Stuart Mill's interpretation, trade theorists have usually 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 emphasize 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 infer England's pattern and gains from trade 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.

Drawing upon 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.[13] In light of this interpretation, Ricardo's gains from trade formulation is a special case of (3). If labour is the only factor, ΔL becomes a scalar and can be thought as a "labour growth equivalent to trade." Applying Ricardo's passage to Figure 2, assume that England exports X_1 units of cloth and imports M_2 units of wine.[14] Ricardo's assertion that "the cloth may require the labour of 100 men" implies that $100=a_1^E X_1$ and his assertion that "if she attempted to make the wine, it might require the labour of 120 men" implies that $120=a_2^E M_2$. England's gains from trade can then be expressed as $\Delta L^E = a_2^E M_2 - a_1^E X_1 = 120-100$ or, as Sraffa (1930, p. 54) put it, England "gains the labour of 20 Englishmen." Analogously, gains from trade for Portugal(P) can be written as $\Delta L^P = a_1^P X_1 - a_2^P M_2 = 90-80$ and "Portugal gains the labour of 10 Portuguese" (see Sraffa (1930, p. 54)).[15] Given the four data points in Ricardo's famous paragraph, Sraffa argues that Ricardo measures the welfare benefits from trade essentially as an increase of 20 workers in England and an increase of 10 workers in Portugal.

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[13] Bernhofen (2009) argues further that the labour content interpretation yields a pattern of trade prediction which restores coherence to this famous passage and is also compatible with Ricardo's labour theory of value.

[14] In what follows, superscripts E and P on input coefficients and endowments pertain to England and Portugal.

[15] If the terms of trade is such that $X_1=M_2=1$, then Sraffa's and Mill's interpretations coincide.

2.4 Measuring the benefits of the factor augmentation

In the Ricardian model, the factor augmentation equivalent is a scalar and the value of trade can be expressed as the equivalent of an increase in a single factor. Even in a world with two or more factors, the factor augmentation approach allows for the possibility that a metric may not be required to assess the value of international trade to an economy. In addition, this approach has the potential to reveal whether trade offers any gains to an economy and it offers clues about the sources of gains (or losses).

Figure 3 illustrates the two-factor case where the economy's endowment vector **L** partitions its endowment space into four quadrants: I, II, III and IV. If $\mathbf{L}^{\mathbf{aug}}$ is revealed to fall in either quadrant I or III, the existence and the composition of the gains (or losses) from trade can be expressed without the need of a metric. For example, if $\mathbf{L}^{\mathbf{aug}}$ falls in quadrant I, the economy implicitly gains in both factors. In this case of unambiguous gains from trade, the vector $\Delta\mathbf{L}$ also provides information on the importance of individual factors for the overall gains and the gain in any factor *i* can be expressed as a percentage increase in the economy's endowment L_i. This case also is consistent with productivity differences being primarily responsible for the gains from trade. If $\mathbf{L}^{\mathbf{aug}}$ falls in quadrant III, the economy experiences unambiguous losses from trade. Economic theory suggests that terms of trade effects, externalities or government-induced distortions could result in this outcome. Since trade could take the economy into quadrant III, the existence of gains from trade becomes an empirically refutable proposition. [16]

[16] If there are more than two factors, quadrant I corresponds to the economy gaining in all factors, quadrant III to the economy losing in all factors and quadrants II and IV 'merge' to the case of the economy gaining some and losing other factors.

Two cases—$\mathbf{L}^{aug}$ falls either in quadrant II or IV—offer ambiguous results on the gains from trade without further information. In these two cases, the factor augmentation approach suggests that trade involves a tradeoff of one factor for another and that Heckscher-Ohlin forces are at work. Additional information in the form of a metric is required to establish whether trade leads to gains or losses for an economy and how large (or small) they may be.

[insert Figure 3 here]

Recall from (3) that $\mathbf{L}^{aug}$ is constructed by adding the factors that would have been necessary to produce the economy's import vector counterfactually at home $\mathbf{A}^{m}\mathbf{M}$ to the economy's endowment and then subtracting the factors embodied in the economy's export vector $\mathbf{A}^{x}\mathbf{X}$. A comparison of the autarky equilibrium ($\mathbf{L}$,$\mathbf{C}^{\mathbf{a}}$,$\mathbf{w}^{\mathbf{a}}$,$\mathbf{p}^{\mathbf{a}}$) with its trade-equivalent autarky equilibrium ($\mathbf{L}^{aug}$,$\mathbf{C}^{\mathbf{t}}$,$\mathbf{w}^{\mathbf{t}}$,$\mathbf{p}^{\mathbf{t}}$) provides a way to analyze the value of trade.[17] The resource constraints corresponding to these two equilibria -$\mathbf{L}$ and $\mathbf{L}^{\mathbf{aug}}$ - are at the heart of the comparison. Note that a competitive equilibrium can be replicated by a constrained optimization problem in which the social planner faces the resource constraints $\mathbf{L}$ and $\mathbf{L}^{\mathbf{aug}}$. In this context, the economy's corresponding factor price vectors $\mathbf{w}^{a}$ and $\mathbf{w}^{\mathbf{t}}$ are equal to the shadow prices at which the planner evaluates any changes in the economy's resource constraints. Starting from the autarky equilibrium, the social planner will view a change in the resource constraint from $\mathbf{L}$ to $\mathbf{L}^{\mathbf{aug}}$ as beneficial only if $\mathbf{w}^{a}(\mathbf{A}^{m}\mathbf{M})>\mathbf{w}^{a}(\mathbf{A}^{x}\mathbf{X})$. In this case, the net gain from the resource exchange is $\mathbf{w}^{a}(\mathbf{A}^{m}\mathbf{M})$-$\mathbf{w}^{a}(\mathbf{A}^{x}\,\mathbf{X})$.[18] With this in mind, we can define a dual to the Slutsky equivalent variation measure (2): the *increase* in factor income that would be equivalent to obtaining the augmented endowment point $\mathbf{L}^{aug}$ at the autarky factor prices $\mathbf{w}^{a}$. This factor income equivalent measure, denoted by ΔL^{EV}, is given by:

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[17] The k-vectors $\mathbf{w}^{\mathbf{a}}$ and $\mathbf{w}^{\mathbf{t}}$ are factor prices in the autarky and trade equilibrium, respectively.
[18] An attractive feature of the shadow price interpretation associated with changes in the resource constraints is that social welfare gains can be expressed without knowledge of the consumption objectives of the society (see Dixit (1990, p. 43)).

$$\Delta L^{EV} = \mathbf{w}^a\mathbf{L}^{\mathbf{aug}} - \mathbf{w}^a\mathbf{L} = \mathbf{w}^a(\mathbf{A}^m\mathbf{M}) - \mathbf{w}^a(\mathbf{A}^x\mathbf{X}). \quad (4)$$

Alternatively, if the social planner starts from the trade-equivalent autarky equilibrium, a change in the resource constraint from $\mathbf{L}^{\mathbf{aug}}$ to $\mathbf{L}$ is viewed as a loss only if $\mathbf{w}^t(\mathbf{A}^m\mathbf{M}) > \mathbf{w}^t(\mathbf{A}^x\mathbf{X})$; here, the net loss would equal $\mathbf{w}^t(\mathbf{A}^m\mathbf{M}) - \mathbf{w}^t(\mathbf{A}^x\mathbf{X})$. Accordingly, we can define a dual to the Slutsky compensating measure (1), which is the change in factor income that would compensate the social planner for being forced to change the economy's endowment from $\mathbf{L}^{\mathbf{aug}}$ to $\mathbf{L}$. We define this as the compensating measure of the net benefit of the augmentation of the endowment and denote it by ΔL^{CV}:

$$\Delta L^{CV} = \mathbf{w}^t\mathbf{L}^{aug} - \mathbf{w}^t\mathbf{L} = \mathbf{w}^t(\mathbf{A}^m\mathbf{M}) - \mathbf{w}^t(\mathbf{A}^x\mathbf{X}). \quad (5)$$

Figure 3 provides a graphical illustration of (4) and (5) in the two-factor case by drawing parallel factor income lines through $\mathbf{L}$ and $\mathbf{L}^{\mathbf{aug}}$ with the slope of $-\frac{w_1^j}{w_2^j}$, (j=a, t). The horizontal distance between the lines measures the benefits of the augmentation in units of factor 1.

The factor income measures (4) and (5) can also be quantitatively linked to the Slutsky expenditure measures (1) and (2). The relationship between the factor income equivalent measure ΔL^{EV} and the Slutsky equivalent variation measure ΔI^{EV} is summarized in the following proposition:

Proposition 1: Assuming that producers maximize profits and consumption conforms to the weak axiom of revealed preference, then $\Delta L^{EV} \geq \Delta I^{EV} > 0$

Proof:[19] From Samuelson (1939) we know that profit maximization in conjunction with the weak axiom of revealed preference implies that $\mathbf{p}^a\mathbf{C}^t > \mathbf{p}^a\mathbf{C}^a$. Recognizing that it is technologically feasible for the

[19] Formally, this proof replicates Deardorff (1982) who links the sign of (4) to a general Heckscher-Ohlin pattern of trade prediction, whereas we argue that the magnitude of (4) is linked to the gains from trade.

economy to produce $\mathbf{C}^t$ from $\mathbf{L}^{aug}$, profit maximization in the autarky equilibrium implies that $\mathbf{p}^a\mathbf{C}^a$-$\mathbf{w}^a\mathbf{L} \geq \mathbf{p}^a\mathbf{C}^t$-$\mathbf{w}^a\mathbf{L}^{aug}$. Rearrangement implies that $\mathbf{w}^a\mathbf{L}^{aug}$-$\mathbf{w}^a\mathbf{L} \geq \mathbf{p}^a\mathbf{C}^t$-$\mathbf{p}^a\mathbf{C}^a>0$.

Proposition 1 establishes that if there are gains from trade in the revealed preference sense, then the factor income measure (4) will always be positive and bigger than the Slutsky equivalent variation measure. The intuition for this outcome is as follows. Since input coefficients (a_{ij}) are evaluated at free trade factor prices, the vector $\Delta\mathbf{L}$ overestimates the addition to endowments necessary to produce $\mathbf{C}^t$ by ignoring the resource savings that would result from optimally adjusting input coefficients to *autarky* factor prices. The relationship between the compensating measures is captured in the next proposition:

Proposition 2: Assuming that producers maximize profits, then $\Delta I^{CV} \geq \Delta L^{CV}$

Proof: Since it technologically feasible to produce $\mathbf{C}^a$ from $\mathbf{L}$, profit maximization in the trade equivalent autarky equilibrium implies that $\mathbf{p}^t\mathbf{C}^t$-$\mathbf{w}^t\mathbf{L}^{aug} \geq \mathbf{p}^t\mathbf{C}^a$-$\mathbf{w}^t\mathbf{L}$. A simple rearrangement yields then $\mathbf{p}^t\mathbf{C}^t$--$\mathbf{p}^t\mathbf{C}^a \geq$ $\mathbf{w}^t\mathbf{L}^{aug}$-$\mathbf{w}^t\mathbf{L}$.

Since the compensating variation measure (1) does not require the weak axiom of revealed preference, Proposition 2 implies that the factor income compensating measure (5) provides a lower bound without having to assume anything about consumer behaviour. A further advantage is that the lower bound requires only data from the trade equilibrium.

If the magnitudes of (1) and (2) are not too different, the factor income measures (4) and (5) are complementary by providing an upper and lower bound for the consumer-based measures of the gains from trade. Furthermore, if (4) and (5) are similar in magnitude, this could be interpreted as providing evidence for validity of the weak axiom of revealed preference in the data set.

Within the context of the factor augmentation characterization of the gains from trade, Debreu's (1951) coefficient of resource utilization provides a convenient measure of the potential sub-optimality of autarky relative to trade.[20] If we start with the trade equilibrium as the reference point, the endowment vector $\mathbf{L}^{\mathbf{aug}}$ corresponds to the economy's optimal utilization of resources. The suspension of trade effectively lowers the economy's resource utilization to **L**. The difference vector $\mathbf{L}^{\mathbf{aug}}\mathbf{-L}$ represents a loss from "non-utilized" resources; it can be evaluated at either $\mathbf{w}^{\mathbf{a}}$ or $\mathbf{w}^{\mathbf{t}}$.[21] The inefficiency of **L** relative to $\mathbf{L}^{\mathbf{aug}}$ can then be expressed by:

$$\rho^j = \mathbf{w}^j\mathbf{L}/\mathbf{w}^j\mathbf{L}^{\mathbf{aug}} , \qquad (j=a,t) \qquad (6)$$

The coefficient ρ^j measures the distance between **L** and $\mathbf{L}^{\mathbf{aug}}$ in the metric of the equilibrium resource prices $\mathbf{w}^j$ (j=a,t,).[22] It is a number between 0 and 1, with a smaller value suggesting a higher degree of inefficiency of autarky relative to trade. If data on the factor prices prevailing in autarky and open trade are available, the coefficients provide a convenient metric to compare the relative magnitudes of (4) and (5) and, following from Propositions 1 and 2, a unified approach to quantify the value of international trade.

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[20] See Deaton (1979) for a discussion of Debreu's coefficient of resource utilization in context of a systematic treatment of distance functions in welfare economics.

[21] Since some components of ($\mathbf{L}^{aug}$-**L**) might be negative, 'non-utilization' pertains, in a general equilibrium sense, to the vector as a whole.

[22] In Debreu's original formulation (see Debreu (1951)), ρ is defined on the economy's "achievement level," which in this case would be the aggregate utility level u^t in the trade-equivalent autarky equilibrium. However, such a formulation would require the introduction of trade and factor trade utility functions in the spirit of Woodland (1980) and Neary and Schweinberger (1986). In terms of Figure 2, L^{aug} could then be thought of lying on a factor trade indifference curve with achievement level u^t. Proposition 2 in Neary and Schweinberger (1986) shows that such a factor trade indifference curve is well-behaved. However, we opted in (6) for a formulation which does not require the assumption of an aggregate social welfare function.

3. Empirical implementation

The opening up of Japan to international trade in 1859 after over two centuries of near autarky provides an unusual opportunity to empirically implement the factor augmentation characterization of the gains from trade. Bernhofen and Brown (2005) first used data that are available from the economy during autarky and open trade to calculate the standard consumer-based equivalent variation measure (1) for eight years of open trade. The same data-rich environment can be exploited to calculate $\Delta\mathbf{L}$ and the equivalent and compensating variation measures of gains from trade (4) and (5). Comparisons with the earlier results suggest that the new measures are robust along several key dimensions.

Bernhofen and Brown (2004 and 2005) describe the episode of Japan's opening up to trade in 1859 in detail. A central feature of the case of Japan is that during its early trading years of 1865-1876, the economy primarily imported goods with very close domestic substitutes.[23] This allows us to calculate the counterfactual domestic factor requirements that would have been necessary to produce foreign imports with domestic production techniques.

The implementation of our gains from trade formulations in section 2.4 requires data on trade flows, domestic factor requirements for both importables and exports and factor prices from autarky and open trade. We restrict our analysis to the years 1865, 1867-1876. Although Japan officially opened up to trade on July 4, 1859, the government of Japan was able to restrict the sale of its main exports

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[23] Imports of modern textile machinery, steam engines, rails and locomotives were insignificant during the first two decades of trade. Western novelties such as watches, carpets or whiskey were unimportant throughout this period. The most important imports for which Japanese production techniques are not available are ships, weapons and ammunition. These were important through 1868. Section 3.1 discusses imports of woolens, which by-and-large substituted for domestically-produced silk cloth and grew in importance over the period.

(products of the sericulture industry) until western military intervention ended these efforts in 1864. Complete trade records for 1866 are missing because of a fire in the customs house of the main trading port, Yokohama. The last trading year chosen is well before significant imports of western technology starting in the 1880s altered the Japanese technology matrix that prevailed for the first period of open trade.

3.1 Data quality and sources

The data appendix provides information on the methods and historical sources used to construct the vectors of exports **X** and imports **M**, the technology matrix for Japan and the vectors of factor prices. The abundant documentation in both the trade statistics and historical sources allows us to define the trading vector and the domestic technology matrix $\mathbf{A}=(\mathbf{A}^m,\mathbf{A}^x)$ at the level of individual products, or at a level of detail that is in most cases superior to the most disaggregated level of contemporary trade data.[24] For example, ten per cent of Japan's imports were an unfinished lighter cotton cloth known as gray shirtings. Abundant documentation allows us to identify the main source of the cloth (Great Britain) and its dimensions (including a weight of about 101 grammes per square meter). Contemporary trade data would have placed this cloth in HS group 5208.12.40, where the average weight would be assumed to equal 150 grammes per square meter. The difference would lead to almost a 55 percent overestimate in the estimated cotton content—with implications for factor usage—of imports of this cloth.[25] In brief, the detail of early Japanese trade statistics and the supporting

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[24] To be precise, the matrix employed in the empirical application is the submatrix of **A** that only includes goods traded at some point during the period. Excluded goods include roofing tiles, high-quality crafts and silk cloth.

[25] The HS classification at the 8-digit level (5208.12.40) refers to cotton cloth weighing from 100 to 200 grammes per square meter manufactured with yarns of 42s fineness and under. Japanese methods implied about 10 percent waste of cotton when spinning yarn.

information from contemporary observers increase our confidence in a close match between the elements of the technology matrices and import and export vectors.

Our historical research on production conditions during the early trade period suggests a level of aggregation over five factors of production—three kinds of labor, capital and land—that is tractable and reasonably descriptive of the essential elements of Japan's technologies.[26] The compilation of the domestic technology matrix **A** took note of three distinctive features of Japanese production systems: the locus of most production in vertically disintegrated and multi-product rural households, the use of female labour for particular tasks on the farm and the importance of a limited number of skilled craftsmen (master smelters, cotton scutchers or tea dryers) at key points in production processes. For that reason, our factor grouping uses three categories of labour measured in days per unit of output: skilled male, unskilled male, and female. Males working on the farm, regardless of task, were classified as unskilled workers. Female labour was often used exclusively for tasks such as cotton spinning and weaving, picking tea or cotton, or reeling silk. The fourth factor is capital, which is the user cost of capital measured in terms of gold ryō with the purchasing power of 1851-1855.[27] Capital costs took account of the relatively high rates of depreciation of wooden tools and equipment and the high rates of interest that prevailed in Japan during both the late autarky and early trade periods.[28] The final factor is land. To facilitate comparisons with Japanese sources, land is measured in terms of *tan*, which is

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[26] The results presented here will distinguish between paddy land (used for rice) and dryfield land (used for all other arable crops).
[27] The gold ryō was the gold-based currency of Japan until it was replaced with the yen in 1871 at one-to-one. Yen and ryō values for years other than 1854-1857 were deflated using the index of non-tradable goods found in Shinbo (1978, Table 5-10).
[28] See Saitō and Settsu (2006) for a review of the available evidence on interest rates, which places the range in 12 to 15 percent.

equivalent to one-tenth of a hectare or one-quarter of an acre.[29] With the exception of rice paddies, all land is assumed to be useable for crops such as soy, wheat, or cotton; land used in this way is known dryfield land in Japan.[30]

The ample documentation from the period and more recent studies ensure that the **A** matrix can account for the factor requirements for intermediate goods such as mulberry leaves (for silkworms), fertilizer, charcoal and firewood. For example, one pound of raw silk, Japan's most important export, required about 16 days of unskilled male labour, about four days of female labour and 0.03 hectares of land. Of this amount, most of the male labour was required to raise the 360 pounds of mulberry leaves required for one pound of raw silk. Three-quarters of the female labour was for reeling silk cocoons and the remainder was for raising the other intermediate products of silkworm eggs and cocoons.

The $\mathbf{A}^{\mathbf{x}}$ sub-matrix includes 24 products, or about 95 percent of Japan's exported goods during the period 1865-1876. Eighty per cent of Japan's exports were concentrated in just three of these: raw silk, silkworm eggs and green tea. The main source for the resource requirements for these exports is the exhaustive prefecture-by-prefecture survey of agricultural production conditions from the late 1880s, the Nōjji Chōsa (see Chō, Shōda et al. (1979)). Accounts of western geologists, other western observers and Japanese local and historical studies provide information on unit factor requirements for coal, copper, various maritime products, mushrooms, camphor and vegetable wax, which accounted for almost all of the rest.

The $\mathbf{A}^{\mathbf{m}}$ sub-matrix, which describes the Japanese technologies that were used to produce imported goods, accounts for about 80 percent of Japan's imports. The Nōji Chōsa provided source

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[29] The final section of the data appendix discusses the treatment of land that was not used for dryfield crops such as wheat, barley, cotton or legumes.

[30] Japanese land consisted of dryfields, which were used for crops such as cotton, soybeans and indigo, and paddy land, which was used for rice.

information for Japanese technologies for producing imported indigo, rice, soybeans and sugar cane.[31] Historical accounts of Japanese firms provide information on the refining stages of products such as indigo and sugar. Several studies, most notably Tanimoto (1998), provide detail on the stages of production and technologies used in the cotton textile industry.[32] The detailed reports of the American geologist Benjamin Smith Lyman (see Lyman (1879)) provide comprehensive accounts of Japanese technologies for drilling and refining petroleum, mining, smelting and metallurgy.

One import that was not produced in Japan deserves particular mention: woolen and worsted cloth, which accounted for 21 per cent of Japan's imports by value. Japan's topography does not lend itself to providing pasture for sheep, so that Japan never produced raw wool and lacked the capability to woolens during the early trade period. Tamura (2004) and Jenkins (1988) have established that imported woolens by and large substituted for various kinds of silk in Japanese dress.[33] A key import during the 1860s, camlets (a moderate-weight worsted cloth), was used for belts and haori (outer jackets). Mousseline de laine and other lightweight worsted or mixed cloths that came to dominate imports during the 1870s substituted for domestic silk cloths such as chirimen in the sewing of kiminos. To account for the implicit factors embodied in imports of woolens, woolen and worsted cloths were grouped into three categories by weight; the factors required to produce the same square yardage of similar silk cloths were then calculated. The main sources for the requirements for silk cloths include Bavier (1874), Porter and National Association of Manufacturers (U.S.) (1898) and Ichikawa (1996). The three cloths were chirimen, habutai and hakata-obi (silk belts).

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[31] Rice yields have been adjusted to reflect the consensus view of historians for the late 1870s (see Rosovsky (1968).

[32] The A^m matrix was constructed to accommodate different cloth weights. It assumed that all imported finished cloth was dyed using indigo dye.

[33] The major exception s were the heavier woollen cloths that were used for military uniforms, the uniforms of some government employees and the western dress that was sometimes worn by a small elite minority.

Finally, the vectors of factor prices $\mathbf{w^a}$ and $\mathbf{w^t}$ must account for potential differences in the two most important economic regions of Japan during autarky and open trade: the Kinai in the west—centered on Kyōtō and Ōsaka) and the Kantō, centered on Edo (Tokyo) in the east. The Kinai was the center of most Japanese manufacturing and metals production during autarky and open trade. The Kantō region became the center of the all-important sericulture industry after trade began. The estimates of wages for unskilled male workers and females for both the autarky (ca. 1851-1855) and open trade periods (ca. 1878) were derived from Saitō (1998), who provides wage series for both regions. Several other local industry studies provide supplementary data on wages for skilled workers.[34] In addition, measures of rents on land must recognize that it varied in quality, use (whether rice paddy or dryfield) and whether it was found in east or west Japan. Hedonic regression analysis of data from two areas in the east (Gunma prefecture and Ashikaga county near Tokyo) and several villages in the vicinity of Osaka was used to find the rent of standard quality dryland and paddyland in each region for 1851-1855; the average rent for dryland and for paddy land are weighted by the amount in each region. Property transactions recorded in the *Tokyo Journal of Economics (Tokyo Keizai zasshi)* provide coverage for much of Japan for paddy land in 1878. These values are adjusted downwards by about one-half to provide an estimate of rents for dry fields.[35]

Capital was the numéraire for the autarky period (priced at one ryō). For the open trade period, the price of capital was inflated to reflect the diminished purchasing power of the ryō by the mid-1870s.

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[34] In ryō, autarky day wages were 0.056 for skilled males, 0.028 unskilled males and 0.0165 for females ca. 1851-55. In yen for 1876-1878, they were about 0.20 for skilled males, 0.14 for unskilled males and 0.11 for females. Regional wage gaps were not that significant during either period.

[35] Le Gendre (1878, Appendix Table 2) provides the data on paddyland and other cropland for all of Japan's prefectures ca. 1874 from the first Meiji production survey. The final rents used in the calculations of (5) and (6) are 1.03 and 1.33 ryō per *tan* (one-quarter acre) for dryland and paddyland in 1851-1855, respectively, and 4.3 and 6.8 yen per *tan* for dryland and paddyland in 1878. Land values were converted to rents using the traditional rate of 9.6 percent.

The price index for non-tradable goods compiled by Shinbo (1978, Table 5-10) was used to arrive at a price of capital that was 4.1 yen ca. 1878.

3.2 Japan's revealed resource augmentation

Table 1 provides the individual components of Japan's revealed resource augmentation **ΔL** (from equation (3)) for each year of our sample period. Factor flows of the three types of labour are measured in millions of days; capital is given in thousands of ryō; and land is measured in thousands of tan. Panel A gives the counterfactual vector of factors necessary to produce Japan's imports domestically, $\mathbf{A}^{m}\mathbf{M}$. Panel B documents the resource outflows embodied in Japan's exports, $\mathbf{A}^{x}\mathbf{X}$ Panel C gives $\mathbf{A}^{m}\mathbf{M}$-$\mathbf{A}^{x}\mathbf{X}$, the factor augmentation necessary to produce Japan's open trade consumption vector domestically in a trade-equivalent autarky equilibrium. A striking feature of Panel C is that the factor content reveals a factor augmentation in each factor for every year during the early trade period. In terms of Figure 2, Japan's implicit factor content of trade reveals no factor trade-offs, which implies that the endowment vector $\mathbf{L}^{aug}$ always lies in quadrant I. Since all components of ($\mathbf{L}^{\mathbf{aug}}$-$\mathbf{L}$) are positive in each sample year, Panel C provides causal evidence of unambiguous gains from trade without the need of factor prices as a metric.

[insert Table 1 here]

A notable feature of the gains in the labour categories, which are easily comparable because all are measured in terms of days of work, is the large augmentation of female labour relative to unskilled male labour. After 1870, the implicit addition of female labour services to the Japanese economy is about twice the increase in unskilled male labour. The intense use of female labour in the import-competing sectors of cotton yarn and cloth and the low productivity of traditional technologies largely account for the importance of female labour in the augmented factor endowment.

Another interesting feature of Panel C is the time series pattern of augmentation in the individual factors. The augmentation of skilled male labour fluctuates more or less around its mean. For the remaining factors, shifts in the pattern of traded goods could prompt substantial shifts in the pattern of resource augmentation. The surge in the implicit imports of land during 1869 through 1871 reflects large imports of rice and beans from Indochina and China after the worst harvest failures (in 1866 and 1869) to hit Japan since the devastating Tenpō famine years of 1833-1839. At its peak, the implicit import of land was equivalent to about 10 percent of Japan's overall arable landl; imports of dryfield crops such as soybeans could have implicitly added as much as 14 percent to the endowment of dryfield land. By the mid-1870s, the augmentation of unskilled male labour had increased by about fifty percent over the first years of trade and the augmentation of female labour had doubled. The final column of Table 1 expresses the resource augmentation as a share of the approximate stock of resources ca. 1872 to 1874. Over the entire period, male labour was augmented by 3.3 percent, female labour by 5.5 percent and land by about 3.9 percent.[36]

An implicit requirement for assessing the static gains from trade is that the economy operates under balanced trade. In a trade deficit year, the economy can be thought of as borrowing foreign factor services and the factor content measure will overstate the gains from trade. In a trade surplus year, the economy can be thought of as lending domestic factor services and the factor content measure will understate the gains from trade. The Japanese economy experienced trade deficits in 1867 and over the period 1869-1875; trade surpluses occurred in 1865, 1868 and 1876.

[36] See Le Gendre (1878, Appendix Table 2) for land endowments and Griffis (1876) for a summary of the population census of 1872. Contemporary sources do not provide an estimate for the stock of capital. It is assumed that the labour force included only the 16.1 million "common people" aged 15 to 80 and that the working year was about 300 days.

The simplest procedure to correct for trade balances is to assume that Japanese preferences are homothetic so that imports are scaled up in trade surplus years and scaled down in trade deficit years. The "adjusted" imports will ensure that the balanced trade condition holds in every year. Panel D reports the resource augmentation adjusted for trade imbalances. For years that saw trade surpluses such as 1865, 1868 and 1876, the adjustments to the factor augmentations are greater than one.[37] For the remaining years, they are smaller. Overall, the basic message from Panel C is preserved in Panel D. Even during years of trade deficits, all components of ($\mathbf{L}^{\mathbf{aug}}$-$\mathbf{L}$) remain positive, which implies that the revealed augmentation in all factors is not caused by trade imbalances.

3.3 Valuing factor augmentation and implications for the gains from trade

Information on factor prices from Japan's autarky and open trade periods allows us to evaluate Japan's trade-induced factor augmentation with the corresponding factor prices. Table 2 presents these results, which are also used to assess the welfare loss from the hypothetical sudden and complete suspension of trade. Panel A offers the results without an adjustment for balanced trade; panels B and C present results assuming balanced trade. Line (1) in Panel A reports the factor content equivalent measure ΔL^{EV} from equation (4), which is based on the factor prices in current ryō that prevailed during the last years of autarky. Recall that ΔL^{EV} is the counterfactual loss in factor income from the suspension of trade that takes Japan's autarky period as the reference point. These estimates of ΔL^{EV} can be compared with the upper bounds of the Slutsky consumer expenditure measures of the gains from trade (I^{EV}) calculated for 1868-1875 and reported in Bernhofen and Brown (2005. Table 2). That paper also takes the autarky period as the reference point, but it evaluates the vector of net imports at autarky

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[37] Adjustments to imports were made to ensure balanced trade in the flows of goods (about 80 percent imports and over 95 percent exports) for which data were available on factor usage. The adjustment factors (for imports) are 1.41 for 1865, 0.87 for 1867, 1.85 for 1868, 0.70 for 1869, 0.47 for 1870, 0.95 for 1871, 0.76 for 1872, 0.81 for 1873, 0.90 for 1874, 0.79 for 1875 and 1.46 for 1876.

goods prices. The second line of Panel A presents those estimates. The results are largely consistent with Proposition 1; the value of I^{EV} is less than the value ΔL^{EV} for seven out of the eight years for which both measures are available. The largest differences between the two measures are observed in 1869 through 1871, when the Japanese economy was suffering from the adverse impact of severe harvest failures.

The first line of Panel B presents the measure ΔL^{EV} under the assumption of balanced trade and the first line of Panel C presents the measure ΔL^{CV}, which is also calculated under the assumption of balanced trade. The estimates of ΔL^{EV} show an average annual growth of about thirteen percent over the early trade years, with a peak in 1871 that reflects the surge in food imports and another peak in 1876, which reflects growth in the imports of cotton and woolen textiles. The measure ΔL^{CV} gives the change in in factor income necessary to compensate the economy for the elimination of the factor augmentation ($\mathbf{L}^{\mathbf{aug}} - \mathbf{L}$) brought about by trade. Since the starting point is the during the open trade regime, the factor augmentation vector $\Delta \mathbf{L}$ is weighted with factor prices from 1875-1879. This approach yields a slightly higher growth rate in the compensation measure of more than 15 percent.

Line (2) of Panels B and C offers estimates of national income in autarky and open trade, respectively. The estimates for autarky are from a study of a prosperous feudal territory of Tokugawa Japan from about 1840.[38] The estimates of autarky income have been adjusted to reflect the potential growth of the economy between the autarky period (1851-55) and the sample years (1865 through 1876).[39] The estimates for the open trade period are in yen of 1878 and are from Okawa (1957). They

[38] The estimate of 2.47 ryō per capita is the “forecast” estimate at found in Bernhofen and Brown (2005, Table 3) assuming a growth rate of per capita real GDP of 0.4 percent. Nishikawa (1987, p. 327) suggests such a growth rate was a reasonable estimate for the mid-century.

[39] Growth of the economy from 1855 to the trade period would have increased the production potential of the economy. These calculations use data on the growth in population from estimates published inBiraben (1993) and the assumption that per capita autarky factor income grew 0.4% per year.

have been adjusted downwards to reflect the potential growth in the economy between 1865 and 1878-1882, the period for which Okawa first presents estimates of GDP.[40]

The final line of panels B and C provide ρ, the coefficient of resource utilization defined in eq. (6). The coefficient calculated with Japan's autarky factor valuation as the reference point (in panel B) varies between 0.86 and 0.96 and averages 0.923 over the period. The consequences for total factor income of eliminating trade ca. 1878 are found in line (3) of panel C. The reference point of this counterfactual exercise is the open trade period. Here, the efficiency measure ranges between 0.88 and 0.97, with an average of 0.937. The compensating variation measure has the advantage that it only requires data observed in the trade equilibrium. This is in stark contrast to the Slutsky compensation measure (2), which requires consumption data under autarky and trade.[41] The slightly higher magnitudes of the coefficient in Panel C can be explained by the free trade period being the reference point for the hypothetical suspension of trade, which corresponds to a higher base production capacity than the one in Panel B.[42] The estimated efficiency cost of 6.3 percent is only slightly less than the result from the equivalent variation measure of 7.7 percent. Recall from propositions 1 and 2 that (4) and (5) are upper and lower bounds of the expenditure measures (2) and (1). The findings in Panels B and C suggest that the two alternative welfare measures give qualitatively similar results. In summary, the

[40] For both measures of income, a growth rate of 0.4 percent has been assumed for the period 1865 to 1878.

[41] See Bernhofen and Brown (2004, p.212) for a detailed discussion of why (2) cannot be approximated by data on prices and trade flows.

[42] The gains from trade can be thought as 'capturing movements along the economy's PPF' which become 'relatively smaller' as the PPF moves further away from the origin. The underlying assumption of the analysis is that the economy's actual growth path is invariant to the static gains from trade. A relaxation of this assumption is beyond the theoretical scope of this static theoretical framework.

average static welfare benefit from trade was about 7 percent in terms of the economy's overall productive capacity.[43]

4. Conclusion

It is quite well known that the factor content of trade is a fruitful device for higher dimensional formulations of the Heckscher-Ohlin theorem.[44] As a result, it has inspired a voluminous empirical literature estimating patterns of international specialization and linking them to various theoretical specifications. To the best of our knowledge, this paper is the first to use the factor content of trade as an analytical device for a new theoretical formulation of the gains from trade and then applies it to an empirical setting compatible with the assumptions of neoclassical theory.

We show that an economy's implicit factor content of trade embodies all the relevant information necessary to calculate a factor augmentation equivalent to trade, which formalizes the insights of eighteenth-century observers about the sources of gains from trade. Viner (1937, chapter 8, p. 9) points out that "[M]any of the classical economists, before and after the formulation of the doctrine of comparative costs, resorted to this eighteenth-century rule as a test of the existence of the gains from trade... Ricardo incorporated it in his [1817] formulation of the doctrine of comparative costs." A main advantage of this formulation is that the gains can be tested without the imposition of a supportive auxiliary hypothesis on aggregate consumer behaviour, such as the weak axiom of revealed preference. This has the important implication that the gains from trade are subject to empirical

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[43] The efficiency loss averages about 8.5 percent for the case of the equivalent variation measure calculated without correcting for the balance of trade.

[44] See Feenstra (2004) and Bernhofen (2011) for recent surveys of the factor content literature.

refutation à la Popper, without qualifications about the testing of joint hypotheses raised by Duhem-Quine.[45]

Applying our formulation to a unique data set on 19th-century Japan, we provide causal evidence of the existence of gains from trade. Trade effectively augmented all of Japan's factors of production during the eleven years that are the focus of this study. In addition, we also show that our theoretical approach provides insights into the deeper determinants of the sources and magnitudes of the aggregate gains from trade. Although the case of 19th century Japan offers distinct advantages for applying our gains from trade formulation, perhaps its most appealing feature is that it can be applied in the numerous historical and contemporary settings that lack autarky data.

Economic theory has suggested circumstances in which international trade might not be welfare improving for an economy: terms of trade effects, production externalities, government subsidization or ill-defined property rights on environmental resources. The prevailing consumer expenditure approaches to measure the gains from trade appear inadequate to empirically address potential losses from international trade. Our factor augmentation formulation provides an alternative framework that allows one to empirically quantify both the benefits and costs of international trade.

[45] The Duhem-Quine thesis raises concerns about the refutability of single hypotheses since hypotheses are often formulated in conjunction with supportive hypotheses that are assumed to be true. In our context, a test of the gains from trade in its revealed preference formulation is always a joint test of the gains from trade *and* the weak axiom of revealed preference. See Cross (1982) for a good discussion of these concerns in the context of testing theories of macroeconomics.

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Figure 1: Expenditure measures of the gains from trade

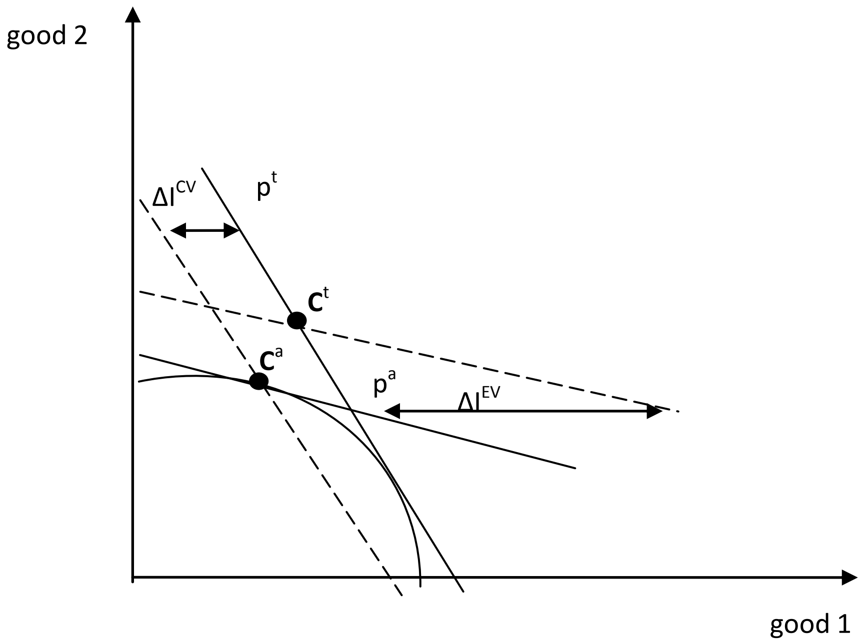

Figure 2: Factor augmentation equivalent to trade

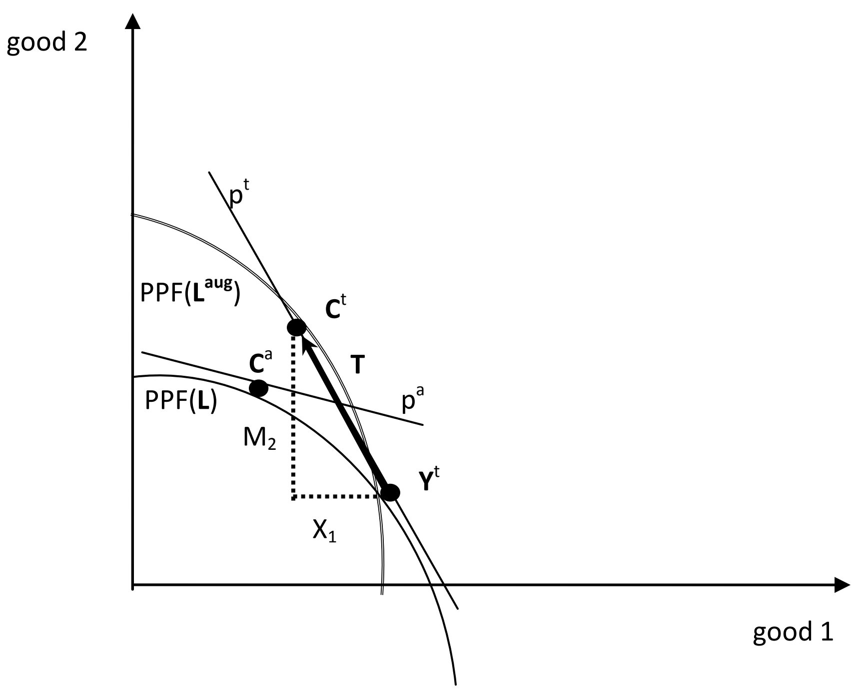

Figure 3: Factor augmentation measures of the gains from trade

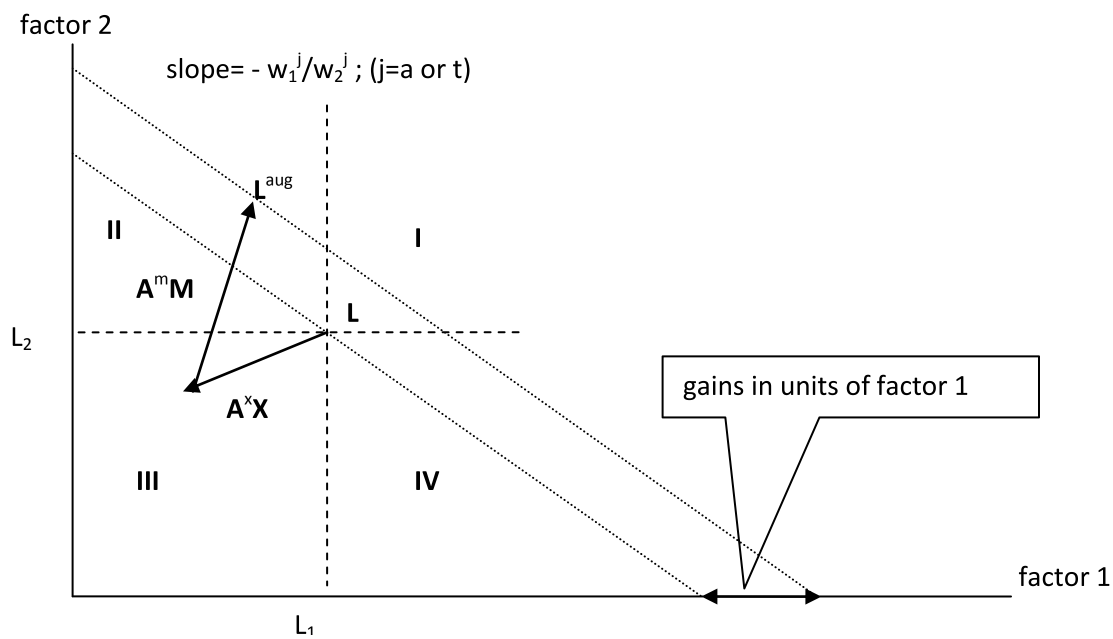

Table 1: Japan's revealed factor augmentation: 1865, 1867-1876

	1865	**1867**	**1868**	**1869**	**1870**	**1871**	**1872**	**1873**	**1874**	**1875**	**1876**	
Panel A: Implicit Factor Imports: $\mathbf{A}^m\mathbf{M}$												
Male skilled (mm days)	32	24	15	18	24	26	26	31	27	35	31	
Male unskilled (mm days)	60	71	49	72	126	121	99	115	102	138	119	
Female (mm days)	60	91	79	100	181	186	167	174	192	206	208	
Capital (1000 ryō)	1,103	1,713	1,261	1,617	2,756	2,855	2,514	2,841	2,769	3,656	3,189	
Land: Paddy (1000 tan)	1,018	1,339	864	1,680	3,249	2,791	1,684	1,930	1,698	2,303	1,983	
Panel B: Actual Factor Exports: $\mathbf{A}^x\mathbf{X}$												
Male skilled (mm days)	6	6	5	4	6	9	8	8	9	10	11	
Male unskilled (mm days)	34	19	27	19	20	34	28	33	31	34	50	
Female (mm of days)	8	5	7	5	6	9	7	9	8	9	13	
Capital (1,000 ryō)	827	521	695	501	586	930	777	875	909	1,001	1,282	
Land (1,000 tan)	608	376	520	368	423	686	577	649	672	716	1,067	
Panel C: Factor augmentation: $\Delta\mathbf{L}=\mathbf{A}^m\mathbf{M}-\mathbf{A}^x\mathbf{X}$												Average of $\Delta L_i/ L_i$:
Male skilled (mm days)	26	17	10	14	18	17	18	23	17	25	20	} 3.3%
Male unskilled (mm days)	27	52	22	53	105	86	71	82	71	105	69	
Female (mm days)	51	86	72	95	175	176	159	165	184	197	194	5.5
Capital (1,000 ryō)	275	1,192	566	1,116	2,170	1,925	1,736	1,966	1,860	2,656	1,907	
Land (1,000 tan)	411	1,251	414	1,851	4,606	3,493	1,107	1,281	1,026	1,588	917	3.9
Panel D: Factor augmentation: $\Delta\mathbf{L}$, adjusted for trade imbalances												Average of $\Delta L_i/ L_i$:
Male skilled (mm days)	39	14	23	8	5	16	11	17	15	18	35	} 3.1%
Male unskilled (mm days)	51	42	63	31	38	80	47	61	61	75	125	
Female (mm days)	76	74	140	64	79	167	120	133	165	153	292	5.2
Capital (1,000 ryō)	727	966	1,637	625	699	1,785	1,139	1,437	1,582	1,871	3,406	

Land (1,000 tan)	828	786	1,079	802	1,093	1,968	706	921	856	1,092	1,849	2.6

Source: For the procedure used to calculate the estimated factor flows, please see the text.

Notes: A tan is about one-tenth of a hectare. The ryō is a currency that was replaced by the yen at one to one in 1871. The values are expressed in terms of the ryō of 1851-1855. The endowments of male and female labor and land are from the summary of the production census of 1874 and 1875 that is reported in Le Gendre (1878) and the population census reported in Griffis (1876). The endowment is defined as “commoners” aged 14 to 80. The net imports as a share of the endowment, $\Delta L_i / L_i$, is for the average for each factor from 1865 through 1876.

Table 2: Evaluating the resource augmentation and the loss of resource use from the suspension of trade

	1865	1867	1868	1869	1870	1871	1872	1873	1874	1875	1876
Panel A: Unadjusted Equivalent variation											
(1) $\mathbf{\Delta L^{EV}}$(in millions of ryō)	3.72	6.38	3.37	6.98	14.26	12.20	8.45	9.56	8.88	11.83	9.03
(2) $\mathbf{\Delta I^{EV}}$(in millions of ryō)			1.20	3.30	7.80	6.60	7.80	11.10	8.40	9.90	
Panel B: Equivalent Variation adjusted for trade imbalance											
(1) $\mathbf{\Delta L^{EV}}$ (in millions of ryō)	6.68	5.12	8.39	3.97	4.58	9.91	6.00	7.49	7.94	8.89	16.07
(2) $\mathbf{w^aL}$ (in millions of ryō) †	87.65	89.95	91.15	91.97	91.88	92.14	93.32	94.20	95.02	95.94	97.08
(3) $\mathbf{w^aL+w^aF}$	94.32	95.07	99.55	95.93	96.46	102.06	99.32	101.69	102.96	104.83	113.15
(4) Debreu's RUC: $\rho^a = \frac{w^aL}{w^aL+w^aF}$	0.93	0.95	0.92	0.96	0.95	0.90	0.94	0.93	0.92	0.92	0.86
Panel C: Compensating variation adjusted for trade imbalance											
(1) $\mathbf{\Delta L^{CV}}$ (in millions of yen)	31.69	25.36	42.23	20.01	23.23	50.00	31.19	38.31	41.41	45.40	82.18
(2) $\mathbf{w^tL}$ (in millions of yen) ‡	552.54	567.06	574.64	579.77	579.24	580.89	588.32	593.83	599.02	604.83	612.00
(3) $\mathbf{w^tL+w^tF}$	584.23	592.42	616.87	599.78	602.47	630.89	619.51	632.14	640.44	650.23	694.18
(4) Debreu's RUC: $\rho^t = \frac{w^tL}{w^tL+w^tF}$	0.95	0.96	0.93	0.97	0.96	0.92	0.95	0.94	0.94	0.93	0.88

†Adjusted for growth in production possibilities from 1855 to the relevant year.

‡Adjusted for growth in real GDP per capita to 1878 from the relevant year at a rate of 0.4 percent per year.

Source: ΔL^{EV} is the inner product of the net imports of factors from Panel D of Table 1 and the vector of autarky factor prices. $\mathbf{\Delta I^{EV}}$is from Bernhofen and Brown (2005, Table 2) multiplied by an estimated population of 30 million. $\mathbf{\Delta L^{CV}}$ is the inner product of the net imports of factors from Panel D of Table 1 and the vector of open trade factor prices.

Notes: The ryō is the currency used in Japan during autarky. The yen was introduced in 1871 to replace the (paper) ryō at a ratio of one to one. Autarky factor prices for the equivalent variation measure are the average for the period 1851-1855. Open trade factor prices for the compensating variation measure are for 1875-1879.

Data Appendix for Daniel M. Bernhofen and John C. Brown, "A factor augmentation formulation of the value of international trade"

The data required for this study include trade flows (in quantities) for the period 1865-1876, the elements of the **A** matrix for exports and for goods substituting for importables, factor prices for the autarky and open trade periods and estimates of GDP for the autarky and open trade periods. This data appendix highlights the sources for these data and some of the issues that necessarily must be resolved when trying to account for factor flows. Maskus (1991, pp. 26-27) discusses the two issues that are most relevant for this study. First, the data must be consistent with the economic framework and second, the aggregation of trade and production data should minimize differences in factor use within categories. Since the economic framework explicitly models factor usage, the dataset assembled here is appropriate to the empirical domain suggested by the factor augmentation approach. The availability of disaggregated product-level rather than industry-level trade and production data for the period of this study directly addresses the second concern.

*Data on **X** and **M***

The import and export data used in this paper are all in quantities of goods and are drawn from two overlapping sources. For the years 1865 and 1867, the reports of the consuls of several European countries and the United States who were located in the main treaty ports of Kanagawa/Yokohama and Nagasaki provide the only sources of data on trade.[46] Fortunately, the consuls had access to the reports of their individual chambers of commerce and the foreign traders living in the foreign enclaves of the treaty ports. Detailed consular reports continue to be available during the 1870s. Reports by several commercial missions in the 1860s and early 1870s provide additional detail on the characteristics of exports and imports.[47] Meiji customs authorities began compiling trade statistics in 1868, which are reported in Shuzeikyoku (1893). The reports from the consulates allow for a more accurate allocation of imports across product categories up through the mid-1870s than what could be achieved by only relying on the Meiji data.[48] Both sources provide detail on trade in products, not industry aggegrates. In the Meiji sources, there are over 200 imported products and well over 100 exported products.

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[46] Of the four treaty ports where trade with foreigners was allowed when Japan first opened up, the two most important were Kanagawa (Yokohama) and Nagasaki. Hiogo was added in 1868 and quickly became the second most important port after Yokohama.

[47] The sources for the consular reports from each treaty port are Belgium: Ministère des affaires étrangères (1865-1868, 1882), Prussia: Ministerium für Handel Gewerbe und Öffentliche Arbeiten (1866-1875), Great Britain: Foreign Office (1859-1876) and United States: Bureau of Foreign Commerce (1864-1877). The following reports of commercial missions provide supplemental information: Switzerland:Eidgenössisches Handels- und Zolldepartment. and Brennwald (1865), Jacob (1861) and Scherzer (1872).

[48] This revision applies primarily to woolens and only the allocation across cloth types (not the total yardage). Many of the types of woolen cloth would have been initially unfamiliar to the Meiji customs officials. The discrepancy between the Meiji reports and those from the local chambers of commerce diminished substantially over the 1870s.

Ideally, the calculated factor content of trade should include all relevant factors used in the production of all tradable products. The usual compromise with this ideal found in contemporary studies—restrict **X** and **M** only to manufactures or lump together all non-manufacturing goods into one category— is not tenable for a country such as Japan during the period of this study.[49] Table A1 provides a comprehensive list of the exports and imports used in this study along with their share in the value of trade.[50] Virtually all of Japan's exports were agricultural raw materials or food (silk, tea, various dried fish and seaweed); 22 percent of its imports were also non-manufactures. For that reason, the study pays close attention to a disaggregated treatment of all traded products as much as possible.

*Matrix of unit input requirements for exports and imports **A***

Consistent with historical descriptions, the **A** matrices were constructed with five factors: three categories of labor (skilled male labor, unskilled male labor and female labor), capital and land.[51] Since most sources provide data disaggregated by production process or task, it is possible to calculate factor usage per unit of output for both intermediate goods such as cocoons, mulberry leaves, charcoal and fertilizer and the final products that entered into trade. Labor is measured in terms of days of work per unit of physical output.[52] Sources generally refer to the gender of workers. The distinction between skilled and unskilled workers was made primarily on the basis of occupational titles or their role in the production processes. Coolies, laborers or "lads" were always unskilled workers. Those with specialized roles in production processes such as tea dryers, silk sorters, dyers and scutchers were skilled. In addition, there was a range of skilled workers in mining and metals. Fishermen of various kinds, who very often owned their own boats, and charcoal burners were treated as skilled workers. In a smaller number of cases, relative wages paid were used to distinguish between skilled and unskilled workers.

The measurement of capital was based on the annual user cost of capital as defined in OECD (2009, p. 65): $c_o=P^o(r+\delta)$, where c_o is the capital cost of production, P^o is the price of the capital (including the construction cost of buildings as well as machinery or tools), r is the relevant interest rate, and δ is the rate of depreciation. In the **A** matrix, the amount of capital used in production (c_o) is expressed per unit of output. Virtually all of the Japanese sources provide $P^o\delta$. Where this information is lacking, a depreciation rate of 30 percent is assumed for wooden capital such as tools.[53] Saitō and Settsu (2006) reviews the literature on interest rates in late autarky Japan and suggests that 12 percent would be reasonable. These rates most likely did not fall during the early trade period. Anonymous (1875, p.

[49] Choi and Krishna (2004), for example, note that bi-lateral data for non-manufacturing industries were not available for their test of Heckscher-Ohlin.

[50] Shuzeikyoku (1893) provides the compilation of trade statistics. Further detail on traded goods is found in the consular reports of Belgium, France, Germany and Great Britain, which drew upon the respective chambers of commerce and western merchants for more information. Reports of trade delegations from Switzerland, Prussia and Austria-Hungary provided additional information on the characteristics of traded goods. See Scherzer (1872),Switzerland. Eidgenössisches Handels- und Zolldepartment. and Brennwald (1865), and Jacob (1861).

[51] In the circumstances where the sources reference the employment of boys, they are assigned to female labor.

[52] The days of labor were are almost always reported in Japanese sources and in western descriptions of Japanese production processes.

[53]See Hokusuikyokai (1935) for an average depreciation of various wooden tools of about 30 percent.

90) describes nominal rates approaching 18 percent ca. 1874. Capital is measured in terms of gold ryō of 1851-1855.[54]

The **A** matrix study takes explicit account of differences in the type of land used in agriculture. In the context of East Asian trade in the nineteenth century, it is sensible to distinguish between two qualities of land: paddy land (irrigated fields suitable for flooding to produce rice) and land for other crops (dry fields). All land is measured in terms of *tan*, an areal measure equivalent to one-tenth of a hectare or one-quarter of an acre, per unit of output.

Bernhofen, Brown et al. (2011) discusses the sources of data for the **A** matrix in detail. The primary source was the multi-volume Nōji Chōsa reprinted in Chō, Shōda et al. (1979). This comprehensive survey of production conditions in most of Japan's prefectures conducted during the mid-1880s provides task-level data on agricultural production conditions in about 35 of Japan's prefectures. For the export products silk and tea, total input requirements were calculated from those prefectures that accounted for the largest share of production of these goods. For silk, the production conditions of the late 1860s through the mid-1870s differed from the conditions described in the Nōji Chōsa in a few ways. Contemporary descriptions of the Japanese silk industry by Syrski (1872) and de Bavier (1874) permit a correction for these differences. Large-scale exports of silkworm eggs reduced the average quality of eggs available for Japanese silk producers, so that the yield of cocoons per egg has been adjusted downwards. The estimates of the 1880s suggest a lower average productivity for a woman reeling silk compared with the 1870s, so data reflecting the higher productivity of the 1870s was sued. Finally, it appears that cocoons yielded more silk in the 1870s than the late 1880s.

Tea is a hetereogenous product; Japan exported primarily varieties of green tea (Sencha) that were of medium quality. Data was chosen from four prefectures that produced teas closest to the unit values of export statistics. Watson (1873) andGribble (1883) provide supplementary information on tea production conditions and processing in the port prior to export. Studies by Japanese economic historians and contemporary accounts filled in the data for marine products, camphor, Japanese wax and copper.[55]

About twenty percent of imports were agricultural products such as rice, beans, sugar and cotton. The Nōji Chōsa provides ample documentation of production conditions for all of these imports. To simplify calculations, imports of beans were assumed to be soybeans, although other beans also play a role in the Japanese diet. Rice productivity during the 1870s was somewhat lower than that reported in the Meiji survey of the late 1880s. The **A** matrix uses the data from the eight prefectures that in aggregate were closest to the yield of 1.29 koku per tan that is now accepted by Japanese economic historians as the national average for the period 1878-1882.[56]

Over one-half of imports were textiles. The consuls reported that imported cotton yarn was primarily of lower counts that averaged 16-24s. That was also the highest quality of yarn that Japanese hand spinners could produce. Imported cloth was generally of lighter weight than the traditional Japanese staple, *shima-momen*. Imported cloths were on average assumed to weigh 0.20 lbs per square

[54] The gold ryō was the gold-backed currency of pre-1871 Japan. It was replaced by the yen in 1871 at a ratio of one to one. When introduced, one yen equaled one United States dollar. The index of non-tradeable goods found in Shinbo (1978, Table 5-10) was used to convert values in yen or other currencies into gold ryō of 1854-1857.

[55] The most important sources for these other industries are Lyman (1879), Coignet and Ishikawa (1957),Greathouse (1887), Gribble (1874) and Nishi Nihon Bunka Kyōkai (1982).

[56] See the account of the debate in Rosovsky (1968).

yard; that is the weight of gray shirtings, which constituted 10 percent of all imports and it is a bit more than the modal finished cloth import: printed cloths and turkey reds. The requirements for finishing assumed that one-half of imported finished cloth was dyed a light blue using indigo dye. Tanimoto (1992and(1998) document the labor productivity and cotton usage for spinning yarn and weaving cloth. Capital costs for spinning machines and looms are found in Meiji Bunken Shiryō Kankōkai (1959). The productivity of dyers is from several villages in the Chōshū domain (see Yamaguchi-ken Monjokan (1960)).

Woolen textiles were not produced in Japan during the 1860s and 1870s, since the absence of land suitable for grazing ruled out the development of a domestic wool industry. Tamura (2004) and Jenkins (1988) note that for the most part, woolens substituted for silk cloth in traditional Japanese dress. Abundant evidence on the dimensions of imported woolens (including the weight) allowed for an allocation of imports across three weight categories.[57] Figure 1 illustrates the rapid shift of imports to the category of light woolens so that by 1870, seventy percent of imports weighed less than 0.25 lbs. per square yard. The literature offers ample evidence that light woolens were substituting for chirimen (silk crepe), which was primarily used in kimonos.[58] The heaviest woolens weighing more than 0.5 lbs. per square yard were assumed to substitute for a heavier silk cloth used in belt manufacture (hakata-obi). Medium-weight woolens were assumed to substitute for figured habutai cloth, which is a bit lighter than belt cloth.[59] The silk content of all of these cloths accounted for 70 to 90 percent of the total labor cost. The main sources for direct factor costs in silk weaving are Ichikawa (1996), Porter and National Association of Manufacturers (U.S.) (1898) and de Bavier (1874).

Vectors of factor prices in autarky ($\mathbf{w^a}$) and open trade ($\mathbf{w^t}$)

Autarky prices for capital, labor and land are expressed in terms of gold ryō and apply to the period 1851-1855.[60] Capital is treated as the numéraire factor priced at one gold ryō. For 1875-1879, capital was value in nominal terms to reflect the 75 percent decline in the real value of the ryō/yen since the late autarky period.[61] Since wages did vary across Japan, two issues matter for determining the appropriate autarky price of labor: the locus of production of tradable goods (rural versus urban) and potential differences in wages in eastern (Kantō) versus western Japan (Kinai). Virtually all production of tradable goods took place in rural locations or small towns, so that wages outside of the major urban centers of Osaka, Kyoto and Edo (Tokyo) are appropriate. The research of Saitō and other historians provides broad coverage of wage rates for the autarky period and the open trade period (see Saitō (1991, 1998a, 1998b and 2005)). Appendix Table A2 presents the averages of the wages used to

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[57] Woolens include all-woolen and all worsted-cloth as well as several mixtures that included cotton.

[58] The cloth mentioned the most often was mousseline de laine, which accounted for up to three-quarters of woolen imports by volume by the mid-1870s.

[59] Tamura (2001, p. 35) notes that imported woolens were generally a bit heavier than the silk cloths they replaced.

[60] All factor prices from the western part of the country, which included the Kinai region in the area of Osaka and Kyoto, used a silver-based currency (the silver *monme)*. The monthly exchange rates of the *monme* with the ryō found in Miyamoto and Ōsaka Daigaku Kinsei Bukkashi Kenkyūkai (1963) are used to convert these values to ryō.

[61] The price index for non-tradable goods found in Shinbo (1978, Table 5-10) was used along with information on the yen-dollar exchange rate after 1877.

calculate the equivalent and compensating variation measures found in Table 2. The table also offers a detailed description of the sources used to supplement the data from Saitō.

Land quality and prices varied across Japan.[62] The most land-intensive imports over the early trade period were cotton and woolen textiles. The most land-intensive exports were tea and silk, although they generally used marginal land that did not compete with crops usually grown on dryfields such as grains and beans. Data on land values and rents during the late autarky period are most readily available for locations in the productive heartlands of autarky Japan, the Kinai (several villages) and from two locations in the Kantō, both of which were silk-growing areas (Gunma prefecture and Ashikaga County).[63] The data include information on the proportion of paddy land and the quality of land according to tax assessments. Rents are expressed either in terms of cash or rice. Multiplying land values by the standard conversion factor for rents of 0.096 provides the estimated rent when actual rents are not available. Since rents in the Kinai were generally much higher than elsewhere in Japan, the average rents for the entire country were a weighted average. Le Gendre (1878, Appendix Table) provides the distribution of all dryland and paddy in Japan from the production census of 1874. About one-third of dryland fields were in the western region (the Kinai), and the remainder was in the east. The sources for rents are outlined in Table A2.

Factor income in the autarky and open trade periods

GDP estimates do not exist for Japan during autarky. However, the estimates from a detailed study of the domain of Chōshū in 1840 provide a starting point that can be used to estimate autarky GDP for Japan as a whole (see Nishikawa (1987)). The results of several alternative calculations based upon different assumptions about real growth rates are found in Bernhofen and Brown (2005, Table 2). The preferred growth rate of 0.4% during late autarky and using the Chōshū evidence as the base yields the GDP estimates for 1851-1855.[64] The earliest estimate of Japan's national income is found in Ohkawa (1957, Table 1) for 1878-1882 and was calculated from value-added.

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[62] Japanese tax authorities classified all plots of land into four categories: very low quality, low quality, medium or standard quality and high quality. Land was also classified as paddy land or dryfield land.

[63] See Hensan-iinkai (1967, Tables 28 and 65) and Takeyasu (1968, Table I-27) for the records of several villages in the vicinity of present-day Osaka. Waseda Daigaku Keizaishi Gakkai (1960) provides the data on land prices in Ashikaga County and Iinkai (1988, pp. 368-377) provides data on land sales in the Gunma prefecture.

[64] The population estimate of about 32.2 million is from Biraben (1993).

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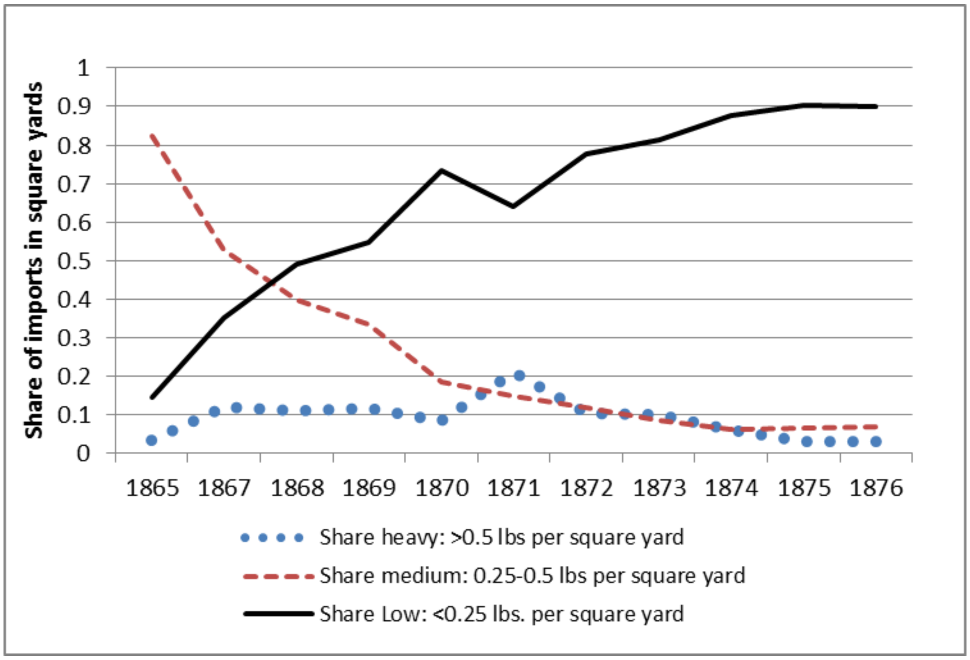
Figure 1: The Distribution of Woolen and Worsted Cloth Imports by Weight Group



Source: Shuzeikyoku (1893) and the consular reports of Belgium, Germany, France and the United Kingdom.

Table A1: Products appearing in the trade vector

Exports	Share of Total	HS Code	Imports	Share of Total	HS Code
Raw Silk	43.09	5002	Rice	8.10	1006.10
Silkworm Eggs	12.08	NA	Soy Beans	1.11	1201.00
Green Tea	23.61	9022	White Sugar	2.82	1701.11
Bancha Tea	0.43	9022	Brown Sugar	6.55	1701.11
Rice	0.85	1006.10	Kerosene	0.74	2710.19.23
Tobacco	0.63	2401.10.44	Pig Iron	0.09	7201
Shiitake Mushrooms	0.67	0712.39	Bar iron, rod iron, iron manufactures	2.57	7206, 7213
Dried Seaweed	0.97	1212.02	Steel	0.01	7206
Dried Cut Seaweed	2.02	1212.02	Lead	0.55	7801 and 7804
Agar-agar (kanten)	0.43	1302.31	Tin	0.13	8001
Dried cuttlefish	0.59	030741.0020	Raw Cotton	2.10	5201.00.05
Dried sea cucumber (iriko)	2.41	0305.63	Cotton Yarn	13.81	5205.12.10
Dried abalone (awabi)	1.98	0307.99.20	Shirtings (cotton cloth)	11.25	5208
Camphor	1.23	2914.21.10	Finished and Unfinished Cotton Cloth[1]	8.24	5208 and 5209
Coal	1.10	2701.11	Woolen and Worsted Cloth (substituting for silk)[2]	20.91	5111 and 5112
Sulphur	0.09	2503			

[1]Composed of 5 subcategories grouped on the basis of weight, count of yarn and finishing. The categories are encompassed in HS codes 5208.11.20, 5801.35, 5208.12, 5308.22.40 and 5208.31.40 and 5208.31.40 and 5208.51.40.

[2]Composed of 11 subcategories that would be encompassed in HS codes 5111.11, 5111.90, 5112.19, 5112.90 and 6301.20.

Source: Shuzeikyoku (1893) and the Harmonized Commodity System and Coding System used for United States Tariffs (found at http://hts.usitc.gov/). See the text for a discussion of the mapping from woolen and worsted cloth to silk.

Table A2 Factor prices

Factor	w^a (1851-1855) (gold ryō)	w^t (1875-1879) (yen)
Skilled Male Labor (per day)	0.056	0.20
Unskilled Male Labor (per day)	0.029	0.14
Female labor (per day)	0.016	0.11
Capital	1.00	4.10
Land: Dryfield (per tan)	1.03	4.29
Land: Paddy (per tan)	1.33	6.78

Sources: For 1851-55 and 1875-1879, wages for female labor and for unskilled male labor in the Kinai and Kantō are from Saitō (1973). In addition, wages for males unskilled labor in eastern Japan are from Suzuki (1990) for an unskilled lad (*wakamono*) at a soy brewery north of Tokyo (including 1 sho of rice each day for a meal), a water-wheel attendant at a charcoal blast furnace in the Iwate prefecture (see Tojo (1992, pp. 207-208)) and the daily earnings of a young male belt weaver in the Ashikagi district northeast of Tokyo (see Waseda Daigaku Keizaishi Gakkai (1960, p. 257)). For the 1850s, the skilled wage is for a carpenter in Okayama (see Hanley and Yamamura (1977, p. 193)), the average wage of the two skilled workers (kashira) found in the Suzuki (1990) study of a soya sauce manufacturer and the wage earned by the “key worker” of a charcoal blast furnace provided by Tojo (1992, pp. 207-208). For 1875-1879, Van Buren (1880) provides wages for a low-skilled packer and cartman and a skilled worker (tea roller) in 1879. In addition, Suzuki (1990) provides wages for skilled and unskilled workers at the soya sauce factory. Finally, Saitō (1973) provides a “high” average wage for Kantō.

The land rents for Kinai for 1851-1855 are from three sources. First, hedonic analysis of plots in the three villages near Fuse fromFurushima and Nagahara (1954, Tables 65-67) yielded estimates of rice rents for standard (second) quality land, which have been converted to values using the price of rice found for the nearby village of Shimo-Kosaka in 1852 Hensan-iinkai (1967, Table 65). The rents for two plots of standard quality dryland in 1852 from Shimo-Kosaka are found inHensan-iinkai (1967, Table 28). Finally, the rents from a nearby village (Kosakuryo) for about 31 plots of land rented out by one farmer suggest a range of rents of 1.59 to 1.71 ryō for 1853 and 1854 (see Takeyasu (1968, Table I-27)). The average of all of these observations was 1.50 ryō .For the Kantō region, hedonic regressions of 33 observations from 1851-1855 from two silk-growing regions (Gunma prefecture and the Ashikaga County) yielded land values of about 8.6 ryō, which would yield a rental value of 0.77 ryō. Waseda Daigaku Keizaishi Gakkai (1960, pp. 178-181) provides the data on land prices in Ashikaga County and Iinkai (1988, pp. 368-377) provides data on land sales in the Gunma prefecture. The average for all of Japan was taken as a weighted average based upon the shares of each area in total dryfield crops. For 1851-1855, the premium on rice paddy was about 32 percent. For 1878, land prices for rice paddy from 23 prefectures were regressed on indicators of quality and region. Again, the average rents for standard paddy land for Japan was a weighted average of higher values for the Kinai and lower values for all other regions, which were multiplied by the standard conversion factor 0.096 to find rents. The premium for paddy was about 58 percent in the early 1880s, and this was applied to the 1878 land rents to arrive at the average rents for dryland in Table A2.