Testing the price version of the Heckscher-Ohlin Theorem: the natural experiment of Japan

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Abstract:

We exploit the 'natural experiment of Japan' to test the general validity of the Heckscher-Ohlin theorem. In contrast to existing tests of the quantity version of Heckscher-Ohlin, which are all based on restrictive assumptions about preferences and technologies, we test a price version of the Heckscher-Ohlin theorem where the existence of positive gains from trade is the only critical assumption. Given that our previous research on the natural experiment of Japan (Bernhofen and Brown, 2005) provided evidence of positive gains from trade, the data environment fulfils the critical assumption of the theory.

Our test combines factor price data in the autarky period with commodity trade data and a technology matrix in the early free trade period. Our data on wages, rental rates of capital and land rents stem from a range of historical studies of the late Tokugawa period. Our technology matrix is derived from a major Japanese survey of agricultural techniques during the early Meiji period, accounts by European visitors and numerous studies by Japanese and western scholars that draw on village records, business accounts and other historical sources.

Our results provide strong empirical support for the price version of the Heckscher-Ohlin theorem. Our factor content analysis reveals that Japan was a net exporter of skilled labour and capital, which were used intensively in the major export sectors. On the factor import side, Japan was a net importer of the factor services of land, unskilled male and female workers.

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1. Introduction

This paper provides the first test of the general validity of the Heckcher-Ohlin theorem as formulated by Alan Deardorff (1982). An attractive feature of Deardorff's Heckscher-Ohlin formulation is that it provides a refutable hypothesis which is valid under very general circumstances. The challenge of testing this general Heckscher-Ohlin prediction is that it requires compatible data of a market economy operating under both autarky and free trade. This paper exploits data on Japan's 19th century transition from a market economy under autarky to a market economy under free trade to test this general Heckscher-Ohlin prediction.

The theoretical trade literature distinguishes between the *quantity or Leontief* formulation and the *price* or *Ohlin* formulation of the Heckscher-Ohlin theorem. In the quantity formulation factor scarcity is measured by data on countries factor endowments; whereas, in the price formulation factor scarcity is measured by autarky factor prices. Since factor endowments embody less information about the economy's underlying fundamentals than factor prices, Heckscher-Ohlin formulations in the Leontief tradition are based on fairly restrictive assumptions. For example, the Heckscher-Ohlin-Vanek formulation (HOV), which has dominated the empirical Heckscher-Ohlin literature for over the last three decades, assumes that all trading economies have both identical technologies and identical homothetic preferences.[2]

To our knowledge of the literature, we are the first to test a Heckscher-Ohlin theorem which falls in the Ohlin tradition of measuring factor scarcity through factor prices. This Heckscher-Ohlin formulation goes back to Deardorff (1982) who has shown that a country's autarky factor price vector imposes a restriction on country's factor content of trade with the rest of the world. It implies that a country will tend to export the services of its abundant factor and import the services of its scarce factor. Deardorff's formulation is quite general in the sense of allowing a country's factor content of trade to be measured in different ways. However, a shortcoming of Deardorff's formulation is that it assumes internationally identical technologies.

In an important follow-up piece to Deardorff (1982), Neary and Schweinberger (1986) have shown that the existence of the gains from trade is a sufficient condition for

[2] The most prominent paper are Bowen et al (1987), Trefler (1993, 1995) and Davis and Weinstein (2001).

Deardorff's Heckscher-Ohlin formulation as long as the country's factor content of trade is measured using the domestic technology matrix. The key advantage of Neary and Schweinberger's (1986) approach is that it allows for different technologies.

Given that our previous research on Japan's 19th century opening to trade provided evidence of positive gains from trade, the case of Japan provides a suitable natural experiment to test the Deardorff-Neary-Schweinberger formulation of the Heckscher-Ohlin theorem. Our test combines factor price data in the autarky period with commodity trade data and a technology matrix in the early free trade period. Our data on wages, rental rates of capital and land rents stem from a range of historical studies of the late Tokugawa period. Our technology matrix is derived from a major Japanese survey of agricultural techniques during the early Meiji period, accounts by European visitors and numerous studies by Japanese and western scholars that draw on village records, business accounts and other historical sources. Applying the data to the theory, we obtain strong empirical support for the general Heckscher-Ohlin prediction.

In section 2 we start out with an intuitive discussion of the quantity and the price measures of relative factor scarcity in the two-factor case. Using a simple graphical framework, we illustrate the inter-relationship between the gains from trade in factor service space and the price formulation of the Heckscher-Ohlin Theorem. Building on Neary and Schweinberger (1986), section 3 uses the concepts of factor trade utility and factor trade expenditure functions to derive the general Heckscher-Ohlin theorem.

Section 4 discusses the empirical domain and the data sources for the construction of the technology matrix and the autarky factor prices. Section 5 discusses the technolgoy matrix, the observed factor content of trade and provides the first preliminary test results.

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

Consider a small open economy, called home, which has the opportunity to trade with the rest of the world (ROW). We initially restrict ourselves to the case where the economy produces *n* goods using only two factors of production, factor 1 and factor 2, given by $\mathbf{V}=(V_1,V_2)$ in Figure 1.

Under autarky, the allocation of factors to the production of the *n* goods is determined by home's factor supplies, the country's technology and consumer preferences. The autarky equilibrium is characterized by equilibrium goods and factor prices. Since our focus is on factor service trade, we can restrict our attention to the economy's equilibrium autarky factor price vector $\mathbf{w^a}=(w^a{}_1,w^a{}_2)$. The vectors $\mathbf{V}$ and $\mathbf{w^a}$ determine home's gross domestic product (GDP) under autarky: $GDP^a=w^a{}_1V_1+w^a{}_2V_2$. Alternatively, $\mathbf{V}$ and $\mathbf{w^a}$ can be thought of defining an *autarky GDP factor line*, as depicted in Figure 1. The factor line goes through the endowment point $\mathbf{V}$ and has a slope of $-w^a{}_1/w^a{}_2$. The line's intercept with the horizontal axis measures autarky GDP in units of factor 1 and its intercept with the vertical axis measures autarky GDP in units of factor 2.

Figure 1 is helpful in illustrating and contrasting the two ways of measuring relative factor scarcity: Leontief's *quantity measure* and Ohlin's *price measure*. Leontief's *quantity measure* of the relative scarcity of factor 1 is given by the economy's relative endowment ratio V_1/V_2. In contrast, Ohlin's *price measure* of the relative scarcity of factor 1 is given by the equilibrium autarky factor price ratio $w^a{}_1/w^a{}_2$. The key point is that since Ohlin's price measure of relative factor scarcity embodies more information about the economy's underlying fundamentals than the quantity measure. [3] Assume that the economy experiences a sudden shift in demand towards the goods that make relatively intensive use of factor 1, ceteris paribus. Since the factor endowments have not changed, this shift in demand does not affect the quantity measure of factor scarcity V_1/V_2. However, such a shift in the relative demand of factor 1 will increase the relative scarcity of this factor. This increase in relative factor scarcity will be captured by an increase in the relative autarky price $w^a{}_1/w^a{}_2$. As a result, the new autarky

[3] The fundamental insight that prices embody all relevant information about relative scarcities was first articulated by Hayek (1945).

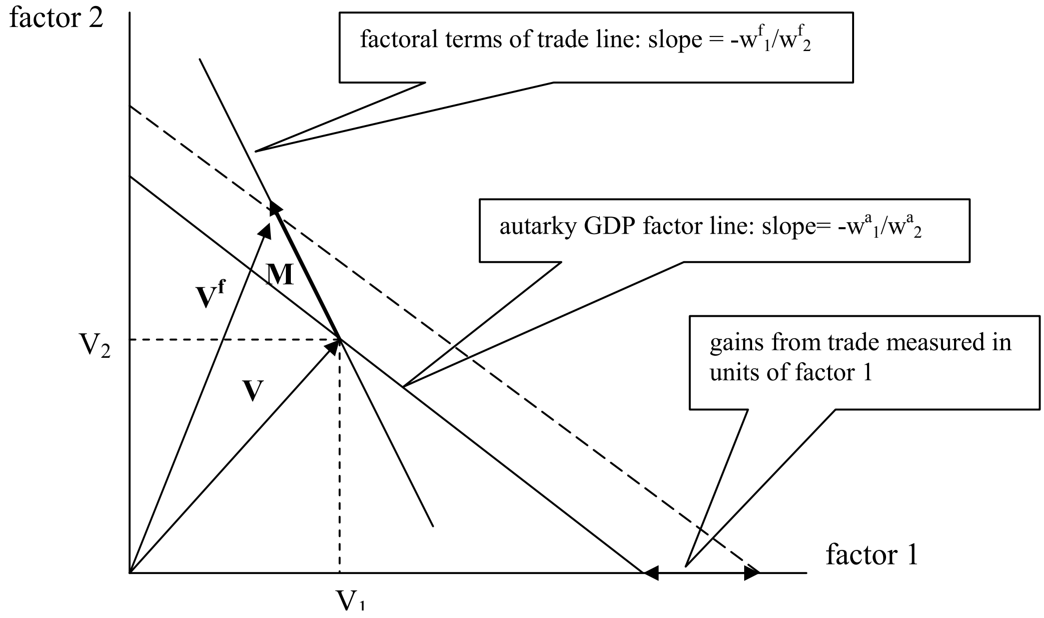
equilibrium will be characterized by a steeper autarky GDP factor line. Now since the new autarky GDP factor line will still go through V, its horizontal intercept shifts to the left and its vertical intercept will shift up. This implies a decrease in GDP when measured in units of factor 1 and an increase in GDP when measured in units of factor 2, or an increase in the relative scarcity of factor 1.

The above discussion illustrates that Ohlin's price measure of factor scarcity embodies more information about an economy's relative factor scarcity than the quantity measure. As a result, a Heckscher-Ohlin formulation which is based on Ohlin's price measure requires fewer assumptions on the economy. In fact, we can show that the gains from trade is a sufficient condition for a Heckscher-Ohlin factor content prediction.

The starting point for such a formulation is the specification of a balanced trade condition of the economy with the rest of the world. In particular, the balance of trade in commodity space will imply a balanced trade condition in factor service trade. Denoting the economy's net factor import vector as $\mathbf{M}=(M_1,M_2)$, (where $M_i>(<)0$ if factor i is imported (exported)), the balance of trade condition requires that $w_1^f M_1+w_2^f M_2=0$, where w_1^f and w_2^f denote the prices under which factor services will be traded internationally. Figure 1 illustrates that the economy's trade must then occur along its factoral terms of trade line. The factoral terms of trade line is anchored at the economy's endowment point **V** and has, in absolute value, a slope of w^f_1/w^f_2. The factoral terms of trade line illustrates that there are only two feasible trading possibilities: export factor 1 and import factor 2 (i.e. $M_1<0$ and $M_2>0$) or import factor 1 and export factor 2 (i.e. $M_1>0$ and $M_2<0$).

But in which direction will the economy trade? The principle that holds for trade in goods holds also for trade in factor services: the pattern of trade is governed by the gains from trade. International trade in factor services enables the economy to reach an augmented endowment point $\mathbf{V^f}$, defined as $\mathbf{V^f}=\mathbf{V}+\mathbf{M}$. The economy will experience a gain from international trade if the augmented endowment point $\mathbf{V^f}$ lies outside its autarky GDP factor line. Since $w^f_1/w^f_2 > w^a_1/w^a_2$, the economy will only experience a gain if it exports factor 1 and imports factor 2. The reason for this is that the relative value of factor 1 is higher in international exchange than it is domestically. In Figure 1, the gains from factor service trade is illustrated by the outward shift of the autarky GDP factor line to $\mathbf{V^f}$.

Figure 1: Heckscher-Ohlin prediction in the 2-factor case



But how can this trading pattern be explained by a comparison of relative factor scarcities at home and in the ROW? As mentioned before, w_1^a/w_2^a measures the relative scarcity of factor 1 at home. But what is the relative scarcity of factor 1 in the ROW? If the trading equilibrium is characterized by factor price equalization then the economy's factor exchange ratio coincide with the factor prices in the rest of the world: $w_1^f=w_1^{ROW}$, $w_2^f=w_2^{ROW}$. If $w_1^a/w_2^a < w_1^{ROW}/w_2^{ROW}$, then home is relatively abundant in factor 1 and the above discussion implies that the economy will export its scarce factor and import its abundant factor. However, if the free trade equilibrium is not characterized by factor price equalization, it is easy to show that w_1^f/w_2^f must always lie between w_1^a/w_2^a and w_1^{ROW}/w_2^{ROW}. As a result, $w^a_1/w^a_2 < w_1^{ROW}/w_2^{ROW}$ implies $w_1^a/w_2^a < w_1^f/w_2^f$ and home will export factor 1 and import factor 2. On the other hand, if home is relatively scarce in factor 1, i.e. $w^a_1/w^a_2 > w_1^{ROW}/w_2^{ROW}$ then $w_1^a/w_2^a > w_1^f/w_2^f$ and the gains from trade imply that home will import its scarce factor 1 and export its abundant factor 2. This leads us to the following 2-factor price formulation of the Heckscher-Ohlin theorem:

Two-factor formulation of the Heckscher-Ohlin Theorem

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

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

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

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

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

$$\mathbf{pT}=0 \tag{2}$$

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

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

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

We assume that the technology in each sector can be represented by a unit cost function which is increasing, concave and homogeneous of degree one in the economy's factor prices $\mathbf{w}=(w_1,\ldots w_l)$. The vector of unit cost functions is denoted by $c(\mathbf{w})$ and the zero profit condition implies that $\mathbf{p}=c(\mathbf{w})$, which means that the equilibrium factor price vector **w** is pinned down by the goods price vector **p**. The balance of trade condition for trade in factor services can then be written as:

$$\mathbf{wM}=0 \tag{4}$$

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

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

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

Recall that the factor price vector **w** is pinned down by the exogenously given goods price vector **p** through the cost-price relationship, $\mathbf{p}=c(\mathbf{w})$. As a result, **w** will capture the effects of international goods prices on the expenditures on factor services. Since the factor trade expenditure function embodies the equilibrium relationships between utility, factor prices and the factor content of trade it is the central tool for proving the autarky price formulation of the Heckscher-Ohlin Theorem. A key property of the factor trade expenditure function, similar to an expenditure function in consumer theory, is that it is increasing in utility, i.e. $e(\mathbf{w},u^1) \geq e(\mathbf{w},u^0)$ for $u^1 > u^0$.

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

General Heckscher-Ohlin Theorem:

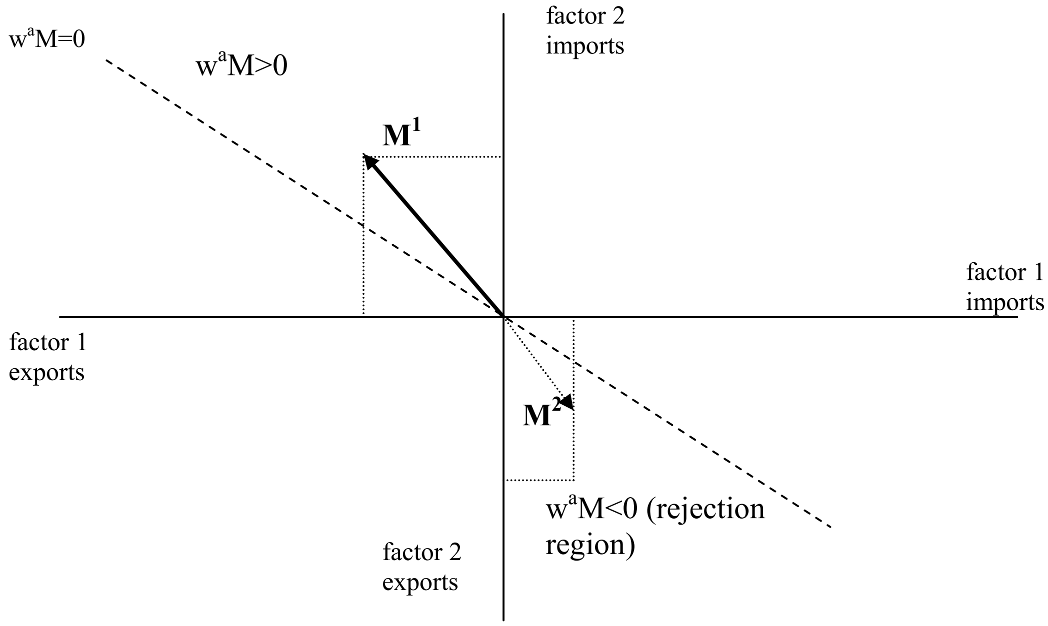
Assume that the economy experiences gains from trade, i.e. $u^f > u^a$. The autarky price vector $\mathbf{w^a}$ imposes a restriction on the factor content of net imports under free trade, such that $\mathbf{w^a M}(\mathbf{w^f},u^f,\mathbf{V}) \geq 0$.

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

Several comments are in order. First, $\mathbf{w^a M}(\mathbf{w^f},u^f,\mathbf{V}) \geq 0$ generalizes the two-factor formulation from the previous section to higher dimensions. However, if there are more than two factors, it is not possible to pinpoint which particular factor is exported or imported. Applying the balanced of trade $\mathbf{w^f M}(\mathbf{w^f},u^f,\mathbf{V})=0$ to the restriction one obtains $(\mathbf{w^a}-\mathbf{w^f})\, M(\mathbf{w^f},u^f,\mathbf{V}) \geq 0$. The latter can be interpreted that the country will, on average, import factor services that have a high factor price relative to its trading partners and import factor services with a relatively low factor price.

Second, since $\mathbf{w^a}$ imposes a restriction on the factor content of net imports $\mathbf{M}$, $\mathbf{w^a M(w^f}, u^f, \mathbf{V}) \geq 0$ constitutes a testable Heckscher-Ohlin hypothesis that can be refuted by the data. This is illustrated in Figure 2 where the economy's autarky factor price vector $\mathbf{w^a}$ identifies a hyperplane, defined as $\mathbf{w^a M}=0$. As a result, the autarky price vector $\mathbf{w^a}$ identifies whether a particular net import vector $\mathbf{M^i}$ is in accord with the prediction, i.e. $\mathbf{w^a M^1} \geq 0$, or not, i.e. $\mathbf{w^a M^2} < 0$.

Figure 2: General Heckscher-Ohlin prediction



Third, an attractive feature of this formulation is that the existence of gains from trade is the only critical sufficient condition for the Heckscher-Ohlin theorem to hold. The deeper reasoning for this generality is that this formulation combines data from two equilibria: autarky and free trade. By contrast, Heckscher-Ohlin formulations which involve only data from a free trade equilibrium require strict symmetry assumptions on technologies and consumer preferences in order to generate predictions of how factor endowment differences affect trading patterns. As a result, there is quite a bit at stake in testing this general Heckscher-Ohlin formulation since a refutation of the prediction could not be accounted for by unmet assumptions on country symmetries regarding technologies or preferences.

4. Empirical domain and data sources

The case for using Japan's 19th century opening up as a natural experiment to test comparative advantage trade theory has already been articulated in Bernhofen and Brown (2004, 2005). However, since the Heckscher-Ohlin framework is a specific comparative advantage trade model the justification for the case of Japan carries over to the test of the Heckscher-Ohlin model. The attractive feature of applying the case of Japan to Heckscher-Ohlin is the ability to test the theorem in the most general form, as discussed in the previous two sections.

The data requirements for such a test are then the following: a domestic technology $\mathbf{A}$ matrix in the free trade period, a vector of autarky prices $\mathbf{w^a}$ and a vector of net imports $\mathbf{T}$, with the theoretical predictions being that $\mathbf{w^aM}=\mathbf{w^a(AT)}>0$. Our test combines data on net imports $\mathbf{T}$, which were used in Bernhofen and Brown (2004, 2005) with newly collected data on $\mathbf{w^a}$ and $\mathbf{A}$. Before describing the data sources for the construction of $\mathbf{w^a}$ and $\mathbf{A}$, we provide a short discussion of the Tokugawa economy (i.e. autarky period) from an endowment and technology perspective.

4.1 The Tokugawa economy: an endowment perspective

The late Tokugawa economy was a well-articulated pre-modern economy with strong trading relationships among the main economic regions and evidence of significant regional specialization. At the same time, a large part of the production of goods that would enter into trade after the opening up in 1859 were produced in rural areas with the household as the production unit. Historians debate how successful the late Tokugawa economy was at overcoming two fundamental constraints: land scarcity and unproductive technologies. The opening up of trade may have been fundamental in relaxing both of these constraints. (Totman and American Council of Learned Societies., 1995) stresses the limits that Japan's geography placed on the resources available to it.

His study of the lumber industry (Totman, 1995) highlights the more general ecological stress of Japan's land scarcity. Japan's topography essentially has only three gradients. A small percentage of the land area is flat land well-suited for rice and other crops. The plains are typically surrounded by diluvial terraces, which give way to steep mountains. The core traditional economic regions of Japan are at the heart of these plains (the Kinki (Osaka/Hyōgo/Kyoto), Nobi (Nagoya) and Kantō (Tokyo)). Additional outposts were Nagasaki on the island of Kyushu and port cities and fishing villages along the coast of the Sea of Japan and the Inland Sea. The remainder of the land area (about 80 percent) is a series of steep mountain ranges that run up and down the spine of all four main islands. Totman argues that by the early 18th century, land scarcity dominated the Tokugawa economy in all resource-intensive areas of production, including agricultural, forestry and mining (Totman, 1995, ch.12). The most prominent adaptation to the scarcity of land was the development of a sophisticated fertilizer industry, which utilized waste organic materials from farms and the cities and drew upon sardine and herring resources available off of the northern island of Hokkaido. High demand for lumber (particularly after disastrous urban fires that followed in the wake of large earthquakes) led to classic Ricardian diminishing returns, as the lumber industry was forced to go ever deeper into the mountains to secure supplies (Totman, 1995a) and (Totman, 1995b).

The other significant feature of Tokugawa Japan that receives attention in the historiography is the state of technological development. On the one hand, historians stress the ability of Japanese produces to develop and adopt new and sophisticated methods for production and organization. The history of innovation in the Japanese fisheries discussed in (Kalland, 1995) and (Howell, 1995), for example, points to considerable ingenuity in both the development of new nets and methods of organizing fishing. On the other hand, the cultural and economic isolation of Japan before 1859—despite the access to Dutch writings on technology—meant that its technologies were unable to take advantage of developments in the substitution of mechanical action for human labor so prominent in the textile sector, advances in metallurgy or the application of inanimate power to drive machines and move earth.

This discussion of the construction of the resource requirement matrix (or **A** matrix) for the late Tokugawa and early Meiji economies (that is, after the opening up of trade in 1859) will focus first on a describing the kinds of sources that are available. It will then turn to the identification of the five main fundamental resources of this economy and two key intermediate goods: fertilizers and charcoal. The integration of the Tokugawa and early Meiji economies meant that production relationships (upstream and downstream) could be quite sophisticated, despite the fact that this was a pre-industrial economy closed off to significant international trade.

Japan's pattern of specialization after the opening up of trade enables ready calculation of the bulk of its factor exports. The pattern of imports is much more diverse, but significant progress can be made by focusing on two major foodstuffs (rice and beans), cotton and manufactures made of cotton and metals.

*4.2 Sources for the **A** matrix*

An initial look at the available sources would suggest some pessimism about the ability to reconstruct the factor requirements of a major set of products during the early years of international trade (1859 to 1875). The first survey of industrial production in Japan only took place in Meiji 7 (1874), and the first comprehensive census—which forms of the basis of reconstructions of Japan's national accounts—only took place in 1885. Nonetheless, a numerous sources exist that allow for a reasonable approximation to resource requirements. Most important, for much of the nineteenth century after 1859 (the opening up), the rapid diffusion of new technologies into the Japanese economy was limited to a few readily identifiable sectors. Partly because they were so remarkable, the diffusion is well documented. Through the late 1880s, most of the economy operated with essentially the same technologies that were in use during the late Tokugawa era. For those sectors that experienced rapid technological change, contemporary documents and the reports of foreign visitors allow a ready assessment of the differences between the modern and traditional technologies, which accounted for virtually all of the production during the first fifteen years or so of open trade.

We know less about the substitution of factors that may have occurred after the opening up, which may make data from traditional technologies that were in use after the opening up suspect. For the most prominent cases, such as the establishment of larger-scale tea refining operations or businesses that specialized in the raising of cocoons, it appears that when factor substitution did take place, it also involved new forms of business organization. Fortunately, it is possible to check the results reached using technological data from the early Meiji period against sources that document actual factor requirements during the Tokugawa period. The discussion of the robustness of the estimates presented here includes this check where possible.

The most important source for this study is the massive *Nouji Chosa*, a series of surveys of agricultural production statistics in Japanese prefectures. The survey took place during the late 1880s, and was reprinted in Chō, et. al. (1979) as a multi-volume set. The basis of the coverage is uneven. Some of the data cover particular villages and other cover counties of prefectures. Some are differentiated according to landlords or tenants. A majority of prefectures did not supply data.[4] An important advantage of this source is its inclusion of all tradable agricultural products (with the exception of vegetable wax) and the astounding detail provided about inputs. Detail is available for all major productive tasks according to the days of labor needed, usually broken down by sex and always including the total cost of labor (from which sex can very often be inferred). For example, the data on tea production includes cultivating, fertilizing, picking and processing. The source provides detail on the weight and type of fertilizer for about twenty kinds of fertilizer. Information is provided on the amount of fixed and working capital used (often with an estimated rate of depreciation) and often on the types of capital used. Other inputs are also reproduced. Finally, the common practice was to record information on inputs per tan, a unit of areal measure equal to 300 *tsubo* or about one-tenth of a hectare. This source provided the starting point for all of the agricultural commodities found in the **A** matrix.

The second important source for this study are the observations of individual travelers and experts hired by the Japanese. The most famous of these is the memorandum written by the French mining engineer, Francisque Coignet, *Note sur la richesse minerale du Japon* (Coignet, et al., 1957), which provides detailed comparisons of the input requirements for all six stages of traditional copper mining, smelting and refining technologies. Three other examples include the reports by the American mining

[4] Usable data from only 19 out of 47 prefectures is available. These are scattered around the country, but are most heavily concentrated in the western part of the country.

engineers Pumpelly and Lyman (Lyman, 1879, Pumpelly, 1866) and the summary of conditions by the German engineer Netto (Netto, 1879).[5] Several foreigner visitors and experts provided detailed reportage on the other main Japanese export industries. One example is (de Bavier, 1874). De Bavier was the representative in Yokohama for one of the most important French importers of Japanese silks. American, British and Austrian observers also offered detailed accounting of production conditions in silk and tea over the late 1860s to the early 1880s.[6] Not all foreign observers had the detailed knowledge of de Bavier or Coignet, but they were accustomed to describing production conditions in terms of inputs used and outputs gained.

Japanese economic and business historians are primarily responsible for the final source for information on technologies and factor usage. Buried away in communal and other governmental archives and business and family papers are detailed accounts of production conditions for a range of industries. Historians have brought these materials together to provide a rich picture of the economic and commercial life of late Tokugawa and early Meiji Japan. Historians have also made use of a few of the *han* surveys of the middle 19th century, which can also help to sort out the basic production conditions.[7]

A review of all of these materials suggests that as a first approximation, technologies of the late Tokugawa economy utilized five basic inputs: skilled male labor, unskilled male labor and female labor. Primarily found in urban areas, skilled labor was found in the traditional crafts and in some industries such as soy brewing. Satio (2005) provides estimates for evolution of skill premium, which was on the order of three or four to one during this period. Male unskilled labor was found in urban and rural areas. The **A** matrix developed here assigns most rural farm labor to the unskilled category, although certain activities in areas such as silk reeling would perhaps be best categorized as skilled.[8] As Japanese economic historians have long recognized, much of rural production was carried out on a by-employment basis (for example, the spinning and

[5] Yoshiki (1979) provides an extended discussion of the reports of the activities of numerous western mining engineers employed to upgrade the technologies used in the Japanese mining industry.
[6] See (Adams, 1870, Gribble, 1883, Scherzer, 1872, Syrski, 1872, Watson, 1873).
[7] See, for example, the survey of the Chōsū *han* conducted in the early- to mid-1840s (Yamaguchi-ken Monjokan, 1960).
[8] See (Narita, et al., 1978) for a contemporary discussion of the skill requirements for raising silk. He argued that proper reeling required in excess of twenty to twenty-five years to fully master the skills required for this task.

weaving of yarn). Although this organization of production allowed the full employment of labor throughout the year, it may have diminished some of the gains accruing to specialization and mastering particular tasks.[9] The final category of labor, female labor, most likely encompassed skilled and unskilled work. It also includes the work of young girls as well as women. As we will see, whether or not the work was primarily performed by women appears to be an important influence on the pattern of trade in factors of production.

The final two factors, land and capital, are treated in this study as homogenous inputs as a first approximation. Land is measured in terms of tan (about one-tenth of a hectare). Measuring of the input land does not distinguish between uplands and plains. Compared with other factors of production the measurement of capital is subject to greater measurement error. At the current state of our knowledge, it is missing for some activities (including smelting and refining activities of metals and some mining). Measurement also posed challenges, but the agricultural survey of the mid-1880s provides a great deal of detail on charges for maintenance of capital. Many other sources also provide either the charges to capital or the initial set-up costs (with implicit rates of depreciation) (Howell, 1995). The measured charges from this source have used the rate of depreciation prevailing in the 1870s and early 1880s, but have adjusted the implicit rate of interest upwards to reflect the higher cost of credit for rural industries.[10] In any event, capital charges have all been converted to the buying power of the ryō of 1851-1853. (See the discussion of factor prices).

The technologies of the period involved two important intermediate inputs: fertilizer and charcoal. Most of the attention in this study has been devoted to fertilizer, which by the early nineteenth century included a supply chain that reached from Hokkaido through the Sea of Japan all the way to the Kinai region, which was the center of cotton production. Although the agricultural survey of the mid-1880s counted over twenty kinds of fertilizer, there were essentially four varieties used in Japan. The variety with a truly national market was fish fertilizer. Fish fertilizer made of sardines had been

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[9] For a full exploration of this question, a comparison with the silk weaving industry may be in order.

[10] Reported rates of depreciation ranged form three or four percent to much higher amounts, depending upon the capital good. The standard interest charge appears to have been 10 percent. This has been adjusted upward to 12 percent.

used substantially up through the 18th century, but the opening of the southern part of the northern island of Hokkaido (and its settlement by the Matsumae clan) led to the development of a seasonal herring fishery.[11] Herring was used both as a foodstuff and was also processed into fish fertilizer, which was then transported primarily to western Japan (the Kantō region relied much less on herring fertilizer). A second important source of fertilizer was human waste, which was primarily available near large cities. Wastes from soybean oil, sake and rapeseed oil production constituted a third source that was available locally. Finally, Japanese farmers relied upon composted leaves from common forest land, rice husks, and other materials. To summarize the resources embodied in these diverse fertilizers, equivalents per kan (equal to about 8.28 lbs.) were established using the relative price information available in the *Nouji Chosa*.

Ascertaining the resource requirements for the production of charcoal, which was used in alternation with wood for all smelting and refining of ores, has proven more difficult. The cost varied substantially depending upon the extent to which forests surrounding sites with ore had been depleted. This part of the input requirement matrix will be filled in using additional data on the charcoal and lumber industries.

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

Japanese and western economic historians (and contemporary observers) have provided a rich documentation of the prices for different kinds of labor. This paper relies heavily upon the work of Saito, which is summarized in his book, several journal articles and book chapters (Saito, 1998, Saito, 1998, Saito, 2005, Saito, 1991). Saito has been able to document the rate of pay for male and female agricultural workers in both the Kinai and the Kantō regions. The rates of pay for urban unskilled workers are available for longer time periods from both Edo (Tokyo) and Osaka/Kyoto. The wages of skilled workers can be inferred from various construction trades and other craft occupations, such as the sewing of tatami mats. For the initial calculations used in this paper, the wages for agricultural workers compiled from the records of landlords from near Osaka found in (Saito, 1973,Table 1) are used for male unskilled and female unskilled labor.

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[11] See (Howell, 1995, Nakanishi and 中西聡, 1998).

The year used is 1856-1860.[12] Most of the export and import-competing industries were based in rural areas, so that these wage series offer the best first approximation to wage costs. For skilled workers, the wage series of Osaka carpenters relative to wages for day laborers in Kyoto provides a good approximation of the skill premium. That was up to four to six times the rate paid unskilled labor.

The valuation of land used two sources: the report of Syrski on the valuation of land around Nagasaki and the report of Gribble on land used for tea shrubs near Shuzuoka.[13] In addition, (Henderson, 1975, pp. 64-65) provides a valuation of a rice field in Shiga Prefecture ca. 1821. These reports resulted in a median of 0.11 ryō in ryō of 1851-1853 using the index of the price of non-tradables found in Shinbo(1978, Table 5-10). The Henderson data for transfer of a rice field yields a an upper bound measure of about 0.14, which provides some assurance that the estimate for the early 1850s is not too far off of the mark.

The price of capital is the relevant interest rate plus depreciation. For most of the industries discussed above, the relevant cost of capital was often (but not always) included a rate of depreciation and an interest rate. From the data for agricultural-based industries, the usual charge appears to have been listed as depreciation or interest. These charges ranged from two percent for rice to up to 8 to 10 percent for the export products, silk and tea. As a first approximation, the results presented here assume that the rural producers of all of these commodities faced an annual interest rate of twelve percent. As Toby and Saito note (Saito and Settsu, 2006, Toby, 2004), actual interest rates paid by small-time producers varied according to a number of characteristics that the data at hand can not identify. Saito (2006, p. 10) cites the studies of Uemura and Nakmura that, despite showing diverging trends in the 1860s and later, are consistent with Toby's finding of 12-15 percent in the 1840s for a village near Nagoya (in western Japan).[14] The resulting charges for capital used in this study were up to 15 or 16 percent for industries such as silk and tea, where the reported maintenance charges were relatively high.

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

[13] See (Gribble, 1883, p. 10, Syrski, 1872, p. 199). The valuations are reported estimates for 1860, the first year of open trade.

[14] All of these studies deal with provinces in western Japan. I am not aware of studies of rural interest rates that provide insight into rates in the rural Kantō.

5. Empirical results

5.1. Technology matrix

A brief review of the elements of the **A** matrix (presented in Table 1) illustrates the net resource requirements of most of Japan's most important tradable goods. Note first of all that the matrix includes all intermediate input-output relationships reduced to their fundamental resource requirements. For some goods, these relationships could be rather intricate. Silk production required purchase or raising of cocoons, which in turn were raised from silkworm eggs usually purchased from an independent vendor. The raising of cocoons required mulberry leaves, which were in turn produced by specialized growers. The calculation of the final input requirements for silk required information about the productivity of silkworm eggs in terms of cocoons that could be raised, the required amount of mulberry leaves for raising cocoons and the productivity of cocoons in terms of reeled silk. The final production of some metals such as lead required knowledge of the resource requirements in the production of pig iron.

The relative importance of particular resources (such as female labor) could in the end depend upon substantial intensity in the production of an intermediate product. Cotton cloth production required yarns that were typically spun by female labor. The use of primarily female labor for the time-consuming task of picking cotton created a bias towards female labor that was present even before the cotton was ginned and sent to the market. Male miners dug out ore from the cramped tunnels or galleries typical of Japanese mines of the 1860s and early 1870s, but women were usually employed to wash the ores and break them (by hand) into small pieces for further processing.

The **A** matrix reveals the diversity of input usage for traded goods. The input usage reflects both the organization of production and assigning of tasks by sex (as well as skill level). Virtually of the goods of an agricultural origin or using raw materials produced in agriculture were produced by peasant households or medium-sized farmers.[15] The raising of silk cocoons was a time-intensive task that took place over a few short weeks. It required the labor of the entire family, which could result in relatively balanced

[15] One exception may be the refining of sugarcane, which required more in capital equipment than would be typical for a peasant household. However, it should be noted that the fishing enterprises that supplied much of the fertilizer industry were essentially small businesses with access to credit markets.

use of male and female labor. Some tasks within the household were specialized by sex, including field tasks such as picking cotton or tea, the spinning of cotton yarn and often the weaving of cotton cloth. More often than not, products that heavily used female labor would be produced in the home.[16]

As the **A** matrix illustrates, skilled labor was much more likely to be found in the mining and metallurgy sector, although skilled male labor was also critical for sorting tea prior to sale. Mines and smelting or refining operations were typically operated as a family firm or a government enterprise. Those in the private sector relied upon teams led by skilled miners, who were identifiable by either their wage or the description provided by the sources.[17] It is also noticeable that if we recognize that 100 catties equal one picul, the resource requirements for soybeans were actually a bit higher than rice. Partly because of the use of fertilizer, cotton and tea required even more resources.

Table 1: The A matrix for Japan ca. 1865/1870

	Male skilled labor (days)	Male unskilled labor (days)	Female labor (days)	Capital (ryō)	Land (tan)
Net Exports					
Silkworm Eggs per sheet	0.035	0.848	0.160	0.065	0.015
Silk	0.409	7.724	10.014	1.701	0.236
Tea	0.248	0.277	0.126	0.088	0.014
Copper	0.129	0.035	0.002	0.000	0.000
Coal per ton	0.008	0.008	0.000	0.000	0.000
Net Imports					
Rice per picul	0.000	6.594	1.038	0.163	0.256
Soybean	0.000	0.058	0.015	0.003	0.005
Lead	0.654	0.565	0.663	0.065	0.000
Tin	1.523	0.841	0.000	0.000	0.000
Pig iron	0.004	0.050	0.000	0.035	0.000
Refined iron	0.021	0.071	0.000	0.083	0.000
Brown sugar	0.000	0.175	0.050	0.007	0.003
White sugar	0.000	0.378	0.109	0.013	0.005
Raw ginned cotton	0.000	0.511	0.526	0.038	0.015
Yarn	0.000	0.538	3.757	0.040	0.016
Unfinished cloth	0.000	0.031	0.399	0.016	0.010

[16] This comment excludes tea firing establishments, which were staffed almost entirely by women. It is also noteworthy that the emergence of many larger-scale production activities (for example, machine reeling establishments, cocoon raising firms or machine spinning) that were carried on outside of the home also relied heavily on child labor.
[17] By the mid-1880s, the standard was in excess of 15 sen per day.

Finished cloth	0.126	0.031	0.399	0.016	0.001

Notes: All resource requirements are per catty (1.33 lbs.) unless otherwise specified. A picul was equal to 133.33 lbs. The ryō was the gold-based currency of the Tokugawa Japan. One tan is about one-tent of an acre.
Sources: For a detailed discussion of the sources, please see the Data Appendix.

5.2. Trade in factor services

Table 2 applies the the technology matrix to commodity exports and imports for each year of 1868-1875. The choice of 1868 reflects the higher reliabitity of the commodity trade data at the beginning of the Meiji period compared. The reason of ending in 1875 reflects the comparability with the autarky period with regard to the domain of importables. Although there is some variation across the period, the results are quite consistent regarding the pattern of factor service trade. Regarding the volume of factor service flows, a striking feature in the labor category is the high magnitude of female labour days embodied in both exports and imports. With the exception of 1868, Japan was a net exporter of skilled labour, reflecting the relative skill intensity of silk production which was the main export sector.[18] On the import side, Japan was a net importer of female workers and land in each trading year. As mentioned before, the net imports of land is quite obvious. The large volume of net imports of female workers suggests that international trade relieved some of the pressure on the domestic female labor supply. (More discussion….)

Table 2: Japan's Net Factor Imports: 1868-1875 (AT)

	Exports	Imports	Net factor imports
1868			
Labor male skilled (days)	2.39	1.62	-0.77
Labor male unskilled (days)	12.36	12.21	-0.14
Labor female (days)	12.50	31.45	18.95
Capital (ryo)	2.69	1.43	-1.26
Land (tan)	0.40	0.53	0.13
1869			
Labor male skilled (days)	2.02	1.83	-0.20
Labor male (days)	8.58	27.34	18.77
Labor female (days)	8.30	41.89	33.58

Capital (ryo)	1.89	2.10	0.21
Land (tan)	0.28	1.17	0.89
1870			
Labor male skilled (days)	3.17	1.37	-1.80
Labor male (days)	9.50	59.03	49.53
Labor female (days)	8.43	59.27	50.84
Capital (ryo)	2.20	2.93	0.73
Land (tan)	0.33	2.20	1.86
1871			
Labor male skilled (days)	4.44	0.73	-3.71
Labor male (days)	15.16	48.01	32.85
Labor female (days)	15.14	52.06	36.92
Capital (ryo)	3.47	2.69	-0.78
Land (tan)	0.51	1.76	1.25
1872			
Labor male skilled (days)	4.63	0.98	-3.65
Labor male (days)	11.83	18.99	7.16
Labor female (days)	10.80	76.83	66.04
Capital (ryo)	2.73	2.60	-0.13
Land (tan)	0.41	0.91	0.50
1873			
Labor male skilled (days)	3.35	0.03	-3.32
Labor male (days)	11.45	16.68	5.23
Labor female (days)	11.44	59.54	48.11
Capital (ryo)	2.64	2.67	0.02
Land (tan)	0.39	0.75	0.36
1874			
Labor male skilled (days)	5.80	1.41	-4.40
Labor male (days)	14.05	23.96	9.91
Labor female (days)	12.49	69.69	57.20
Capital (ryo)	3.49	3.58	0.10
Land (tan)	0.52	0.96	0.44
1875			
Labor male skilled (days)	5.59	2.18	-3.41
Labor male (days)	13.92	28.27	14.36
Labor female (days)	12.64	87.36	74.72
Capital (ryo)	3.50	4.29	0.79
Land (tan)	0.52	1.18	0.66

Notes: The net factor trade is **A**T, where T=(imp-exp). All values are expressed in millions.
Source: Trade data from the Meiji trade statistics. See the data appendix for the sources of data for the **A** matrix.

5.3 Test results

Table 3 contains the autarky price values of Japan's exports, imports and net imports for each of the trading years 1868-1875. The main results, i.e. the sign of the inner product $\mathbf{w^a AT}$, are reported in the last row of this Table. With the exception of 1868, the sign is positive for each of the trading years. So far, the findings provide strong evidence for the Heckscher-Ohlin hypothesis. However, the following robustness exercises are still awaiting further execution: (i) use of alternative autarky factor price measures, (ii) completion of technology matrix for some "minor" export and import goods (i.e. those with small trading quantities) and (iii) robustness regarding trade deficits (Note: a trade deficit biases the inner product towards a positive sign).

Table 3: The value of Japan's Factor Trade in the Early Years of Open Trade (in thousands of gold ryō (w^aAT))

	Price ca. 1853-1856 (In gold ryō)	1868	1869	1870	1871	1872	1873	1874	1875
Exports									
Labor male skilled	0.16	388	328	513	720	750	542	940	905
Labor male	0.03	334	232	256	409	319	309	379	376
Labor female	0.02	225	149	152	272	194	206	225	228
Capital (per unit)	0.24	655	460	536	844	664	643	848	852
Land (per tan)	0.11	44	31	36	56	45	43	57	58
Total (w^a**AX**)		1645	1199	1493	2302	1972	1701	2393	2360
Imports									
Labor male skilled	0.16	262	296	222	119	159	5	228	353
Labor male	0.03	330	738	1594	1296	513	450	647	763
Labor female	0.02	566	754	1067	937	1383	1072	1254	1573
Capital (per unit)	0.24	347	512	713	655	632	649	872	1045
Land (per tan)	0.11	58	128	241	193	100	82	106	130
Total (w^a**AM**)		1564	2428	3837	3201	2786	2259	3107	3863
Imports-Exports									
Labor male skilled	0.16	-125	-32	-291	-601	-591	-537	-712	-552
Labor male	0.03	-4	507	1337	887	193	141	267	388
Labor female	0.02	341	605	915	665	1189	866	1030	1345
Capital (per unit)	0.24	-308	52	177	-189	-33	6	24	193
Land (per tan)	0.11	15	97	205	137	55	40	48	73
Total Net (w^a**AT**)		-81	1229	2343	899	813	558	714	1503

Notes: The value in each row is the net valuation of the trade in that factor at factor prices prevailing under the last years of aut1rky (1853-1856). For a discussion of the valuation of factors of production, please see the text.

References

Adams. "Report by Mr. Adams, Secretary to Her Majesty's Legation in Japan on the Central Silk Districts of Japan." 353-71, 1870.

Atkinson, R. W. "The Chemistry of Sake Brewing." *Memoirs of the Science Department Tokio Daigaku (University of Tokyo)* no. No. 6 (1881).

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

Bernhofen, Daniel. M., and John C. Brown. "A Direct Test of the Theory of Comparative Advantage: The Case of Japan". *Journal of Political Economy* 112, no. 1 (2004): 48-67.

Bernhofen, Daniel M., and John C. Brown. "An Empirical Assessment of the Comparative Advantage Gains from Trade: Evidence from Japan." *American Economic Review* 95, no. 1 (2005): 208-25.

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

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

Deardorff, Alan V. "The General Validity of the Heckscher-Ohlin Theorem." *American Economic Review* 72, no. 4 (1982): 683-94.

Gribble, Henry. "The Preparation of Japanese Tea." *Transactions of the Asiatic Society of Japan* 12, no. 1 (1883): 1-87.

Hauser, William. *Economic Institutional Change in Tokugawa Japan: Osaka and the Kinai Cotton Trade*. London: Cambridge University Press, 1974.

Hayek, Friedrich A. von. "The Use of knowledge in Society." *American Economic Review* 35 (1945), 519-30.

Henderson, Dan Fenno comp. *Village "Contracts" In Tokugawa Japan : Fifty Specimens with English Translations and Comments*, *Asian Law Series ;; No. 2;*. Seattle: University of Washington Press, 1975.

Howell, David Luke. *Capitalism from within Economy, Society, and the State in a Japanese Fishery.* Berkeley: University of California Press, 1995.

Ichiro, Takahashi. "Wrought Iron from the Traditonal Tatara Furnace." In *History of Industry and Technology of Japan*, edited by Erich Pauer, 137-52, 1995.

Itoh, Motoshige, and Masayuki Tanimoto. "Rural Entrepreneurs in the Cotton-Weaving Industry of Japan." In *In: Toward the Rural-Based Development of Commerce and Industry: Selected Experiences from East Asia; 47-68; Edi Learning Resources Series. Washington, D.C.: World Bank*, edited by Yujiro Hayami, 1998.

Japan. Ōkurashō. *Shuzeikyoku. Dai Nihon Gaikoku Bōeki Nijūgonen Taishōhyō : Meiji Gannen Yori Dō Nijūgonen Ni Itaru*. Tōkyō: Koide Yoshifusa, 1893.

Japan. Rinji Hakurankai Jimukyoku (Chicago Exposition 1893)., and Japan. (Chicago Exposition 1893). "Naikoku Kangyō Hakurankai Shinsa Hyōgo." In *Meiji zenki*

sangyō hattatsushi shiryō : Kangyō hakurankai shiryō ; 191. Tōkyō Meiji Bunken Shiryō Kankōkai, 1975.
Kalland, Arne. *Fishing Villages in Tokugawa Japan*, Nordic Institute of Asian Studies Monograph Series. Richmond, Surrey: Curzon Press, 1995.
Kasuga, Yutaka. "Transfer and Development of the Coal Mine Industry in Hokkaido." In *HSDP-JE Series*. Tokyo: United Nations University, 1982.
Lyman, Benjamin Smith. *Geological Survey of Japan: Reports of Progress for 1878 and 1879*. Tookei: Public Works Department, 1879.
Nakanishi, Satoru. *Kinsei Kindai Nihon No Shijō Kōzō : "Matsumae Nishin" Hiryō Torihiki No Kenkyū* Shohan.. ed. Tōkyō: Tōkyō Daigaku Shuppankai , 1998.
Narita, Shisai, Kanrei Koyana, Kinzaburō Igarashi and Hiroshi Ishiyama. *Kogai Kinuburui Taisei*, *Edo Kagaku Koten Sōsho ; 14*. Tōkyō: Kōwa Shuppan, 1978.
Neary, J. Peter, and Albert G. Schweinberger. "Factor Content Functions and the Theory of International Trade." *Review of Economic Studies* 53, no. 3 (1986): 421-32.
Netto, C. *On Mining and Mines in Japan [Microform]*, *Memoirs of the Science Department, University of Tokio, Japan*. Tokio, Japan: The University, 1879.
Oka, Mitsuo, and Ryūzō Yamazaki. *Nihon Keizaishi : Bakuhan Taisei No Keizai Kōzō* .Shohan. ed. Kyōto: Mineruva Shobō, 1983.
Pumpelly, Raphael. *Geological Researches in China, Mongolia, and Japan, During the Years 1862-1865*, *Smithsonian Contributions to Knowledge. [Vol. Xv, Art. 4]*. [Washington,: Smithsonian institution, 1866.
Saito, Osamu. "Edo Shichyu Ni Okeru Service Gyo Chingin: 1775-1871 (Wage of Service Industry in Edo)." *Nihon Rekishi* 430 (1998): 81-85.
———. "The Labor Market in Tokugawa Japan: Wage Differentials and the Real Wage Level, 1727-1830." In *In: Japanese Economic History, 1600-1960. Volume 6. The Japanese Economy in the Tokugawa Era, 1600-1868; 266-82; New York and London: Garland*, edited by Michael Smitka, 1998.
———. "Movements of Agricultural Wage Rates in Japan." *Shakai-Keizai-Shigaku* 32, no. 2 (1973): 50-69.
———. "Wages, Inequality, and Pre-Industrial Growth in Japan, 1727-1894." edited by Robert C. Allen, Tommy Bengtsson and Martin Dribe. Oxford and New York: Oxford University Press, 2005.
———. "Women's Labor in Agricultural Development--Japan's Historical Experience (in Japanese)." *Economic Review (Keizai Kenkyu)* 42, no. 1 (1991): 31-41.
Saito, Osamu, and Tokihiko Settsu. "Money, Credit and Smithian Growth in Tokugawa Japan." Tokyo: Hitotsubashi University, 2006.
Scherzer, Karl. *Fachmännische Berichte Über Die Österreichisch-Ungarische Expedition Nach Siam, China Und Japan (1868-1871.)*. Stuttgart,: J. Maier, 1872.
Shinbo, Hiroshi. *Kinsei No Bukka to Keizai Hatten : Zen Kōgyōka Shakai E No Sūryōteki Sekkin*. Tōkyō: Tōyō Keizai Shinpōsha, 1978.
Syrski, S. "Landwirtschaft in Japan." In *Fachmännische Berichte Über Die Österreichisch-Ungarische Expedition Nach Siam, China Und Japan (1868-1871.)*, edited by Karl Scherzer, 175-227. Stuttgart: Julius Maier, 1872.
———. "Über Seidenkultur in Japan." In *Fachmännische Berichte Über Die Österreichisch-Ungarische Expedition Nach Siam, China Und Japan (1868-1871.)* edited by Karl Scherzer, 228-86. Stuttgart: Julius Maier, 1872.

Takeda, Haruhito. *Nihon Sandōgyōshi*. Shohan. ed. Tōkyō: Tōkyō Daigaku Shuppankai, 1987.

Tanimoto, Masayuki. "The Evolution of Indigenous Cotton Textile Manufacture before and after the Opening of the Ports." *Japanese Yearbook of Business History* 9 (1992): 30-56.

Toby, Ronald P. "Country Bankers in Proto-Industrial Japan: The Transformation of Credit." In *In: The Economic History of Japan: 1600-1990. Volume 1. Emergence of Economic Society in Japan, 1600-1859; 301-36; Oxford and New York: Oxford University Press*, edited by Akira Hayami, Osamu Saito and Ronald P. Toby, 2004.

Totman, Conrad. *The Lumber Industry in Early Modern Japan*: Honolulu Univ. of Hawaii Press, 1995.

Totman, Conrad D., and American Council of Learned Societies. *Early Modern Japan*. 1st pbk. print. ed. Berkeley: University of California Press, 1995.

Uchida, Hoshimi. "Narrow Cotton Stripes and Their Substitutes." *Textile History* 19, no. 2 (1988): 159-70.

Uemura, Masaharu.

Wada, Tsunashirō. *The Mining Industry of Japan During the Last Twenty Five Years, 1867-1892 [Microform]*. Tokyo: Printed at the Tokyo Tsukiji Type Foundry, 1893.

Watson. "Reports on the Production of Tea in Japan." In *British Parliamentary Papers*, 1873.

Woodland, Alan D. "Direct and Indirect Trade Utility Functions." *Review of Economic Studies* 47, no. 5 (1980): 907-26.

Yamaguchi-ken Monjokan.*Bōchō Fūdo Chūshin'an*.Yamaguchi: Yamaguchi-ken Monjokan,1960.

Yoshiki, Fumio. "Metal Mining and Foreign Employees." *The Developing Economies* 14, no. 4 (1979): 484-505.

Data Appendix for construction of the A matrix

This discussion of the data sources for the **A** matrix is divided according to each product. The discussion is broken down according to agricultural products (materials), agricultural products (food) and mineral products. The first category includes sericulture and related products and raw cotton and cotton textiles. The second category includes tea, rice, soybeans, brown sugar and white sugar. The final category includes coal, lead, tin, copper (refined), pig iron and iron manufactures.

Sericulture

Sericulture involves four separate products: mulberry leaves, silkworm eggs, cocoons and raw silk (reeled from cocoons). Several sources provide details about the interrelationship among these products and some information on resource use.[19] By the end of the Tokugawa era, the raising of mulberry leaves and of silkworm eggs had become separate enterprises with some degree of regional specialization. During the early trade period, cocoons were raised by individual households within the home using household labor. There were only a few of the larger-scale cocoon-raising establishments, which seem to have become more widespread during the 1880s and later. Where the cocoons were raised had important implications for the division of labor. Within the household, it would be a mix of male and female labor. In specialized cocoon-raising establishments, the labor was primarily younger women with an overseer. The technology matrix used here assumes that cocoons were raised by peasant households. Finally, during the early trade period, silk reeling using hand methods continued to dominate.

Chō, et al. (1979) provides the most detail on resource use in multiple volumes dedicated to the results of surveys carried out by prefecture (or by county, or *gun*). Not all prefectures were important sources of silk production and by no means is the coverage of the agricultural survey complete. Based upon the discussion of de Bavier (1874), the prefectures for which data were available and which are also more important for silk production were included in the analysis. They included Aomori, Akita, Yamagata and Yamanashi prefectures for mulberry leaves, cocoon raising and the production of

[19] Adams (1870), Bavier (1874), Syrski (1872).

silkworm eggs. The reeling of silk also took place for the most part within peasant households using hand methods during the early period of open trade.[20] By the mid-1880s (the period of the agricultural surveys), machine reeling was diffusing rapidly, although most Japanese silk was still reeled using hand methods. These calculations used only data from respondents to the survey who explicitly stated they were using hand methods. This consideration necessarily broadened the scope of included prefectures; for silk reeling, the study included Osaka, Hyōgo, Tottori, Ehime, Oita, Nagaski and Aomori prefectures. Most of these prefectures lie outside of the classic central silk producing region, but data from these areas would be more likely to capture the productivity of reeling using hand methods.

Cotton and cotton textiles

The main source for cotton production was Chō, et al. (1979). The prefectures included for the study are from the western part of Japan, which was the main cotton producing area. The prefectures included in the analysis were Ehime, Hiroshima, Tottori and Yamaguchi. Fortunately, the average productivity per *tan* was similar to the average productivity found for the cotton-growing areas of the Kinai, which was the center of production for the best-known cottons during Tokugawa Japan Hauser (1974,Table 14 on p. 124). Hauser (1974, pp. 130-131) also provided estimates of fish fertilizer in kan per tan, which were used in placed of the data found in the survey. Japanese cotton competed with the ginned imported cotton. For that reason, the estimates for Japan include the labor cost of ginning. Hauser (1974, p. 131) argues that one kan of seed cotton yielded 390 momme (or 39 percent) of ginned cotton. Cotton was typically ginned on the farm using hand methods. The estimates here assume that one-half day of labor was needed to gin one kan of cotton.[21]

Cotton yarn was a significant import during the early years of trading. Yarn was produced in the household using primarily female labor.[22] There are a range of estimates

[20] The preliminary estimation of the factor content of trade excluded the small amount of cocoons (waste and pierced) and noshi and floss silk that was also exported. These products were essentially joint products of the main output. To account for these products in the resource usage of silk producers, the quantity of output has been adjusted upwards by the ratio of the total value of output to the value of output for first-quality silk products.

[21] One kan is 8.27 lbs. or 3.75 kg. The estimate is from Hauser (1974, Table 28 on p. 163).

[22] See Itoh and Tanimoto (1998) for an extended discussion of the structure of the cotton textile industry during the late Tokugawa and early open trade periods.

of productivity found in Hauser (1974, Tanimoto (1992, Uchida (1988). The productivity did depend to some extent on the weight of the yarn. Productivity estimates in these sources range from 0.03 to 0.15 kan of yarn per day. The estimates used here are from Tanimoto (1992, p. 40), where it was estimated that a spinner could spin about 100 momme of yarn in about two days.[23]

Weaving requires both preparation of the warp as well actual time for weaving. The same sources listed above provide some estimates of weaving productivity, although it should be noted that since Uchida's study was of domestic cotton striped cloth—which tended to be much heavier than the bulk of imported cloths (shirtings)—may underestimate the relevant productivity. Here there is much more agreement between Hauser and Tanimoto.[24] The estimates used here assume one day per tan and another day for preparation.

Finally, data on finishing cloth (including the cost of dyes and other materials) is much more difficult to come by. We know that dyers tended to be specialized in that activity rather work at it as a by-employment, which was the case with spinners and weavers. Uchida (1988, p. 162) estimates the contribution the costs of dyeing yarn to the cost of cotton striped cloth at about 6.8 momme. At an estimated wage of 2 momme per day, that would yield a daily productivity of 0.3 tan. Evidence from the villages in the Chōshu Han would suggest a daily productivity of 0.73 tan. This higher productivity was assumed to apply to the labor component of all finished cloth.[25]

Tea

Tea was Japan's second most important export after the products of sericulture. Contemporary discussion by foreign observers of the Japanese tea industry included Syrski (1872) and Gribble (1883, Watson (1873). All three sources provide substantial detail about the steps involved in the growing and preparation of Japanese tea for export. In addition, the data fromChō, et al. (1979) are very useful. Tea is a heterogenous

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[23] Given the wide variation in estimated productivities (and also for different cloths that were woven), this issue requires further research.

[24] Hauser (1974, p. 138) estimates that a weaver could produce up to one *tan* of cloth per day. Tanimoto (1992, pp. 40 and 45) suggests about one tan per day for a weaver in the Toyama and Nagano prefectures and from 1-2 tan per day depending upon the skill level for a weaver in the district of Izumi (near Osaka).

[25] The ample evidence on the indigo and other dyestuffs industries should allow some refinement of these rough estimates. Finished cloth was a little above one-tenth the yardage of all imported cotton cloth during the period of analysis.

commodity, with widely varying resource requirements depending upon the quality of the final product. Most exported Japanese tea was green tea, which was dried in the countryside and then received some drying in the export port (Nagasaki or Yokohoma) prior to packaging and shipment. Based upon the per unit value from the export statistics, data from Hyōgo, Hiroshima, Oita and Sagea prefectures was used along with Gribble (1883). The labor requirements for fertilizing and cultivating came from the agricultural survey evidence, as did the data on capital, land and fertilizers. Gribble (1883, p. 8) provides a helpful breakdown of the productivity of (female) labor in picking tea and in the (skilled) labor used in the sorting and refining processes. Watson (1873, pp. 11-13 and 19) provides data on the labor requirements for the tea firing establishments in the port cities.[26]

Rice

As the staple Japanese grain, data on rice production was available from fourteen of the prefectures covered by Chō, et al. (1979). Surprisingly, production conditions were relatively reasonably uniform across the country. The coefficient of variation of land productivity was, for example, only 0.22. The coefficient of variation of male labor requirements was only a bit more. To convert the production data, which was by volume (koku), into the weight equivalent, Atkinson (1881) provided reasonable equivalents.[27] These estimates did not assume double-cropping in a year.

Soy Bean

Legumes constituted an important import during some of the early years of Meiji. Since the export data do not distinguish among legumes, soybeans were chosen to stand in for all field beans in terms of determining the amount of resources embodied in imports. Chō, et al. (1979) provides data on soybean production for nine prefectures, which were used to construct the elements of the **A** matrix pertaining to legumes. The United States Department of Agriculture's conversion of volume to weight suggest that

[26] Chō, et al. (1979) also includes data on the production of bancha (coarse) tea. Japan's exports of bancha tea were about one-tenth of the exports of higher quality green teas.

[27] The measure of rice used in export statistics was by weight (picul, or 133.33 lbs.).

there are 0.772 kilograms of soybeans to one liter. This implies about 23 catties per to, which is the conversion factor used in the analysis of the agricultural survey data.

Brown and White Sugar

Japan's sugar production was confined to the eastern and southernmost areas of the archipelago. Two sources are available for estimating the resource requirements for raw cane production and the refining of sugar cane into brown and white sugar. The data from the agricultural survey Chō, et al. (1979) for Ehime, Nagasaki and Osaka were used to calculate resource requirements for sugar cane. Data from the Sanuki Han (on Shikoku) from Meiji 4 offer detail on the costs of refining sugar cane into brown sugar Oka, et al. (1983). The process for grinding sugar can used power from a cow or other animal to power a mill; the boiling of the cane used firewood and charcoal. Refining brown sugar into white sugar required additional firewood and more labor for bleaching. The source for these added resource requirements is Uemura).

Mineral Products

Estimating the resource requirements of mineral products presents its own challenges. Japan possessed relatively abundant deposits of copper and silver ore, which were heavily mined during the Tokugawa period. Japanese mining technology and metallurgy posed significant barriers for taking full advantage of these deposits (see Netto (1879) for a classic statement of the deficiencies from the perspective of a German mining engineer). By the end of the Tokugawa era, the constraints of Japanese mining techniques meant that most productive deposits of ores bearing copper, silver and gold had already been heavily mined and output was quite limited. This came about for several reasons. Areas with mineral deposits were not mined by one firm. Instead, individual miners received contracts to mine subareas of a deposit. Mining technology did not use powder (not to speak of steam power) to excavate mine shafts, so that the dimensions of mine shafts were often very narrow with low ceilings. Japanese pumping technology was for the most part limited to hand pumps, which would require a large area as well as massive amounts of labor to pump areas prone to flooding. These technological constraints meant that mined areas were typically confined to veins that were close to the surface. The scale of mining was thus quite limited. Western engineers visiting Japan remarked on the honeycombed appearance of what had once been productive mining deposits. The dressing of ores occasionally used water power, but most often female labor without any inanimate power. The transport of ores was usually by coolie labor and only occasionally by horses. Perhaps because many mines cam under direct government ownership after the Meiji Restoration, mining experienced some of the earliest technological improvements using western methods of any Japanese industry. The 1870s—the second part of the early trade period—were at the beginning of a period of transition, and accounts of mines from time reveal improvements in some parts of the operation (more often than not, gathering ores) and traditional Japanese technologies in others. For the data used in the **A** matrix, mining, smelting and refining operations have been chosen that continued to adhere to traditional technology.

Traditional Japanese metallurgy also was not as efficient in using existing ores as western methods Japan. Rinji Hakurankai Jimukyoku (Chicago Exposition 1893). (1975)). The processes used large amounts of charcoal (which led to deforestation in neighboring areas) and were conducted in small batches in specially constructed furnaces, which would be broken up after several charges. Metallurgy was also quite diverse in practice, since it needed to adjust to the variety of ores found across Japan. For that reason, contemporary reports of production conditions Lyman (1879) and Pumpelly (1866) suggest quite a range of both scale and productivity. Throughout the 1870s, most—but not all—smaller mines in Japan adhered to traditional methods of both mining and metallurgy. The upsurge in copper exports notable after the early 1870s reflects primarily the application of western methods to mining (the use of explosives to build mine shafts, conveyance by small trucks on tracks and steam pumps) and to metallurgy. The development of the resource requirements for the **A** matrix for mineral products used the data on relatively productive sources. One challenge that further research must resolve is providing valuation for the capital invested in mines and metal processing facilities.

Copper

Japan possessed a sophisticated and at one time highly productive copper industry. During the period of very limited trade through Nagasaki, Japan exported primarily copper in exchange for goods imported by the Dutch and Chinese. The two largest minds of the early open trade era—the Bekko mine and the Kusakura mine—

were analyzed by Coignet, et al. (1957) and other observers (see Lyman (1879, pp. 230-236)). According to these accounts, significant differences existed in the productivity of these mines, particularly at the gathering and washing stage of the operation (prior to smelting). The data from the Bekko mine found in Coignet, et. al. (1957, p. 81) were used in the **A** matrix for the copper industry, but other mines would yield much less productivity.[28] The remaining input requirements were also taken from the Bekko mine, which are found in Coignet, et. al. (1957, p. 130). As is the case with other mines, there is not any reporting of capital for the four stages of processing and the one stage of smelting.

Iron

The next most important metals industry in Japan was the iron industry. A nice treatment of the early years of the industry is found in Takeda (1987), who also outlines some of the main steps towards upgrading mining and processing of iron ore. Pig iron and iron manufactures were an important import during the early trade years. Japan's iron industry relied almost entirely upon the smelting of iron from sand iron. Wada (1893,pp. 227-229) describes the Neu iron sand mine and processing operation. At this mine, local farmers gathered iron sands during the off-season. Given a daily wage of about 12 sen, the estimated labor requirement is about 0.5 days per kan (or 3.75 kg.). For the remaining steps of processing, Coignet, et al. (1957, pp. 37, 40-41) provides a useful summary of resource requirements. His data can be checked against the account of Ichiro (1995), which describes some of the variety of production methods for iron, steel and wrought iron.[29] As with the processing of copper, the resource for which more research is required is the large amounts of wood that was burned either directly or as charcoal, which would often be processed on the spot.

Lead

Japan was a net importer of lead, except during the period 1872-1874. Lead mines shared the fate of other metal mines during the Tokugawa era. Once easily-accessible ores had been worked, the cost of extracting ore (and then processing it) required rising

[28] For example, Lyman (1879, pp. 230-236) reports that from 0.25 to 0.5 person-days per kan were needed to mine and wash the ores at the Kusakura Mine. The requirement was about 0.1 at the (unprofitable) Nameradiki. The Bekko and Kusakura mines supplied much of Japan's copper production during the early trade period. The yield at the Bekko mine was about seven percent of copper ore by weight.

[29] See also Lyman (1879), who visited several iron processing facilities.

amounts of labor. One lead mine that was visited in the early 1860s in Hakodate does provide data on resource requirements. The American mining engineer visited the lead mine at Ichinowatari in Hakodate in 1862 when he was employed by the Bakufu. His report serves as the basis for the estimated resource requirements for lead mining and smelting Pumpelly (1866, p. 81). Unfortunately, Pumpelly's account also lacks any discussion of capital needs, although fuel requirements are well documented.

Tin

Japan imported tin for use in the packaging of tea and other purposes. During the early period of open trade, it had only one tin mine. Fortunately, this mine was also on the itinerary of Lyman's year-long tour of Japanese mines. His report is used for the evaluation of resource requirements in tin Lyman (1879, pp. 169-172). The high labor requirements for both tin and lead reflect the relatively poor quality of the deposits then being worked.

Coal

The final mineral product traded by Japan during the early years of trade was coal. Japan had long had a coal mining industry that served the domestic needs primarily of the salt processing industry. Output was limited because of the circumstances prevailing in other types of mining operations. After the opening up of trade, interest grew in the deposits at Takashima and Miike. Deposits in Hokkaido also attracted attention. One complication in assessing resource requirements for Japanese coal mines is the extensive use of convict labor; some prisons were relocated to be in close proximity to the coal mines Wada (1893, p. 239). As with other mining operations, the resource requirements for coal mining varied widely among mines depending upon the thickness of the seam and its proximity to the surface. For assessing the resource requirements for coal, data from the late 1860s in Hokkaido were used Kasuga (1982). As is the case with other mineral industries, there was no information on the size of the capital investment in this mine (the Kayanuma Coal mine).