A direct test of the Stolper-Samuelson Theorem: the natural experiment of Japan[1]

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Abstract:

We exploit Japan's dramatic 19th move from economic isolation to open trade as a natural experiment to test the general validity of the Stolper-Samuelson theorem. We argue that the Japanese trade liberalization provides an usual opportunity to observe the effects of goods price changes on factor prices for a Walrasian economy in a time period long enough for factors to reallocate in response to goods price changes but also short enough to fulfil the critical ceteris paribus assumption of no technological change. We consider a general specification of the theorem which allows for an arbitrary number of goods and factors and test it on a historical data set on 17 commodity prices, 5 factors of production and a carefully constructed matched technology matrix drawn from numerous historical sources. Using a variety of specifications, our estimates provide strong empirical support for the empirical validity of the Stolper-Samuelson theorem.

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1. Introduction

Since it was first formulated over 70 years ago Stolper and Samuelson (1941) the Stolper-Samuelson theorem has remained one of the most fundamental propositions of general equilibrium (trade) theory. The theorem predicts how trade-induced changes in commodity prices affect changes in factor prices in a Walrasian competitive equilibrium under the assumptions of fixed technologies, factor supplies and tastes. Although Stolper-Samuelson has served as a key framework for thinking about the distributional implications of international trade, the implausibility of these ceteris paribus assumptions regarding modern globalization experiences have prevented the provision of any direct test of the Stolper-Samuelson prediction.

This paper breaks new ground by exploiting Japan's 19th century move from autarky to open trade a natural experiment to conduct a direct test of the Stolper-Samuelson theorem in its most general formulation. This general formulation goes back to Ethier (1982, 1984) who generalized Stolper and Samuelson's (1941) original two-good, two-factor formulation to any number of goods and factors. It states that for any vector of goods price changes, the accompanying vector of factor price changes will be positively correlated with the vector of factor intensity-weighted averages of goods price changes. Intuitively, there is a tendency for changes in relative prices to induce increases in the rewards of factors employed most intensively by those goods whose prices have relatively risen the most and employed least intensively by those goods whose relative prices have fallen the most. A great virtue of this formulation is that it is a refutable general equilibrium prediction which is not conditional on special restrictions on dimensionality, technologies or consumer preferences.[2]

We argue that Japan's mid-19th century opening up to world commerce yields two "experimental windows" where it is possible to observe a Walrasian economy before and after an exogeneous shock in goods prices, ceteris paribus. Specifically, the time

[2] In a higher dimensional settings, it is only possible to derive a refutable prediction on the effects of goods price changes on changes in nominal factor prices. Although theory is able to identify the existence of factor winners and losers in real terms, it is not possible to identify who the winners and losers are.

period between these two experimental windows is long enough for factors to reallocate in response to goods price changes but also short enough to fulfil the critical assumptions unchanged of fixed technologies, factor supplies and tastes.

Our test combines high quality commodity and factor price data for 17 traded commodities and 5 factors of production from Japan's late autarky (early 1850s) and early free trade period (the 1870s). A major innovative component of the data analysis is the employment of a unique technological matrix for the Japanese economy. The technology matrix is constructed from input requirements at the task level for Japan's traded and key intermediate goods. It draws from a range of historical sources, including a major Japanese survey of agricultural techniques, accounts by European visitors and numerous studies by Japanese and western scholars that draw on village records and business accounts. Using a variety of specifications that adjust for price inflation and the regional segmentation of factor markets, our estimates provide strong support of the general Stolper-Samuelson prediction.

2. Related literature

Since its first formulation, the Stolper and Samuelson Theorem stimulated a large research agenda aimed at extending the proposition beyond the original two-good, two-factor setting. This has resulted in two complementary formulations by Jones and Scheinkman (1977) and Ethier (1982)who have shown that Stolper-Samuelson's principal insights are generally preserved in higher dimensional settings.[3]

Why has Stolper-Samuelson experienced this enduring popularity? The answer lies in its applicability to address the distributional welfare aspects of an economy's move towards either more open or more restricted trade. Specifically, the Stolper-Samuelson

[3] In honor of the 50th anniversary of the theorem, Deardorff (1994) edited a special volume which highlights the impact this theorem has had on the trade literature and also contains the most important contributions in this prominent branch of the general equilibrium trade literature.

framework has played a critical role in the 'trade and wages' and the 'trade and protection' literatures.

The central question in the trade and wages debate is to what extent globalization (through trade) has been responsible for the observed increase in the wage premium between skilled and unskilled workers in the OECD countries.[4] While trade economists, such as Leamer (2001) have identified a Stolper-Samuelson chain of causation, labor economists, such as Katz and Murphy (1992) have stressed the role of skill-biased technological change. The challenges of applying the Stolper-Samuelson framework to recent globalization experiences is that globalization comes in different forms, with price changes being only one of many channels. Since it is often accompanied by foreign or home grown technological changes, it is difficult to isolate and identify the role of price changes alone.

A second major empirical application of Stolper-Samuelson occurs in the political economy literature which investigates protection seeking of individual factors of production. In an influential paper, Magee (1980) aimed to test Stolper-Samuelson by examining the lobbying position of representatives of capital and labor with respect to free trade.[5] Applying the two-factor formulation of Stolper-Samuelson to this setting, the theorem would predict that capital and labor take opposite sides politically. Having found that capital and labor take the same side and that lobbying for trade is affected by industry employment, has been interpreted against Stolper-Samuelson in favor of a specific factor model prediction. Deardorff (1994, p. 32) has pointed out that Magee's finding provides only evidence against the strict two good, two-factor formulation of the theorem and is quite compatible with the higher dimensional formulations of the theorem.

3. Theoretical framework

Consider a Walrasian economy producing n goods from a set of l factors of production. Our analysis involves two equilibria. In the initial autarky equilibrium goods

[4] See Katz and Murphy (1992), Lawrence and Slaughter (1993) and Leamer (2001).

[5] See Beaulieu and Magee (2004) for a similar approach using more recent data.

prices are given by the *n*-vector vector $\mathbf{p^a}$ =(p_1^a,p_2^a,…p_n^a) and equilibrium factor prices by the *l*-vector $\mathbf{w^a}$=(w_1^a,w_2^a,…,w_l^a). Production techniques are captured by the economy's technology matrix, denoted by $\mathbf{A}=\langle a_{ij}\rangle$, where a_{ij} are the units of factor *i* necessary to produce one unit of good *j*. Under variable input coefficients, the technology matrix will depend on the factor price vector $\mathbf{w^a}$, i.e. $\mathbf{A}=\mathbf{A}(\mathbf{w}^a)$.

Competitive behavior by a mass of producers all operating under constant returns to scale technologies implies that the general equilibrium relationships between goods and factor prices are given by *n* zero profit conditions. The autarky equilibrium is then characterized by:

$$\mathbf{p^a}= \mathbf{w^a A(w^a)} \qquad (1)$$

Our specification is quite general by not imposing any restrictions on dimensionality and also not requiring that all factors are used in the production of all goods. Also factors can be specific to any subset of goods.[6]

Assume the economy experiences now a change, or shock, to goods prices. Such a change could occur from the government imposing taxes on domestic goods, or through adjustment of domestic prices to international prices resulting from an opening up of international trade.[7] Since our empirical implementation exploits an opening up experience, we denote the new equilibrium as the trade equilibrium. The corresponding equilibrium price vector under trade is denoted by $\mathbf{p^t}$=(p_1^t,p_2^t,…,p_n^t).[8]

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[6] The specific factors model, where one factor is specific to a good and one factor is mobile, is a prominent special case.

[7] In the Stolper and Samuelson (1941) original formulation, goods price changes arise because of import tariffs.

[8] Because of transportation costs, the domestic price vector $\mathbf{p^t}$ might differ from world prices.

A critical assumption of the theory is that the exogenous shock to goods prices does not affect domestic technological conditions. However, since the change in goods prices will change factor prices, the new equilibrium factor price vector will be $\mathbf{w^t}=(w_1^t,w_2^t,\ldots,w_l^t)$. The trading equilibrium is then characterized by a new set of zero profit conditions:

$$\mathbf{p^t = w^t A(w^t)} \qquad (2)$$

The Stolper-Samuelson Theorem yields a prediction on how factor prices in the *l* factor markets must respond to exogenous changes in the *n* goods markets. Following Ethier (1982), we define a function $b(\mathbf{w})=\mathbf{wA(w)(p^t-p^a)}$ and apply the mean value theorem to it. This means that there exist a factor price vector $\hat{\mathbf{w}}$ such that this function can be written in the following way[9]:

$$b(\mathbf{w^t}) = b(\mathbf{w^a}) + (\mathbf{w^t-w^a})[\mathbf{A}(\hat{\mathbf{w}})+\hat{\mathbf{w}}\mathbf{dA}(\hat{\mathbf{w}})]\,(\mathbf{p^t-p^a})\,. \qquad (3)$$

Recognizing that cost minimization implies that $\hat{\mathbf{w}}\mathbf{dA}(\hat{\mathbf{w}})=0$, we obtain

$$b(\mathbf{w^t})-b(\mathbf{w^a}) =(\mathbf{w^t-w^a})\mathbf{A}(\hat{\mathbf{w}})(\mathbf{p^t-p^a}) \qquad (4)$$

Noticing that $b(\mathbf{w^t})-b(\mathbf{w^a}) =(\mathbf{p^t-p^a})(\mathbf{p^t-p^a})>0$, we obtain a three-way relationship between changes in goods changes, $\Delta\mathbf{p}= \mathbf{p^t-p^a}$, changes in factor prices, $\Delta\mathbf{w}= \mathbf{w^t-w^a}$, and the corresponding matrix of factor input requirements **A** evaluated at $\hat{\mathbf{w}}$.

[9] The expression (3) can be also thought as the Taylor series expansion of b.

Stolper-Samuelson Theorem:

Assume an economy experiences a change in goods prices, ceteris paribus. Then the vector of goods price changes, $\Delta\mathbf{p}= \mathbf{p}^{t}-\mathbf{p}^{a}$, and the technology matrix $\mathbf{A}(\hat{\mathbf{w}})$ impose the following restriction on the corresponding change in the factor price vector $\Delta\mathbf{w} = \mathbf{w}^{t}-\mathbf{w}^{a}$:

$$\Delta\mathbf{w}(\mathbf{A}(\hat{\mathbf{w}})\Delta\mathbf{p}) = \sum_{i=1}^{l} \Delta w_i \left(\sum_{j=1}^{n} a_{ij}\Delta p_j\right) > 0. \qquad (5)$$

The Stolper-Samuelson theorem can be thought of a general equilibrium restriction on how factor prices respond to changes in goods prices. It can be interpreted as saying that on average, high values of Δw_i are associated with high values of both a_{ij} and Δp_j . There is a tendency for changes in relative prices to induce increases in the rewards of factors employed most intensively by those goods whose prices have relatively risen the most and employed least intensively by those goods whose relative prices have fallen the most.[10] The logic of the theorem implies that the factor input requirements are evaluated at some factor price vector $\hat{\mathbf{w}}$ which could be different from the observed factor prices in either equilibrium. If $\Delta\mathbf{w}$ is sufficiently small, $\hat{\mathbf{w}}=\mathbf{w}^{a}$ and the input requirements pertain to the initial equilibrium. In the case of Japan, we will argue that the factor input requirements changed relatively little between the two equilibria, so that we can test (5) using the factor input coefficients from the trade equilibrium.

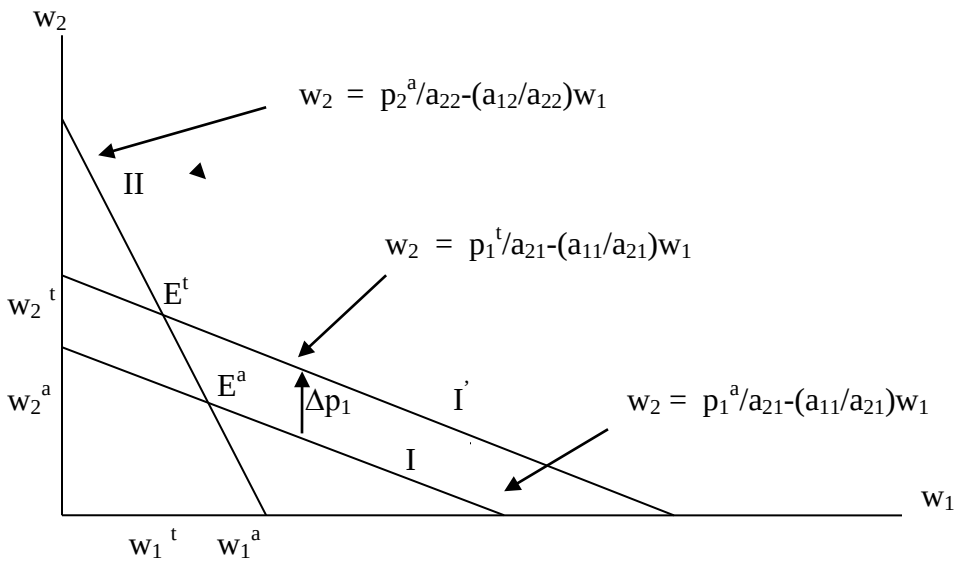
An attractive feature of (5) is its great generality as it does not require any special assumptions on either dimensionality, technology or complete factor mobility. However, as a trade-off, it does not provide any inference of how changes in good prices affect real factor returns. The Friends and Enemies formulation of Stolper-Samuelson, developed

[10] This tendency relationship is often referred to as the correlation version of Stolper Samuelson (see Deardorff (1994)). A shortcoming of the correlation terminology is that it masks the fact that the theorem makes a causal prediction of how factor prices will respond to exogenous changes in goods prices.

by Ethier (1974) and Jones and Scheinkman (1977), predicts the existence a real (factor) winner and loser resulting a single price change. But it does not identify the specific winner or loser.

The prediction (5) is a clear generalization of the familiar two-good, two-factor textbook formulation. Since the forcefulness of this general equilibrium prediction is most easily illustrated with the 2x2 case under the assumption of fixed input coefficients, let us consider this special scenario. The determination of factor prices is illustrated in Figure 1, which plots the zero profit conditions (1) and (2) in factor price space (w_1,w_2). Autarky goods prices p_1^a and p_2^a and input coefficients define two zero profit lines I and II whose intersection E^a determines the equilibrium factor prices w_1^a and w_2^a.

Figure 1: Stolper-Samuelson prediction



Assume now that the economy experiences an exogenous increase in the price of good 1, denoted by $\Delta p_1>0$**,** while the price of good 2 is assumed to remain the same. This will lead to an upward shift of good 1's zero profit line to I', while good 2's zero profit line remains the same. The direction of the resulting change in factor prices is determined by the relative magnitude of the factor input requirements. Figure 1 is drawn such that good 2 is assumed to be more intensive in its use of factor 1, i.e. $(a_{12}/a_{22})>(a_{11}/a_{21})$. To accommodate the price-induced increase in the demand of good 1 requires that both

factors must be reallocate from good 2 to good 1. However, since the price of good 2 has remained unchanged, this can only be accomplished by an increase in the price of factor 1 and a decrease in the price of factor 2.

The Stolper-Samuelson logic has been applied to investigate the role of international trade in factor returns; in particular to account for the observed decrease in real wages of low-skilled workers used intensively in US imports. The difficulty of applying the Stolper-Samuelson to account for this observation is that the Stolper-Samuelson theorem assumes unchanged technological conditions. The identification problem that arises in the presence of technological changes can be illustrated in Figure 1. The upward shift of the zero profit line for good 1 was assumed to be caused by the trade-induced increase in the price of this good. However, the upward shift could have also resulted from a technological change reducing the input requirement of factor 2 in the production of good 1, i.e. a decline in a_{21}. This factor-based technological change in good 2 will have the same qualitative effects on factor prices as the increase in the price of this good. So in the presence technological changes, the links between goods and factor price changes are difficult to identify.

4. Empirical implementation

4.1. Maintained hypotheses and conditions for the test

The test of the Stolper-Samuelson theorem involves an examination of the interaction of the productivity and prices of resources used in production with changes in the price structure facing the economy. An expansion of equation (5) helps to illustrate both the prediction itself and some of the challenges in the implementation of it:

$$\Delta \mathbf{w}(\mathbf{A}\Delta \mathbf{p}) = \sum_{i=1}^{l}(w_i^{\mathbf{t}} - w_i^{\mathbf{a}})(\sum_{j=1}^{n} a_{ij}(p_i^{\mathbf{t}} - p_i^{\mathbf{a}})) \geq 0 \qquad (6)$$

where **a** indicates a year or period during autarky and **t** indicates a year or period of open trade. This test of the theorem takes advantage of the natural experiment of the opening up of Japan to international trade, which exerted a price shock to the Japanese economy

that was so severe that it is known in the Japanese historical literature as a price revolution (seeMiyamoto (1980)).

Bernhofen and Brown (2005) provides a more detailed account of the natural experiment of the reversal of Japan's trade policy, which resulted in potentially a large price shock ($\Delta\mathbf{p}$ in eq.(5)). From near autarky at the beginning of 1859, Japan moved to a very open trade regime *de jure* by the end of that year, which became *de facto* in 1864 after western military interventions convinced the Tokugawa rulers of Japan to fully meet the obligations to open markets stated in the trade treaties of commerce with western powers.

An attractive feature of the natural experiment is that the price shock hit an economy that had the core elements of a Walrasian economy. The products that would eventually be traded were relatively homogenous compared with modern economies. With the notable exception of the brewing industry and a few of the larger copper mines, production technologies were constant returns to scale. The most important branches of the economy producing manufactured goods (silk, cotton, iron manufactures) were vertically dis-integrated and linked by a dense network of markets. Most production of tradable goods took place in the countryside in rural farm households that functioned as multi-product, small-scale firms. Markets for land and labor, while formally subject to restrictions on the transfer of land and choice of occupations carried over from the feudal era, responded to price signals to reallocate productive resources.[11]

In brief, the price shock of opening up hit an economy that was as highly developed commercially as any economy in south and east Asia. It differed from the Robinson Crusoe economy of the international trade textbooks primarily in terms of scale. It produced the full range of agricultural and industrial goods consumed by its

[11] A large Japanese literature summarized in Saitō (2009) documents ways in which markets for land and labor functioned during the middle third of the nineteenth century despite the presence of formal restrictions on the sale of land and some restrictions on occupational mobility.

population, albeit with a significant degree of regional specialization.[12] Final and intermediate products were traded in markets throughout the country; the most important was the commercial center of the country, Osaka. In addition, the immense administrative center of Edo (present-day Tokyo) offered one of the largest agglomerations of consumers on the planet. The high degree of commercialization accounts for the rich deposits of price records stretching back into the eighteenth century for most of the commodities that eventually entered into trade.

The placement of the treaty ports (which were the entry points for imported goods during the early open trade era) and Japan's commercial and physical geography also ensured that price shocks would be registered deep into the interior. Japan's economy was for the most part oriented towards the Pacific Ocean. Even during autarky, the most productive part of the economy and much of the population was found in three coastal plains bordered by steep mountains that were adjacent to the Pacific Ocean or the Inland Sea: the Kansai (centered on Kyoto and Osaka), the Kantō region (centered on Edo) and the Chūgoku region (centered on Nagoya). The two main treaty ports of Hiogo (later Kobe) and Kanagawa (later Yokohama) were established in close proximity to the Kansai and the Kantō regions; both provided ready access by coastal transportation to the Chūgoku region. In addition, the cost of transporting the most popular imports (cotton textiles and woolen cloth) to the interior was a relatively small share of its delivered price. Likewise, the chief exports of silk and tea had a high value to weight ratio and could be transported from the interior at a small share of the FOB price.[13] Low import tariffs equivalent to less than five percent *ad valorem* imposed by the western powers also ensured that import protection would not cushion the impact of the price shock on Japan's markets.

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[12] The main exceptions are small imports of woolens from the west and ginseng, woven silk and sugar from the east. These imports had dwindled to insignificance by the 1840s.

[13] Syrski (1872, p. 261) notes that the cost of transportation from the producing region to the export port of Yokohama was only 3 percent of the farmgate price of silkworm eggs, for example.

Leamer (2012, p. 6) notes that the length of the interval for a test of the Stolper-Samuelson theorem (**t-a** in the notation employed in eq. (6)) involves a critical tradeoff. The test interval must be long enough to allow for the factor price changes ($\Delta\mathbf{w}$) that signal a reallocation of factors across sectors and of sufficient length to allow the reallocation of the resources in response to the initial price shock (or shocks) to take place. At the same time, the longer the interval, the more likely that the underlying *ceteris paribus* conditions on the economy may not obtain: tastes, technologies or factor supplies may change in a significant way.[14] A final concern not included in Leamer's comments but relevant for the case at hand is that a longer test interval ensures that decision-makers will be able to distinguish longer-term permanent price shocks from short-term temporary shocks.

These three considerations are directly relevant for this test of the theorem. Figure 2 shows the main events that marked the twenty-nine years spanning the last years of autarky and the first decades of open trade. Admiral Perry first arrived in Tokyo harbor in July, 1853 to request that Japan be willing to provide safe harbor for whalers whose ships were disabled. By 1858, trade treaties had been negotiated between Japan and several western powers that led to the opening up of trade on July 4, 1859. Japan's raw silk markets were not fully opened up to trade until late 1864, when the Shogunate abandoned attempts to control the amount of silk coming on to the market in the face of western shelling of shore batteries at Shimonoseki. The Meiji revolution of March, 1868 and the most severe harvest failures since the Tenpō famine of the 1830s marked the late 1860s.

Figure 3 (Panel A) shows the evolution of the prices of the main export (raw silk) and the largest import, cotton yarn over the same period. The disruption of the American Civil War in the first half of the 1860s and the harvest failures of 1869 provided for severe swings in relative prices, which only stabilized (relatively) during the 1870s (see

[14] See Leamer (2012, p. 6).

Panel B). The relative price of silk to yarn rose from 1.63 during the early 1850s (1851-55) to 2.73 in the early 1870s (1871-74) and 2.52 in the late 1870s (1875-1879).[15]

The sequence of historical events and price swings suggest that the early 1850s (1851-55) would be best suited for the autarky period (**a**) and that two candidates are available for the open trade period (**t**): 1871-1874 and 1875-1879. The maximum length of these two candidate test intervals would be about 10 years (1865-1874) and 15 years (1865-1879). Do these two test intervals meet the two Leamer criteria: a long enough time for reallocation to take place, but a short enough interval to maintain the ceteris paribus conditions on preferences, technologies and endowments?

Consider first the time for reallocation. The agricultural technologies used in Japan's two main export industries, tea and sericulture, imply significant lags in the ability of producers to respond to an initial price shock. Syrski (1872, p. 211) notes that tea shrubs required at least four years of growth before they were ready to be harvested. Syrski (1872) reports that mulberry trees, which provide the leaves that are fed to silkworms, required from three to up to eight years to fully mature. Some of the skills used in the sericulture industry also required several years to develop. Only one day may be needed to train a family member to prepare a sheet of silkworm eggs; other tasks such as picking mulberry leaves may require two years to master. A well-known handbook of the sericulture industry estimated that learning how to reel silk (draw silk from a cocoon) could take up to the 25 years to master.[16]

Although goods markets were as well-integrated as possible given an economy that relied upon pack horses and human labor for transport on land, labor markets and land markets (particularly rents on land) may have responded only slowly in response to factor prices. Skilled labor may have been mobile across the most developed portions of Japan, but it is unlikely that long-distance migration of low-skilled and female labour was

[15] Note that this is an increase in the barter terms of trade between silk and yarn of 50 to 67 percent over the period.

[16] See Narita, Koyana et al. (1978, pp. 7-8). This source is a treatise on sericulture that was first published in 1814.

characteristic of the Japanese economy during the first period of open trade. To test the robustness of the results to the potential for *regionally* integrated labor markets but nationally dis-integrated labor markets (at least in the shorter term), a specific factors approach to the test of the theorem uses regionally-disaggregated factor price data. As will become apparent with the presentation of the results, adjustment to the terms of trade shock suggested by Figure 3 most likely required a minimum of 10 years and more likely close to 15 years.

The transition period from autarky to open trade exposed the Japanese to encounters with western preferences and new steam-based technologies. During this period, preferences were reasonably stable and the economy did not experience significant changes in technologies. Despite the enthusiasm of some elites for western culture and institutions after the Meiji restoration of 1868, preferences for consumption remained largely unchanged during the first two decades of open trade. The imports most sensitive to changes in tastes would have been imports of cotton and woolen textiles, which accounted for one-half of Japan's imports during the early trade period. Uchida (1988) and Tamura (2001) provide ample evidence that western merchants quickly learned about the need to adapt western cloths to Japanese styles of clothing and tastes. The Japanese readily adapted imported machine-spun yarns to their traditional hand looms. The marketing strategies of western merchants assumed continued use of traditional clothing.[17]

During the first two decades of open trade, virtually all of the production of tradable goods continued to rely upon the traditional technologies in use during the

[17] See German Consul in Hiogo (1873). The German Consul in Edo (1873) reports that the use of woolen cloth for western dress was restricted to government uniforms of various kinds and some of the wealthiest classes.

autarky period. The adoption of steam-based technologies from the west was limited to a few sites. High interest rates relative to the price of labour was one important reason for the persistence of labour-intensive methods. Anonymous (1875, p. 90) notes nominal rates of 18 percent ca. 1874 made mechanization of silk reeling using the steam technologies found in France or Italy unprofitable. Lyman (1879, pp. 258-259) argues that drilling oil wells with hand labour was lower-cost than using steam technology and Gribble (1874, p. 99) makes a similar argument for the continued use of physical labour to produce vegetable (or Japan) wax rather than western-manufactured steam presses.

By the close of the test period (1879), the Meiji government and some western investors had introduced some western methods in government-run armories and a handful of coal and copper mines, but most steps in the processes relied upon traditional Japanese technologies.[18] Land transportation continued to rely upon pack horses. The largest change occurred in coastal shipping, with the introduction of some steamships and western sailing vessels.[19]

Endowments were also relatively stable. Population growth was modest in the years following the opening up. Biraben (1993, Table 7) reviews the evidence and concludes that population would have grown about eight percent over the test period. Mortality and birth rates do not show a strong break with trends evident during the period prior to opening up, which suggests the absence of dramatic changes in the age structure

[18] British consuls in the treaty ports complained repeatedly that the government's hostility to foreign ownership prevented modernization of the mining and metallurgy sectors. See the summary report by Plunkett (1875). Full-scale adoption of western methods in the mining sector took place during the 1880s.

[19] Unlike in Latin America, the Anglo-Saxon regions of recent settlement or colonial Africa, foreign capital played virtually no role in the establishment and construction of modern transportation systems in Japan.

or sex ratios. There was no sizeable emigration or immigration, nor were there substantial imports of capital goods during this period. Two reforms associated with the Meiji revolution that later influenced labor supply were not consequential for this period. The institution of universal conscription affected only about two to three percent of those aged 20-23 during the 1870s. Meiji efforts to commutate the stipends of the samurai, who constituted about eight percent of the working-age population, were carried out during the 1874-1876 period. These reforms only began to affect the labour force participation of former samurai only in the late 1870s and early 1880s. By then, all samurai had been required to accept compulsory commutation of stipends that left them with a best a few years of income.[20]

3.2 Data for the hypothesis test

The test of the hypothesis found in equation (5) requires consistent data on goods prices, factor usage (the **A** matrix) and factor prices. The full details of the dataset utilized in this study are available in a data Appendix. This discussion highlights the key issues associated with collecting data on each of the three elements of the test expression and the approach that was followed to address the substantial price inflation that took place over the test periods.

The eventual test used price and factor usage data for 17 traded goods. Nine of these were exports and eight were imports. Although in principle the test of the theorem applies to any subset of goods markets, a test that incorporates as wide a range of goods as possible is most preferable. Table 1 lists the goods for which price data were available and the change in price over the two test intervals. For the most part, prices of imports tended to fall and prices of exports tended to rise. The table also includes the sources for the prices. Continuous data on same quality of commodity are available for most goods

[20] See Rokuhara (2005), Harootunian (1960) and Flath (2005). A guaranteed income of four to six years (allocated between cash and bonds) replaced the lifetime stipends.

from the Osaka market records compiled by Miyamoto (1963). The notes on the sources in the table provide additional information for some additional commodities.

Table 1 includes the prices of yarn and cotton cloth, which amounted to about one-third of domestic Japanese consumption (by weight) by the late 1870s and constituted all told the most important import by value. It also includes the price of bar iron, which was determinant for the prices of manufactured iron products such as nails. Japan's imports of iron accounted for about one-quarter of its domestic consumption by the end of the 1870s. Brown and white sugar were the most important import of foodstuffs, once the effects of the poor harvests of 1868 and 1869 had been overcome. Silk and silkworm eggs at times accounted for three-quarters of the value of Japanese exports. Tea was the third most important export, eventually followed by copper.

The price changes in Table 1 are expressed in *en*, which was worth one-thousandth of a ryō.[21] To ensure that the inflation that occurred from the 1850s through the early 1870s does not distort the results, the price index for non-trade goods compiled by Shinbo (1978, Table 5-10) was used to convert prices to constant *en* using 1855 as the base year. The largest positive percentage changes for the shortest period of analysis (1851/55-1871/74) were for seaweed (87%), silkworm eggs (74%) and raw silk (47%). The largest negative percentage changes were for yarn (-68%), copper (-34%), bar iron (-31%) and white sugar (-68%).

The second component of the test expression (5) is the **A** matrix for the seventeen commodities for which price information spanning the periods of the test could be found. A data appendix available from the authors provides a complete discussion of the procedure used to construct the matrix. The core source for agriculturally-based commodities (rice, soybeans, sugarcane, tea, cotton, silkworm eggs and raw silk) was the multi-volume survey of agricultural production conditions from the mid-1880s known as the Nōji Chōsa (see Chō, Shōda et al. (1979)). This source details the labour, capital and land requirements for a all of the tasks associated with producing virtually all agricultural

[21] The ryō was the gold-based currency of Tokugawa Japan. It was replaced with the yen at a ratio of one to one in 1871.Prices in Osaka were quoted in silver *monme*. They were converted to ryō using the monthly exchange rates found in Miyamoto (1963).

commodities at the prefectural level. For goods produced throughout Japan (soy and rice), the averages were used for resource requirements. For goods where regional specialization mattered (sugarcane, cotton, tea, and products of sericulture), only those prefectures contributing significantly to production at the time of the Meiji census of production in 1874 were included.[22] To ensure the appropriate estimate of productivity in silk reeling, only estimates from prefectures still practicing hand reeling were used. In addition, the data for tea was restricted to varieties (such as *sencha*) that would be likely to be exported.

The production conditions of these industries suggested that a division of labor into three categories (skilled male, unskilled male and female) provided an appropriate compromise between detail and comprehensive coverage. Skilled male labor played an important role at certain points in Japanese production processes (in processing tea or scutching cotton, for example). It was also important for several processes in mining and metallurgy. Since a large share of production was by household units based on the farm, female labour was ubiquitous in Japan.[23] Male labour was rarely involved with tasks such as picking tea, reeling silk, spinning, weaving or preparing copper ore for roasting. For tasks that may have involved the labour of male and female labour, the ratios in the respective sources were used. In addition, the **A** matrix took account of three important intermediate inputs: fish fertilizer, which was produced using herring caught off the coast of Hokkaido, charcoal, which was used in enormous quantities in metallurgy and wood.

Data for the remaining industries drew upon a plethora of Japanese and western sources. Uemura (1986) and Oka and Yamazaki (1983) are key sources for sugar refining. Tanimoto (1998) provides an excellent review of the technologies in use in cotton processing, spinning and weaving. Doi (1984) and Ichiro (1995) provide excellent coverage of the tatara technology used in the production of iron. Lyman (1879) is an oft-cited source for details of iron production technology and copper mining and smelting.

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[22] See Le Gendre (1878) for an English-language summary of the main results.

[23] This study has included the labour of older children with the labour of women.

The final component of the test statistic is the vector of factor prices for the three test periods. For evidence on wages that spans the entire period, Saitō (1973) and Saitō (1998) (a summary volume) provide series of wages for male and female workers in eastern (Kantō) and western (Kinai) Japan. The base data are in five-year averages, which coincide with the periodization used in this paper. Another important source for skilled wages and the wages of women in a range of occupations is an 1880 retrospective survey of wages that provides evidence for 1860, 1870 and 1880. The data have sufficient regional coverage to estimate wages for both all of Japan and for the two separate regions.

The price of capital is the user cost of capital. The most important component of this price that could have changed over the test period is the interest rate. Rather than attempt the impossible task of estimating the price of capital for the diverse uses to which it was put, this study tests for the sensitivity of the final results to a significant change in its price. Under the assumption that the real price of capital goods (virtually all made of wood) did not change much over the period, most important change in the price of capital would have been a rise or fall in the implicit interest rate. Contemporary observers such as Lyman (1879) noted the high rates of interest prevailing in Japan in the 1870s, which are consistent with the findings of economic historians discussed in Saitō and Settsu (2006) for the late autarky and open trade periods. High interest rates of 12 to 15 percent were not uncommon.

The final factor of production is land. With the exception of rice, every other agriculturally-based commodity analysed in this study was produce on "dry fields" rather than the paddies used for rice production. Fortunately, detailed cross-sectional data are on rents for this kind of land both for the Kansai and the Kantō regions for the late autarky period. Hedonic regressions of the data in these sources and other data established base rents for dry fields of a "standard" quality.[24] Additional time series sources are available

[24] The data from Kinai region includes a dataset on 33 plots across three villages, a dataset on rental prices for 20-25 plots that were rented out over about 40 years, the rents charged in a village for two different qualities of land and average sales prices for a mix of paddy and dry land fields. All of the data are from the area around Osaka. The data from the Kantō are from a silk-producing region north of Tokyo (see Waseda

for both regions to provide guidance on the trend in rents through the early 1870s. Additional detailed data on land values from sales within the same district are available from the *Japanese Economist* for 1875 and 1878. Hedonic regressions of these land values were used for estimates of rents during the second half of the 1870s.

3.3 Test results

As noted above, the tests of the Stolper-Samuelson theorem were conducted over two different spans of time and under two assumptions about the integration of markets for labour. (Both sets of results assume full integration of goods markets, which is a reasonable assumption for Japan during the period of this study). The first set of results, presented in Table 2, provides the two main steps and the outcome for the calculation of the inner product for the two test intervals. The second and fourth columns provide the results of the calculation of $\mathbf{A}\Delta p$; each row has the results for one of the five factors. The third and fifth columns provide the estimates of the changes in factor prices ($\Delta\mathbf{w}$) over the test intervals (with the exception of capital). The final row has the resulting inner product of the restriction captured by $\mathbf{A}\Delta\mathbf{p}$ and the actual change in factor prices $\Delta\mathbf{w}$ for the two test intervals. In both cases, the inner product $\Delta\mathbf{w}(\mathbf{A}\Delta\mathbf{p})$ is positive and the test of the Stolper-Samuelson theorem is confirmed.

The shaded cell in italics is the amount of the change in the price of capital that would be required to reject the Stolper-Samuelson hypothesis. For 1871-74, the price of capital would need to decline by 0.02, which would imply a modest decline in interest rates.[25] In reality, it is likely that nominal interest rose in the early Meiji period relative to the late autarky period. Anonymous (1875, p. 90) notes nominal rates of 18 percent ca.

Daigaku Keizaishi Gakkai (1960)) (and include observations through the early 1850s) and a data set of land transactions from the Gunma prefecture, which was also a silk producing area further north and east of Tokyo (see Gunma-ken (1977)). The data on sales prices were converted to rents by multiplying the sales prices by the 9.6 percent used the Japanese valuation of land at the time.

[25] Depreciation rates on Japanese capital such as tatara furnace used in the smelting of iron sand were about ten percent. For wooden tools or wooden boats, which is more likely closer to the kinds of capital employed in the tradable sector, they were closer to 20 percent. At these high rates of depreciation, a large change in the interest rate is needed to achieve even a modest reduction in the user cost of capital.

1874 in a discussion of the potential for mechanizing the silk reeling industry; these are higher than the range of 12-15 percent cited in Saitō and Settsu (2006). These high rates would reflect ongoing uncertainty about monetary arrangements and the lack of development of a formal banking sector until the 1880s. The results for the 1875-1879 period are even stronger and would require a 10 percent *decline* in interest rates (to 2 percent) to offset the positive impact of the other elements of $\Delta\mathbf{w(A\Delta p)}$.

Although the results appear to be reasonably robust with respect to both the test period chosen and reasonable assumptions on changes in interest rates, it is possible that averages across regions are concealing movements in factor prices that are inconsistent with the test proposition in equation (5). After all, there is a long historiographical tradition that argues that even as the eastern part of Japan (particularly the Kantō region and adjacent silk-producing areas) benefited from the extraordinary rise in the price of silk above levels prevailing in autarky, the western part of Japan centered on the Kansai was hit with the destruction of the cotton spinning industry, the incursion of inexpensive unprinted English cloth and the incursion of inexpensive Chinese cotton and Formosan sugar. Table 3 extends the test results presented in Table 2 to allow for regionally differential impacts of price changes on both wages and rents. For the purposes of the test, all of Japan is assumed to produce soy and rice; the Kantō region (broadly construed) produces raw silk, silkworm eggs and tea; and the "Kansai" region is assumed to specialize in the production of remaining exported and imported goods.[26]

The results, which appear in the final column of Table 3, are even stronger than was the case under the assumption of equal prices for land and labour across all of Japan. With the exception of wages for skilled labour in the longest test period, changes in wages were roughly parallel across the two regions. The main difference was in changes in rents on land. Notably, rents on dryland fields in the Kinai began to decline in real terms almost immediately after the opening up. The results for Kantō suggest that changes in real rents of dryland fields were negligible through the early 1870s, but

[26] In this event, the Kansai definition includes the remainder of the west of Japan. Further refinement of the regional definitions is possible, but unlikely to materially affect the results presented here.

exhibited substantial appreciation thereafter. The divergence in rents by the late 1870s is also associated with the land intensity of sericulture in contrast with the products that were produced in the Kinai. It is also consistent with Nakamura (1962), who found rents increasing in most plots of dry land during the early period of open trade (through the 1860s) in the silk producing areas of the Suwa prefecture.

4. Conclusions

The Stolper-Samuelson framework is one of the theoretical pillars of the neoclassical trade model. However, existing empirical investigations of the theorem are either restrictive regarding the assumed degree of aggregation regarding factors and industries or they confront identification problems associated with technological changes that are so characteristic of the modern age of globalisation. Since induced price changes, under the ceteris paribus assumption of unchanging technologies are at the heart of the theorem, there is a mismatch between empirics and theorem. This suggests that Japan's 19th century trade liberalization characterized by dramatic price changes under relatively stable technological conditions provides a natural setting for examining the theorem. We use Stolper-Samuelson logic to help us identify both the potential factor winners and losers from Japan's trade liberalization and also for testing the most general formulation of the theorem.

The general formulation of the Stolper-Samuelson theorem only provides information on the correlation of price changes, factor intensities and factor price changes. It is not possible to identify clear winners and losers in comparison with the much more restrictive models generally used in the historical literature. Further attention can be directed, however, at a description of the channels by which the price shock of integration into the world economy hit Japanese factor markets. In this case, international trade in rice or sugar had virtually no appreciable impact on factor prices. Sericulture's relative factor intensity drove most of the positive changes in factor prices (in eastern Japan), but the price changes in importables (whether cotton, yarn or cotton cloth) simply were not large enough to have much impact on remuneration of any of the factors employed in those industries despite the large degree of import penetration evident by the

mid-1870s. The first years of globalization were less about the impoverishment of workers in import-competing cotton and iron and more about the enrichment of labor and land employed in the production of silk.

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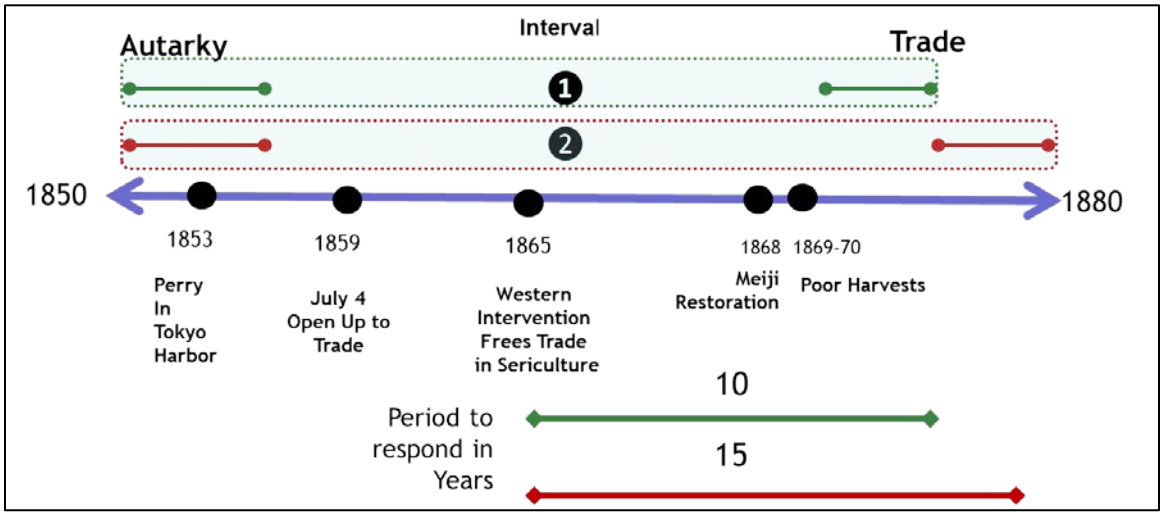
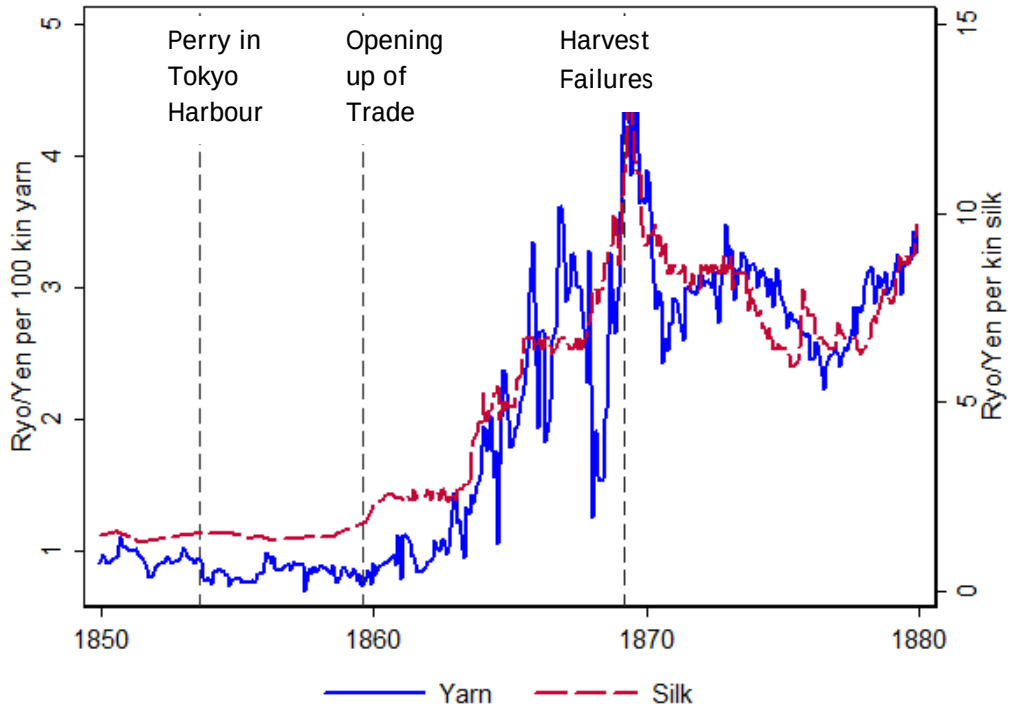
Figure 2: Test Intervals for the Test of the Stolper-Samuelson Theorem

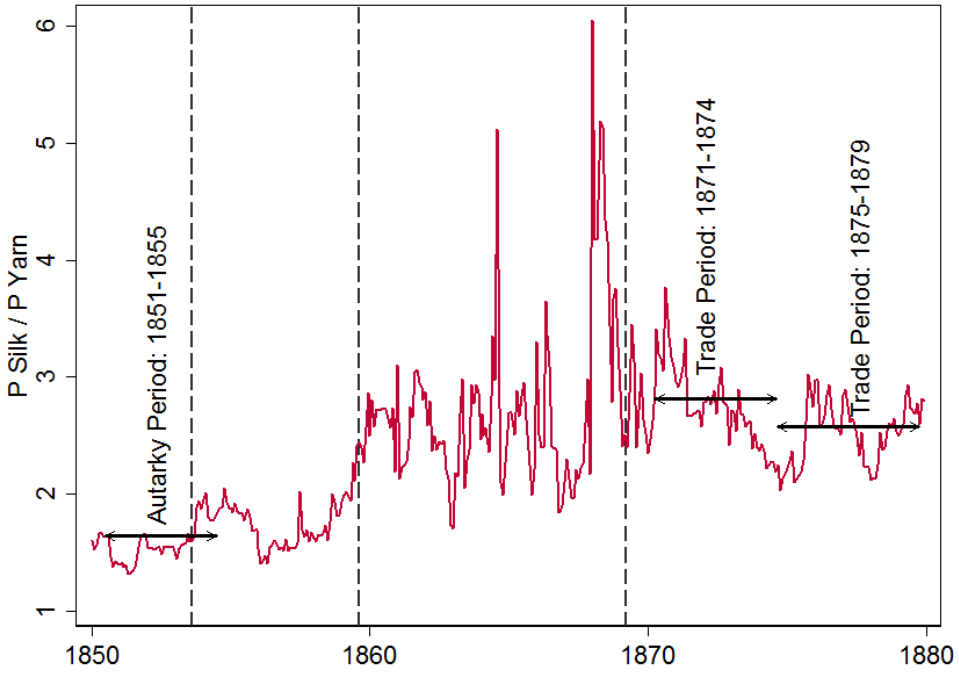


Notes: The figure shows the two test intervals: 1851-55 to 1871-74 and 1851-55 to 1875-79. For a discussion of the figure, please see the text.

Figure 3: Relative Price Shocks: 1850-1880



Panel A: Prices of cotton yarn and silk



Panel B: Price ratios and periods of autarky and open trade
Source: Miyamoto and Ōsaka Daigaku Kinsei Bukkashi Kenkyūkai (1963, Tables 18 and 19)

Notes: The prices of yarn (in silver *monme*) are converted to gold ryō using the monthly exchange rates found in Miyamoto and Ōsaka Daigaku Kinsei Bukkashi Kenkyūkai (1963, Table 7)

Table 1: Commodities, Price Changes and Sources

	Δ**p** (in real en per kin)		
Commodity	1851/55-1875/79	1851/55-1870/74	Source
Imported Goods			
Rice	-0.15	0.69	Osaka market
Soy	-0.18	-0.06	Osaka market
Bar Iron	-4.9	-7.6	Osaka market
Brown Sugar	-1.4	-0.6	Osaka market
White Sugar	-8.9	-7.6	Osaka market
Cotton	-9.1	-1.1	Osaka market
Yarn	-21.7	-88.2	Osaka market
White Cloth	-19.2	-6.0	Osaka market
Exported Goods			
Camphor	-0.3	-5.3	Nagasaki sales price, consular reports
Vegetable Wax	-115.5	85.3	Edo
Shiitake	0.6	5.8	Osaka market
Seaweed Cut	4.5	3.6	Consular Report
Copper	-12.7	-22.3	Osaka market
Cuttlefish	13.9	4.0	Consular Report
Tea	17.5	9.8	Osaka market
Silkworm Eggs	77.2	102	Merchant average sales price
Raw Silk	375.3	619.4	Osaka market

Notes: All prices changes are in real *en* of 1855-1856 per kin. One kin is equal to 1.33 British lbs. The only exception is silkworm eggs, which are measured in sheets. The en was worth one-thousandth of a gold ryō, which was equivalent to one yen when it replace by the yen in 1871. Rice prices per *koku* (a measure of volume) were converted to kin using the data from Atkinson (1881) and soy prices per *koku* were converted using data from the United States Department of Agriculture. Cloth prices for one *tan* of cloth were converted to the equivalent in kin by assuming that the cloth used 95 *monme* of yarn (or about 0.8 lbs.).

Sources: Miyamoto and Ōsaka Daigaku Kinsei Bukkashi Kenkyūkai (1963) provides monthly or annual notations of goods from the Osaka market for that include the period 1851-1879. Camphor prices during autarky are purchase prices of the bakufu (the Shogunate) at Nagasaki for 1850 and 1851/1852 found in Kōsha (1956). Prices for the 1870s are average market prices reported in German and British consular reports. The cut seaweed price during autarky is for June, 1859 just at the beginning of open trade in Kanagawa as reported by the British consul. The autarky prices during the 1870s are average export prices at the treaty ports and market prices provide by the German and British consuls. The price of silkworm is based upon market prices for higher quality silkworm eggs (sold in July and August) in 1866 and 1867. The records of the average sales price of a silkworm egg merchant found in Honda (1936, pp. 105-107) were used to estimate prices in autarky. Subsequent prices are for eggs from the production regions of Oshiu, Sinshiu and Joshiu reported in Bavier (1874), Syrski (1872) and the British and German consular reports for the 1870s.

Table 2: **Tests of the Stolper-Samuelson-Ethier Theorem Assuming Integrated Labor Markets for Two Test Intervals**

	1851/55-1871/74		**1851/55-1875/79**	
Factor	**A∆p**	**∆w**	**A∆p**	**∆w**
Skilled Male	6.769	-0.005	4.896	-0.008
Unskilled Male	42.671	0.004	30.584	0.008
female	3.850	0.002	2.400	0.010
capital	0.765	*-0.019*	0.542	*-0.30*
land	0.671	-0.169	0.479	-0.140
∆w(A∆p)		**0.015**		**0.163**

Notes: The value for capital in the shaded cells is the amount by which the price of capital must have fallen in order to reject the test of the Stolper-Samuelson Theorem.

Source: For a discussion of the underlying calculations, please see the text.

Table 3: Tests of the Stolper-Samuelson-Ethier Theorem Allowing for Regional Differences in Factor Price Changes

Test Interval and Factor	Rice and Soy (All of Japan)		Tea and Sericulture Kantō (East)		All other Goods Kinai (West)		Entire Economy
	A∆p	**∆w**	**A∆p**	**∆w**	**A∆p**	**∆w**	**∆w(A∆p)**
1851/55-1871/74							
Skilled Male	0.000	-0.005	6.780	-0.006	-0.012	-0.005	
Unskilled Male	0.000	0.004	42.683	0.002	-0.012	0.005	
female	0.000	0.002	3.975	0.003	-0.125	0.002	
capital	0.000	0.000	3.150	0.000	-0.002	0.000	*-.012*
land	0.000	-0.169	0.671	-0.030	0.000	-0.680	
∆w(A∆p)		0.000		0.040		0.000	**0.040**
1851/55-1875/79							
skilled	0.000	-0.016	4.908	-0.012	-0.013	0.006	
unskilled	0.000	0.008	30.661	0.010	-0.077	0.007	
female	0.000	0.010	2.635	0.007	-0.235	0.013	
capital	0.000	0.000	2.237	0.000	-0.007	0.000	*-0.31*
land	0.000	-0.140	0.479	0.860	-0.001	-0.300	
∆w(A∆p)		0.000		0.692		-0.003	**0.688**

Source: For a discussion of these calculations, please see the text.

Notes: The change in the price of capital for which the theorem would be rejected is in the final column of the table.