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Estimating the Elasticity of Substitution for Traded Products: Evidence from Japan

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Abstract

This paper estimates product-level elasticities of substitution for Japanese imports using HS6-digit trade data and the empirical framework developed by Feenstra (1994), incorporating the refinements proposed by Soderbery (2015). While much of the existing literature relies on U.S. data or world trade data, we focus on Japan and systematically examine how methodological choices affect the level and distribution of the estimated elasticities and the range of products for which estimation is feasible.

The central contribution of this study is to analyse explicitly the role of reference country selection in elasticity estimation. Specifically, we compare a product-specific reference country rule, under which the reference country for each product is Japan's largest import partner, with a rule that fixes the United States as the reference country. The results show that reference country choice substantially affects not only the level and distribution of estimated elasticities, but also the extensive margin of products for which elasticities can be estimated.

We find that conclusions about the mean difference between the two reference country rules depend on the estimation stage and on the treatment of outliers. Moreover, the distribution of product-level differences includes products with large gaps, so that the absence of a significant mean difference is not sufficient to conclude that the estimates agree. We also confirm that using the two rules together makes estimates available for 3,997 products.

Through this analysis, the study provides systematic product-level estimates of substitution elasticities for Japan's imports and shows that reference country selection plays an important role in understanding import structure, in welfare analysis, and in the quantitative evaluation of trade policy.

Keywords: Substitution elasticity; Reference country selection; HS6-digit trade data; Extensive margin; Trade policy analysis

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1 Introduction

The elasticity of substitution for traded products is a central parameter in the analysis of economic effects in international trade and macroeconomic models. For this reason, a large body of research has attempted to estimate it, and the topic has attracted strong interest from researchers and policymakers in the field of international trade.

Representative studies in this field include Feenstra (1994), Broda and Weinstein (2006), and Soderbery (2015). The estimation framework proposed by Feenstra (1994) became the foundation for subsequent research. Broda and Weinstein (2006) analysed the United States and had a major influence on the development of empirical research on the welfare effects of trade. Soderbery (2015) subsequently reduced the statistical bias of the earlier estimation methods. Meanwhile, research at CEPII, including Fontagné et al. (2022), has estimated product-level trade elasticities using world trade data at the HS6-digit level.

Applying these estimates to the analysis of Japan, however, raises several issues. First, if substitution elasticities depend on the import possibilities of each country, applying estimates for the United States directly to other countries is not necessarily appropriate. Second, it is not clear how well estimates based on world trade data are suited to country-specific welfare analysis. In addition, the meta-analysis by Bajzik et al. (2020) documents large dispersion in the estimates reported in earlier studies, and Boehm et al. (2023) point out that results can differ depending on the timing and length of the data used.

The estimation method of Feenstra (1994) assumes that the elasticity of substitution for traded products is constant over time. In reality, however, the entry and exit of trading partners and the emergence of new traded products are observed continuously. The measurement of substitution elasticities is therefore not a one-time exercise, but something that should be re-examined on an ongoing basis.

This study therefore uses Japanese import data to estimate substitution elasticities for as many products as possible at the internationally common HS6-digit level. We also compare a method that fixes the reference country as the United States with a method that selects the largest import partner for each product. Through this comparison, we examine how the choice of reference country affects the estimates and the range of products for which estimation is feasible.

2 Background

2.1 Changes in Global Trade Structure and the Role of Substitution Elasticity

Classical theories of international trade, such as the Ricardian model and the Heckscher–Ohlin (HO) model, focus on the mechanism through which trade raises production efficiency, and place comparative advantage arising from differences in relative technology and factor endowments at the centre of the theory. As interest in technological progress and economies of scale grew, the theoretical perspectives used to explain trade patterns also broadened. In addition to production efficiency,

consumer demand for product variety and changes in market structure came to be emphasised.

This shift in theoretical perspective began in the late 1960s and the 1970s. Armington (1969) proposed the hypothesis that consumers distinguish products by their place of production, calling into question theories premised on homogeneous goods. Subsequently, Lancaster (1977) and Krugman (1979) formalised consumers' preference for variety and laid the foundations of the new trade theory. These studies show that product variety is an important source of consumer welfare and, at the same time, a major factor driving changes in international trade patterns.

In particular, the monopolistic competition model of Krugman (1979) integrated economies of scale with preferences for variety, thereby clarifying the central role of the elasticity of substitution in trade models. The elasticity of substitution not only measures how easily varieties of a product can be substituted for one another, but also directly affects the extent of the welfare gains that consumers derive from an expansion of variety. Precise estimation of the elasticity of substitution is therefore important in research based on the new trade theory. The estimates provide a basis for understanding the structure of world trade and the changes in import composition that accompany price changes, and for examining trade policy.

2.2 The Role of Substitution Elasticity in International Economics

The elasticity of substitution discussed in the previous subsection is also important when evaluating how the expansion of variety through trade and changes in policy affect economic welfare. This subsection reviews its application in empirical analysis.

In empirical work, Feenstra (1994) proposed an innovative method for estimating the elasticity of substitution based on changes in import unit values. This method made it possible to quantify the welfare gains from increased variety implied by the new trade theory, and it has played a foundational role in subsequent research.

Broda and Weinstein (2006) applied Feenstra's approach to estimate substitution elasticities for U.S. imports systematically, and proposed a method for measuring empirically how changes in the number of varieties through trade affect consumer utility. Ossa (2015) further showed that accounting for cross-industry variation in substitution elasticities greatly magnifies the estimated gains from trade.

In recent years, substitution elasticities have also been widely used in the evaluation of tariff policy. Soderbery (2018) derived optimal tariff rates using product-level elasticity estimates based on U.S. trade data, providing a quantitative basis for trade balance and policy evaluation. Amiti, Redding, and Weinstein (2019) analysed how the tariff increases under the Trump administration affected consumer welfare through price changes and substitution across varieties, and showed that the elasticity of substitution is a central parameter determining the size of welfare losses.

3 Literature Survey

3.1 Why Adopt the Feenstra (1994) Approach?

The previous section described the role of substitution elasticities in welfare analysis and policy evaluation. This section reviews the related theory and estimation methods and explains why this study adopts the approach of Feenstra (1994).

With the Ricardian model of productivity distributions by Eaton and Kortum (2002) and the heterogeneous-firm model of Melitz (2003), the theoretical analysis of international productivity differences and of firm-level export entry and exit advanced considerably. By introducing supply-side heterogeneity explicitly, these models provide a basic framework for analysing changes in trade structure, the incidence of welfare effects, and the impact of policy shocks.

Alongside these supply-side approaches, another important theoretical lineage consists of models based on the Armington assumption. Under this assumption, consumers regard products belonging to the same product category as different goods if their countries of origin differ. On this premise, the models describe substitution between goods differentiated by country of origin. In Armington-type models, the elasticity of substitution between varieties is the core structural parameter governing the response of demand to changes in prices and trade costs. This elasticity determines the direction and magnitude of the effects of tariffs, transport costs, and other trade barriers on trade structure and consumer utility.

There are several approaches to estimating trade elasticities, including models that treat firm heterogeneity explicitly and structural gravity models that use bilateral trade flows (Melitz, 2003; Head and Mayer, 2014). Which method is appropriate depends on the definition of the elasticity of interest and on the data available.

The object of this study is the elasticity of substitution between imported goods of different origins within the same HS6-digit product. The framework of Feenstra (1994) estimates demand-side and supply-side parameters using variation in prices and import shares across import partners. It therefore does not require firm-level data and is well suited to the purpose of this study, which can draw on trade statistics by product and partner country.

The substitution elasticities obtained from this framework are also used to evaluate price indices and welfare effects associated with changes in import variety. What this paper examines directly, however, is the sensitivity of the estimates to reference country selection and the range of products for which estimation is feasible; it does not measure the effects of the entry and exit of import partners themselves.

3.2 Empirical Applications of the Feenstra Framework

Feenstra (1994) was the first to present systematically a method for estimating the elasticity of substitution in import demand based on changes in the prices and market shares of imported products. The method allows consumer preferences to change over time, avoids explicit estimation of price indices that are difficult to observe directly, and identifies the elasticity of import demand

from information on variation in import shares and import prices. It is thus a structural approach that estimates elasticities on the basis of the equilibrium between demand and supply in the trade market, and it provided an important foundation for subsequent empirical trade research.

Broda and Weinstein (2006) extended the framework of Feenstra (1994) and estimated substitution elasticities systematically for a broader range of imported products. To deal with the extreme values and hard-to-interpret estimates that appear in some of Feenstra's (1994) results, they also proposed a more stable mixed GMM estimator. Using this method, they measured empirically the effect of the expansion in the number of imported varieties on consumer utility in the United States and quantified the gains from greater variety.

The estimation method of Broda and Weinstein (2006), however, left open issues of computational efficiency and estimation precision arising from its use of grid search. In response, Soderbery (2015) proposed a new estimation method that retains Feenstra's basic framework but uses limited information maximum likelihood (LIML). This method mitigates the small-sample bias found in the estimates of Feenstra (1994) and Broda and Weinstein (2006) when short panel data are used. Soderbery's contribution lies in improving the estimation of substitution elasticities within the Feenstra/Broda–Weinstein (hereafter F/BW) framework from both the theoretical and the econometric side.

Empirical research on substitution elasticities for Japan remains limited, and detailed product-level analysis in particular has not accumulated sufficiently. Against this background, Ito and Matsuura (2017) and Aoyagi, Ito, and Matsuura (2022), in analysing the effect of Japan's trade on economic welfare, applied the method of Soderbery (2015) and estimated substitution elasticities using Japanese import data at the HS9-digit level. These studies occupy an important position as prior work that partly fills the empirical gap in this field for Japan.

3.3 Originality and Contributions of This Study

The Japanese studies introduced in the previous subsection estimate substitution elasticities at the HS9-digit level in order to analyse welfare effects.[1] The HS9-digit classification has the advantage of dividing products finely and capturing differences between goods. When finer disaggregation makes trade observations intermittent, however, it becomes difficult to secure the time series needed for estimation.

In contrast, a clear feature of this study is its use of import data at the HS6-digit level. The aim of this study is to estimate substitution elasticities for as many products as possible using a common product classification that provides a basis for international comparison. The reason for adopting HS6-digit lies in this aim and in the requirement of securing the observations needed for estimation. In the framework of Feenstra (1994), a reference country must be set in order to remove common time shocks, and import prices and import shares must be double-differenced. For the

[1] In the publicly available working paper (Aoyagi, Ito, and Matsuura, 2021, pp. 5–6), elasticities are estimated separately for the period corresponding to each HS revision and are aggregated to JIP sectors using an HS–IO–JIP concordance. This procedure is distinct from linking HS9-digit time series to identical products over the entire period.

reference country, continuous observation of imports must be secured so that changes in the price and import share of the product concerned can be computed.

When the product classification is excessively fine, the decline in the number of trading partners and breaks in the observation period make it difficult to set a reference country at all. With a fine classification such as HS9-digit, it becomes difficult to satisfy the conditions for a reference country when trade is observed only sporadically. As a result, the set of products for which estimation is feasible (the extensive margin[2]) may be constrained.

The HS6-digit classification, by contrast, groups a wider range of goods into the same product than the HS9-digit classification, so that a product may contain goods of differing nature. On the other hand, it is likely to be easier to secure import partners that can be observed continuously for each product. Whereas the HS9-digit classification is specific to Japan, the HS6-digit classification is internationally common and provides a basis for product-level comparison under a unified classification. When estimation periods or methods differ, however, a common classification alone does not guarantee the comparability of estimates. Taking this limitation of aggregation into account, this study adopts the HS6-digit classification, giving weight to the common basis for international comparison and to the range of products for which estimation is feasible. In addition, HS6-digit is an internationally harmonised classification system used as standard by major international organisations and research projects such as UN Comtrade, the WTO, and CEPII, and it therefore provides a basis for international comparison and policy analysis with aligned product classifications.

A further feature of this study is that it explicitly examines how the rule for selecting the reference country affects the estimated substitution elasticities and the range of products for which estimation is feasible. Specifically, we adopt two rules: (i) a *Product-Specific Reference* rule, under which the reference country for each product is Japan's largest import partner; and (ii) a *Fixed Reference: U.S.* rule, under which the United States is the common reference country for all products. We compare the substitution elasticities estimated under each rule.

This comparison makes it possible to clarify not only how the setting of the reference country affects the level and distribution of the estimates, but also the extent to which it expands or constrains the set of products for which estimation is feasible (the extensive margin).

In sum, this study provides new evidence in two respects: (i) it systematically estimates product-level substitution elasticities for Japan's traded products using HS6-digit import data; and (ii) it empirically examines how reference country selection, an important element of the estimation, affects the estimates and the set of products for which estimation is feasible. In doing so, it aims to deepen the understanding of Japan's trade structure and to provide an empirical basis for future tariff policy evaluation and welfare analysis.

[2]In this study, the extensive margin does not refer to the entry of new products or new partner countries as such. It is an operational concept denoting the breadth of the set of products for which the elasticity of substitution σ can be estimated under different choices of reference country.

4 Model

This section sets out the theoretical framework for estimating the elasticity of substitution for traded products, following Feenstra (1994). In particular, it makes explicit how differencing relative to a reference country removes unobservable price indices and common shocks and allows the demand-side elasticity of substitution and the supply-side elasticity to be identified simultaneously.

4.1 Consumer Preferences and Demand Structure

We assume that, for each traded product defined at the HS6-digit level, Japanese consumers consume goods differentiated by country of origin. That is, goods belonging to the same product are regarded by consumers as different varieties if their countries of origin differ. This setting is based on the Armington (1969) assumption and makes it possible to capture explicitly substitution across countries of origin within a product.

Let q_{gct} denote the quantity consumed of product g from country of origin c in year t. Subutility for product g is represented by the following CES function:

$$U_{gt} = \left(\sum_{c \in \mathcal{C}_{gt}} d_{gct}^{\frac{1}{\sigma_g}} q_{gct}^{\frac{\sigma_g - 1}{\sigma_g}} \right)^{\frac{\sigma_g}{\sigma_g - 1}}, \quad \sigma_g > 1, \tag{1}$$

where $\sigma_g > 1$ denotes the elasticity of substitution across countries of origin for product g. The term d_{gct} captures consumers' preferences for, and assessment of the quality of, product g produced in country c. $\mathcal{C}_{gt}$ is the set of exporting countries supplying the product to Japan in year t.

Under CES preferences, consumers shift demand towards goods from countries of origin whose relative prices have fallen, and the size of this response is governed by σ_g. σ_g is therefore the central structural parameter measuring the sensitivity of the import structure to price changes.

The import share s_{gct} of country of origin c in product g is then given by

$$s_{gct} = \frac{d_{gct} p_{gct}^{1-\sigma_g}}{\sum_{k \in \mathcal{C}_{gt}} d_{gkt} p_{gkt}^{1-\sigma_g}}, \tag{2}$$

where p_{gct} is the import price of product g from country c. This expression shows that import shares are determined as a function of relative prices, but the right-hand side contains an unobservable price index, so that σ_g cannot be estimated directly from it.

4.2 Import Demand and Supply

Under the CES preference structure, the demand function for the imported good of product g from country of origin c is given by

$$q_{gct} = d_{gct} \left(\frac{p_{gct}}{P_{gt}} \right)^{-\sigma_g} Q_{gt}, \tag{3}$$

where p_{gct} is the import price of product g from country of origin c, P_{gt} is the CES price index for product g, and Q_{gt} is total consumption of the product.

The import share of country of origin c in product g is

$$s_{gct} \equiv \frac{p_{gct}q_{gct}}{P_{gt}Q_{gt}} = \frac{p_{gct}q_{gct}}{\sum_{c' \in \Omega_{gt}} p_{gc't}q_{gc't}}.$$

Using this expression, the demand function in equation (3) can be rewritten in terms of import shares:

$$\ln s_{gct} = \ln d_{gct} + (\sigma_g - 1) \ln \left(\frac{P_{gt}}{p_{gct}} \right). \tag{4}$$

Taking the difference of the log import-share demand function in equation (4) relative to period $t-1$ yields

$$\Delta \ln s_{gct} = \varphi_{gt} - (\sigma_g - 1)\Delta \ln p_{gct} + \varepsilon_{gct}, \tag{5}$$

where $\varphi_{gt} \equiv (\sigma_g - 1)\Delta \ln P_{gt}$ and $\varepsilon_{gct} \equiv \Delta \ln d_{gct}$. The term φ_{gt} contains the product-level price index and does not depend on the country of origin.

On the supply side, following Feenstra (1994), we specify the supply curve as

$$p_{gct} = v_{gct} q_{gct}^{\omega_g}, \tag{6}$$

where v_{gct} represents changes in supply conditions due to technological change and other factors. $\omega_g \geq 0$ is the inverse supply elasticity: when $\omega_g > 0$, the supply elasticity is $1/\omega_g$, and $\omega_g = 0$ corresponds to a horizontal supply curve. Substituting $q_{gct} = s_{gct}P_{gt}Q_{gt}/p_{gct}$, which follows from the definition of the import share, taking logarithms, and differencing relative to period $t-1$ yields

$$\Delta \ln p_{gct} = \psi_{gt} + \frac{\omega_g}{1+\omega_g} \Delta \ln s_{gct} + \delta_{gct}, \tag{7}$$

where $\psi_{gt} \equiv \frac{\omega_g}{1+\omega_g}\Delta \ln(Q_{gt}P_{gt})$ and $\delta_{gct} \equiv \frac{1}{1+\omega_g}\Delta \ln v_{gct}$.

Both the demand-side and the supply-side relationships contain unobservable price indices and common shocks, and are therefore difficult to estimate directly as they stand. The next subsection sets out the role of reference country differencing, which is introduced to resolve these problems.

4.3 Reference-Country Differencing and Derivation of the Estimating Equation

The core of Feenstra's (1994) method is to remove unobservable common terms by differencing relative to a reference country k within the same product. Specifically, for product g at time t, we define the following differenced variables by taking log differences between country of origin c and reference country k:

$$\Delta^k \ln s_{gct} \equiv \Delta \ln s_{gct} - \Delta \ln s_{gkt}, \tag{8}$$

$$\Delta^k \ln p_{gct} \equiv \Delta \ln p_{gct} - \Delta \ln p_{gkt}. \tag{9}$$

This operation eliminates the price index and aggregate demand term common at the product level, as well as common time shocks, and extracts only the relative variation in prices and import shares across countries.

Applying this reference country differencing to the demand and supply functions yields the following two equations:

$$\Delta^k \ln s_{gct} = -(\sigma_g - 1)\, \Delta^k \ln p_{gct} + \varepsilon^k_{gct}, \tag{10}$$

$$\Delta^k \ln p_{gct} = \frac{\omega_g}{1+\omega_g}\, \Delta^k \ln s_{gct} + \delta^k_{gct}. \tag{11}$$

Equation (10) represents the demand curve and equation (11) the supply curve. Here ε^k_{gct} and δ^k_{gct} are error terms representing relative demand-side and supply-side shocks, respectively.

Combining these two structural equations yields, as shown by Feenstra (1994), the following estimating equation, which is expressed as a quadratic form in import shares and import prices:

$$Y_{gct} = \theta_{1g} X_{1gct} + \theta_{2g} X_{2gct} + u_{gct}, \tag{12}$$

where

$$\begin{aligned}
Y_{gct} &\equiv \left(\Delta^k \ln p_{gct}\right)^2, \\
X_{1gct} &\equiv \left(\Delta^k \ln s_{gct}\right)^2, \\
X_{2gct} &\equiv \Delta^k \ln s_{gct}\, \Delta^k \ln p_{gct}, \\
u_{gct} &\equiv \frac{\varepsilon^k_{gct}\, \delta^k_{gct}}{\sigma_g - 1}, \\
\theta_{1g} &\equiv \frac{\rho_g}{(\sigma_g - 1)^2 (1 - \rho_g)}, \\
\theta_{2g} &\equiv \frac{2\rho_g - 1}{(\sigma_g - 1)(1 - \rho_g)}, \\
\rho_g &\equiv \frac{\omega_g(\sigma_g - 1)}{1 + \omega_g \sigma_g} \in \left[0, \frac{\sigma_g - 1}{\sigma_g}\right].
\end{aligned}$$

Substituting the estimates of θ_{1g} and θ_{2g} obtained from equation (12) into the relationships above makes it possible to recover the product-level elasticity of substitution σ_g and the inverse supply elasticity ω_g simultaneously.

In analysing U.S. imports, Feenstra (1994, pp. 165–166) chose Japan as the reference country because it supplied all six of the manufactured products under study in every year, and used Canada, a principal supplier, for gold and silver. This choice illustrates the importance of securing continuous observations for the supplying country that serves as the reference country. In light of this, we compare a method that selects the reference supplier to Japan product by product with a method that fixes it as the United States. The rule of selecting the largest import partner is the specific implementation adopted in this study.

Reference-country differencing removes the terms common to all suppliers of the same product,

but it does not remove shocks specific to the reference country. When a shock specific to the reference country occurs, its effect is contained in common in the reference country differences computed for every supplier. Consequently, even when nothing changes for the other suppliers, a change in the reference country generates changes in relative prices and relative import shares. To assess how such variation affects the estimates, this study compares the results obtained under different reference country selection rules.

Specifically, in the subsequent estimation of σ_g, we adopt a rule under which the largest import partner for each product is the reference country k and a rule under which the United States is the common reference country k for all products.

Based on this theoretical framework, the next section describes the data and the estimation method actually used.

5 Data

5.1 Data Sources

This study estimates substitution elasticities for imported products using annual Japanese import data for 1996 to 2023 from the UN Comtrade database. The sample ends in 2023 because that was the latest year for which Comtrade data were available when the analysis began.

The product classification is unified to HS1996, and we use the data that UN Comtrade provides in this classification. For data reported in later classifications, we rely on the classification conversion carried out by UN Comtrade. This allows the long series from 1996 onwards to be handled in a single classification, without the researcher having to link classifications across years independently. It does not, however, eliminate the aggregation constraints that accompany classification conversion.

We use import data by partner country as reported by Japan. Because the Comtrade monthly data do not extend back to 1996, we adopt annual data, which secure the long sample period from 1996 to 2023.

The data for this period comprise 4,199 products and a cumulative total of 3,234,776 observations. Using these data, we estimate substitution elasticities for as many products as possible. The Comtrade database provides three measures of import value: FOB value (free on board), CIF value (cost, insurance, and freight), and Primary value.[3] In theory, the CIF value is closest to the definition of import cost in the model. However, FOB and CIF values are missing for some years and products. Moreover, a comparison of the three measures shows no large differences overall. To secure broad coverage, this study therefore uses Primary value to compute import shares.

[3]Primary value is measured on a CIF basis for imports where available and on an FOB basis otherwise; for exports it is measured on an FOB basis.

5.2 Construction of Product-Level Data

The unit of analysis is the combination of product g defined at the HS6-digit level, exporting country c, and year t. For each observation, we compute import value, import quantity, import unit value, and the within-product import share.

The import share s_{gct} of exporting country c in product g in year t is defined as

$$s_{gct} = \frac{V_{gct}}{\sum_{k \in \mathcal{C}_{gt}} V_{gkt}}, \tag{13}$$

where V_{gct} is the value of imports of product g from exporting country c in year t, and $\mathcal{C}_{gt}$ is the set of exporting countries supplying product g to Japan in that year.

The import unit value p_{gct} is defined as

$$p_{gct} = \frac{V_{gct}}{Q_{gct}}, \tag{14}$$

where Q_{gct} is the import quantity.

Observations for which the import quantity is not reported, or is reported as zero, are excluded from the analysis because the unit value cannot be defined.

5.3 Sample Restrictions and Data Processing

Because the estimation method of Feenstra (1994) uses rates of change in import shares and import prices over time, each product must be observed for at least two periods. The analysis is therefore restricted to products for which imports are observed in consecutive periods.

To mitigate the influence of extreme price movements and measurement error, we apply outlier treatment to the log changes in import unit values and import shares. Specifically, we compute the distribution of log changes for each product and exclude observations above the 99th percentile or below the 1st percentile.

In addition, because measurement error is likely to have a large effect on the estimates for observations with very small import values, we also conduct a robustness check that excludes observations whose within-product import share falls below a given threshold.

5.4 Reference-Country Selection Rules

To examine how reference country selection affects the estimated substitution elasticities, this study adopts two different reference country selection rules.

The first is the *Product-Specific Reference* (PSR) rule.[4] Under this rule, for each product g, the exporting country with the largest import value for that product is selected as the reference

[4]PSR selects, for each product, the single country with the largest share of imports into Japan over the base period (in this study, 1996–2023) and uses it as a fixed reference country throughout the sample period. FR uses the United States (U.S.) as the reference country for all products.

country. The feature of this rule is that it takes as the reference point the country that has the largest influence on Japan's import structure for the product concerned.

The second is the *Fixed Reference: U.S.* (FR: U.S.) rule. Under this rule, the reference country is fixed as the United States for all products and years, because the United States continuously supplies a broad range of products to Japan and can be expected to be usable as a reference country for many products. This rule serves as the benchmark for comparison with PSR, which selects the reference country product by product.

By comparing the distributions of the estimated substitution elasticities and the number of products for which estimation is feasible under these two rules, we systematically examine the effect of reference country selection on the estimates.

6 Results

Based on the theoretical framework of Feenstra (1994), and incorporating the refinements of Soderbery (2015), this study estimates the elasticity of substitution (σ) for Japan's imported products. In the method of Feenstra (1994) described above, one of the partner countries from which Japan imports the same product is set as the reference country in order to remove time effects. The choice of this reference country may change the estimated elasticities.

We therefore adopt the following two reference country rules:

- the *Product-Specific Reference* (PSR) rule, under which the reference country for each of Japan's imported products is the largest import partner; and
- the *Fixed Reference* (FR: U.S.) rule, under which the United States is the common reference country for all products.

Comparing these two rules allows us to examine the robustness of the model estimates and, at the same time, to assess the plausibility of the elasticity of substitution σ.

6.1 Descriptive Statistics by Reference-Country Rule

Table 1 reports descriptive statistics for the elasticity of substitution σ of Japan's imported products estimated under the two reference country rules, PSR and FR: U.S. The table makes it possible to compare the distributions of σ obtained under the two rules.

Panel A covers products for which a theoretically admissible estimate was obtained in the first step under each rule. Panel B reports the final estimates, including those obtained in the second step. Because the sets of products for which estimation was feasible differ between the two rules, the table does not compare estimates for the same products; it compares descriptive statistics computed from each rule's sample.

Looking across quantiles, the difference between the two rules at the reported quantiles is larger at higher quantiles. In Panel A, the difference at the 10th percentile is 0.030, whereas it is 2.591 at the 90th percentile. In Panel B, the difference is likewise 0.012 at the 10th percentile and 2.530

Table 1: Baseline estimates of substitution elasticity (σ) at HS6-digit: comparison of reference country rules

Estimate	N	10th	50th	80th	90th	95th	99th	Mean
Panel A: Feasible first-step estimates								
Product-Specific Reference	2,774	1.349	2.555	6.061	10.483	18.364	92.466	11.386
Fixed Reference, FR: U.S.	2,944	1.318	2.233	4.844	7.893	12.811	70.517	6.810
Difference		0.030	0.322	1.217	2.591	5.553	21.949	4.576
Relative Difference (%)		2.3%	12.6%	20.1%	24.7%	30.2%	23.7%	40.2%
Panel B: All final estimates, including second-step								
Product-Specific Reference	3,506	1.273	2.324	5.731	11.016	26.194	559.175	36.913
Fixed Reference, FR: U.S.	3,727	1.261	2.087	4.754	8.486	18.374	477.161	31.236
Difference		0.012	0.236	0.977	2.530	7.820	82.014	5.677
Relative Difference (%)		0.9%	10.2%	17.0%	23.0%	29.9%	14.7%	15.4%

Notes: PSR denotes the product-specific reference rule and FR the fixed reference rule with the United States as the reference country. Differences are differences between the corresponding descriptive statistics computed from each rule's sample, not differences between estimates for the same product. Differences and relative differences are computed from unrounded values.
Letting S^{PSR} and S^{FR} denote the descriptive statistic in each column, the difference is $\max(S^{PSR}, S^{FR}) - \min(S^{PSR}, S^{FR})$, and the relative difference (%) is this difference divided by $\max(S^{PSR}, S^{FR})$ and multiplied by 100.

at the 90th percentile. The median in Panel B is 2.324 under PSR and 2.087 under FR: U.S., a relative difference of 10.2%.

Turning to the means, in Panel A the mean is 11.386 under PSR and 6.810 under FR: U.S., a difference of 4.576. In Panel B, which includes the second-step estimates, the means are 36.913 and 31.236, respectively, a difference of 5.677.

In terms of relative differences, Panel A shows 2.3% at the 10th percentile, 24.7% at the 90th percentile, and 40.2% for the mean. In Panel B, the corresponding figures are 0.9%, 23.0%, and 15.4%. These figures show that the distributions of the estimates differ between the two rules, but the comparison reflects both differences in the estimates for the same products arising from reference country choice and differences in the sets of products for which estimation is feasible.

6.2 The Set of Estimable Products (Extensive Margin)

The descriptive statistics in the previous subsection compare the distributional characteristics of the elasticities σ estimated under the two reference country rules, but σ cannot be estimated under both rules for every product. This is due to data completeness and the constraints of reference country setting, and it means that the choice of reference country rule also affects the set of products for which estimation is feasible.

Specifically, σ could be estimated under both rules for 3,236 products. A further 270 products could be estimated only under PSR, and 491 products only under FR: U.S. Estimation is therefore feasible for 3,506 products under PSR and 3,727 products under FR: U.S., and the total number of products estimable under at least one rule is 3,997.

Thus, under either reference country rule there are a certain number of products for which estimation is infeasible, but their composition differs between the rules. In other words, the choice between fixing the reference country and setting it flexibly product by product has a material effect not only on the level and distribution of the estimated σ, but also on which products are included in the analysis.

These results suggest that setting the reference country flexibly can expand the range of products for which σ can be estimated. In particular, reliance on a single reference country rule raises the risk that, for certain products, the conditions for a reference country are not met and estimation becomes impossible. Using several reference country rules together, by contrast, expands the set of estimable products and makes it possible to evaluate substitution elasticities for more products.

This point indicates that the construction of the comprehensive elasticity measure proposed later in the paper—that is, an integrated baseline that takes account of differences across reference country rules—can play an important role in empirical analysis.

6.3 Tests of Differences Between Reference-Country Rules

The descriptive statistics presented so far show differences in the overall distributions of the elasticities σ obtained under the two reference country rules. They do not, however, allow us to judge directly whether the differences in σ estimated for the same product are statistically significant. In this subsection, we therefore conduct statistical tests on the differences between the elasticities obtained under the two rules, in order to examine whether the setting of the reference country rule has a systematic effect on the estimates.

Of the 3,236 products for which elasticities could be estimated under both rules, the United States is also selected under PSR for 315 products, so that the reference countries coincide. Because the purpose here is to compare estimates when the choice of reference country differs, we exclude these 315 products and test the remaining 2,921 products.

The null hypothesis is that the mean difference between the PSR and FR: U.S. elasticities is zero for the products compared:

$$H_0 : \ E[\sigma_g^{PSR} - \sigma_g^{FR}] = 0.$$

The tests are conducted for three samples defined according to the estimation stage. *Overall* includes, among the products compared, those for which an elasticity estimate was obtained under both PSR and FR: U.S., regardless of the estimation stage. Here, the first step refers to estimation by linear LIML, and the second step to estimation by nonlinear LIML, which is carried out when the first step does not yield admissible estimates of the structural parameters. *First-step* is restricted to products for which first-step estimates were obtained under both rules, and *Second-step* to products for which second-step estimates were obtained under both rules. Products for which a first-step estimate was obtained under one rule and a second-step estimate under the other are included only in Overall. The First-step and Second-step sample sizes therefore do not sum to the Overall sample

size. Using these samples, we examine the differences in estimates due to reference country choice for the whole sample and by estimation stage.

The test results are reported in Table 2. The difference is defined as the PSR estimate minus the FR: U.S. estimate. Panel A reports the results when no additional trimming is applied to the estimates. The p-values for Overall, First-step, and Second-step are 0.9369, 0.1404, and 0.3618, respectively, and in no case can the null hypothesis of a zero mean difference be rejected at the 5% level. The absence of a significant difference, however, does not mean that the estimates under the two rules are equivalent.

Next, to examine the sensitivity of the test results to the treatment of extreme values, we apply two types of 99% trimming. Panel B reports the results after trimming based on the absolute difference between the estimates under the two rules. The 99th percentile of the absolute difference is computed separately for each of the Overall, First-step, and Second-step samples, and products exceeding the threshold are excluded; products equal to the threshold are retained. Although the absolute difference is used to decide exclusion, the test is applied to the mean of the signed difference, PSR minus FR: U.S. The Overall mean difference is positive at 3.095 but is not significant at the 5% level ($p = 0.0740$). The First-step mean difference is 0.682 and is significantly positive at the 5% level ($p = 0.0261$). The Second-step mean difference, by contrast, is -111.183 and is significantly negative at the 5% level ($p = 0.0262$). After this treatment, therefore, PSR exceeds FR: U.S. on average in the First-step sample, whereas it falls below FR: U.S. in the Second-step sample.

Panel C reports the results after trimming based on σ itself. Specifically, for each of the Overall, First-step, and Second-step samples, we compute the 99th percentile of the PSR estimates and of the FR: U.S. estimates, and exclude products for which either estimate exceeds the corresponding threshold. Estimates equal to the threshold are retained, and the lower tail is not trimmed. The stage-specific thresholds are computed separately from each stage's sample; the stage-specific samples are not subsets of the trimmed Overall sample. The Overall mean difference is 1.781 and is significantly positive at the 5% level ($p = 0.0213$). The First-step mean difference is also positive at 1.026 and is significant at the 1% level ($p < 0.0001$). In contrast, the Second-step mean difference is -83.231 and is significantly negative at the 5% level ($p = 0.0449$). Thus, under both trimming methods, the direction of the mean difference differs between the First-step and Second-step samples.

These results show that conclusions about the mean difference between the reference country rules depend on the estimation stage and on whether, and how, trimming is applied. Without trimming, no difference significant at the 5% level is found in any sample. After trimming, significant mean differences are found that are positive for First-step and negative for Second-step, while the significance of the Overall difference depends on the trimming method. In assessing the effect of reference country choice, it is therefore necessary to check the results by estimation stage and the treatment of extreme values, in addition to the overall mean difference.

Table 2: Stepwise one-sample t-tests for difference in σ (PSR vs. FR: U.S.)

	N	Mean	t	p	95% CI
Panel A: Full Sample Result					
Overall	2,921	0.707	0.079	0.9369	[−16.808, 18.222]
First-step	1,969	5.720	1.475	0.1404	[−1.886, 13.325]
Second-step	173	−63.019	−0.914	0.3618	[−199.049, 73.012]
Panel B: Results after Difference-Based Trimming (99%)					
Overall	2,892	3.095	1.788	0.0740	[−0.300, 6.490]
First-step	1,950	0.682	2.226	0.0261	[0.081, 1.283]
Second-step	172	−111.183	−2.243	0.0262	[−209.049, −13.316]
Panel C: Results after Sigma-Based Trimming (99%)					
Overall	2,865	1.781	2.304	0.0213	[0.266, 3.297]
First-step	1,931	1.026	4.994	< 0.0001	[0.623, 1.429]
Second-step	171	−83.231	−2.021	0.0449	[−164.539, −1.923]

Notes: The difference is the PSR estimate minus the FR (U.S. fixed) estimate, and the null hypothesis is that the mean difference is zero. p-values are two-sided. p-values displayed as 0.0000 in the statistical output are reported as < 0.0001. The products compared are the 2,921 products obtained by excluding, from the 3,236 products with estimates under both rules, the 315 products for which the United States is also the reference country under PSR. In Panel B, products exceeding the 99th percentile of the absolute difference in each sample are excluded, and products equal to the threshold are retained; the test uses the signed difference. In Panel C, the 99th percentiles of PSR and FR are computed separately for each of the three samples, and only products for which both estimates are at or below their respective thresholds are retained; the lower tail is not trimmed.
Overall includes products with estimates under both rules regardless of estimation stage. First-step is restricted to products with first-step estimates under both rules, and Second-step to products with second-step estimates under both rules. Products with a first-step estimate under one rule and a second-step estimate under the other are included only in Overall, so the stage-specific sample sizes do not sum to the Overall sample size.

6.4 Distribution of Differences and Quantile Analysis

The previous subsection confirmed that the direction of the mean difference between the reference country rules differs by estimation stage and that its significance depends on whether, and how, trimming is applied. In this subsection, we present the distribution of the differences by quantile in order to examine in more detail their magnitude and distributional structure, in particular the behaviour of the tails.

Table 3 reports, by quantile, the distribution of differences between the product-specific reference rule (PSR) and the fixed reference rule (FR: U.S.), using the sample obtained after the 99th-percentile trimming on σ itself in Panel C of Table 2.

Panel A reports the absolute difference between the estimates under the two rules. The Overall median is 1.470, but the difference is 13.383 at the 90th percentile, 29.180 at the 95th percentile, and 220.108 at the 99th percentile, so that the absolute difference is larger at higher quantiles. For First-step as well, the median is 1.477, the 90th percentile is 10.106, and the 99th percentile is 45.399. For Second-step, the median of 1.625 is close to that of First-step, but the 90th percentile is 311.203 and the 99th percentile reaches 3,853.393. These results show that the upper tail of the absolute difference between the rules is especially long for products estimated in the second step.

Panel B reports the relative difference, defined as the absolute difference divided by the larger of the two estimates. For Overall, the median relative difference is 43.273%, the 75th percentile is 68.610%, and the 99th percentile is 99.105%. The medians for First-step and Second-step are 42.157% and 49.704%, respectively. At the 90th percentile, the relative difference is 81.984% for First-step and 99.192% for Second-step. Large discrepancies are therefore found in the upper quantiles for Second-step in relative as well as in absolute terms. These results suggest that, when the estimates are used, their sensitivity to reference country selection needs to be checked product by product.

Table 4 classifies the 2,865 products in the Overall sample into five intervals according to the relative difference reported in Panel B of Table 3. The numbers of products in the intervals are, in ascending order of relative difference, 680, 651, 570, 526, and 438, and for each interval the table reports the distributions of the PSR and FR: U.S. estimates.

In the interval with a relative difference of at least 0% and less than 20%, the medians under PSR and FR: U.S. are 1.726 and 1.708, and the 99th percentiles are 9.642 and 9.456, so that the distributions under the two rules are close. In the interval with a relative difference of at least 80% and at most 100%, by contrast, the medians are 9.700 and 2.765, and the 99th percentiles are 408.572 and 354.315. In the interval with the largest relative difference, the upper-quantile estimates are high under both rules, and the medians also differ substantially.

Not all quantiles rise monotonically across the relative difference intervals, however, and the PSR estimates do not always exceed those under FR: U.S. For example, in the interval with a relative difference of at least 60% and less than 80%, the 99th percentile is 20.902 under PSR but 26.500 under FR: U.S. These results show that the differences in estimates arising from reference

Table 3: Distribution of differences in σ between PSR and FR: U.S. (HS6-digit, Japan, 1996–2023), by estimation stage

	N	25th	50th	75th	90th	95th	99th
Panel A: Absolute Difference							
Overall	2,865	0.464	1.470	4.374	13.383	29.180	220.108
First-step	1,931	0.478	1.477	4.009	10.106	17.930	45.399
Second-step	171	0.398	1.625	8.462	311.203	820.786	3,853.393
Panel B: Relative Difference (%)							
Overall	2,865	21.245%	43.273%	68.610%	86.124%	93.431%	99.105%
First-step	1,931	20.683%	42.157%	66.179%	81.984%	89.310%	95.320%
Second-step	171	20.899%	49.704%	81.714%	99.192%	99.801%	99.967%

Notes: PSR denotes the product-specific reference rule and FR the fixed reference rule with the United States as the reference country. Each row uses the corresponding sample from Panel C of Table 2, and the trimming thresholds are computed separately for each sample. The absolute difference is $\max(\sigma^{PSR}, \sigma^{FR}) - \min(\sigma^{PSR}, \sigma^{FR})$, and the relative difference (%) is this absolute difference divided by $\max(\sigma^{PSR}, \sigma^{FR})$ and multiplied by 100.

Table 4: Percentile distribution of estimated trade elasticities across PSR–FR deviation intervals

	N	25th	50th	75th	90th	95th	99th
Panel A: Overall $[0, 20)\%$							
PSR	680	1.405	1.726	2.404	3.523	5.208	9.642
FR	680	1.405	1.708	2.446	3.699	5.393	9.456
Panel B: Overall $[20, 40)\%$							
PSR	651	1.546	2.042	2.890	4.334	6.087	11.192
FR	651	1.551	1.957	2.730	4.492	5.774	10.161
Panel C: Overall $[40, 60)\%$							
PSR	570	1.869	2.814	4.091	6.094	8.531	16.069
FR	570	1.566	2.359	3.576	5.512	8.471	16.119
Panel D: Overall $[60, 80)\%$							
PSR	526	1.753	4.197	6.108	8.795	12.079	20.902
FR	526	1.578	2.933	5.400	8.076	10.903	26.500
Panel E: Overall $[80, 100]\%$							
PSR	438	1.790	9.700	24.319	73.489	198.162	408.572
FR	438	1.500	2.765	13.704	54.974	128.781	354.315

Notes: The intervals are based on the relative difference defined in Table 3. Each interval includes its lower bound and excludes its upper bound, except for the last interval, which includes both endpoints. The sample is the Overall sample in Panel C of Table 2, and the numbers of products in the five intervals sum to 2,865.

country selection are not uniform. Note that the classification by relative difference is constructed ex post from the estimates, and this comparison alone does not allow the differences to be attributed to the nature of the products or to the frequency of trade.

6.5 Construction of the CBR Measure and Capped Estimates

The analysis so far has confirmed that the reference country selection rule has a material effect on the estimated elasticities σ, and that this effect is particularly pronounced in the upper part of the distribution. It has also shown that there are products for which estimation is infeasible under either rule, and that reliance on a single rule constrains the range of products covered by the analysis.

In light of these points, we construct the CBR (*Conservative Baseline Reference* elasticity), a comprehensive elasticity measure that covers a wider range of products than either rule alone by integrating the estimates obtained under the two reference country selection rules.

The CBR is defined as follows. For products for which σ can be estimated under both the product-specific reference rule (PSR) and the fixed reference rule (FR: U.S.), we adopt the smaller of the two values as the more conservative baseline:

$$\sigma_g^{CBR} = \min\left(\sigma_g^{PSR},\ \sigma_g^{FR}\right). \tag{15}$$

For products that can be estimated under only one of the reference country rules, the σ obtained under that rule is adopted as it is.

The CBR measure defined in this way integrates the PSR and FR: U.S. estimates on a product basis (taking their union) and includes all products for which estimation was feasible under at least one rule. As a result, σ based on the CBR is available for 3,997 products, which expands the range of estimable products relative to reliance on a single reference country rule (3,506 products under PSR and 3,727 products under FR: U.S.).

Here, "conservative" refers to the selection rule of adopting the smaller σ for products with estimates under both rules. This rule alone does not guarantee that estimation error is reduced or that the value is closer to the true one.

Furthermore, to limit the influence of extremely large estimates, we set a common upper bound of 131.5 on the estimates under each rule. This value is taken with reference to the upper limit of the grid search used by Broda and Weinstein (2006, p. 566). The treatment in this paper, however, applies a cap to estimates already obtained and is distinct from the search constraint imposed during estimation in that paper.

Table 5 reports the distributions after capping. The median of the CBR is 1.741 and its mean is 4.115, both lower than under PSR and FR: U.S. Because the sets of products differ across the rules, however, this comparison of distributions reflects both the rule of adopting the smaller value and differences in the composition of the products covered.

The advantage of the CBR is that it makes substitution elasticities available for 3,997 products

under an explicit selection rule. When it is used for policy analysis, it is desirable to report the PSR and FR: U.S. results alongside it for products where they are available and to check the sensitivity to reference country selection.

Table 5: Capped substitution elasticity estimates (σ) at HS6-digit: PSR vs. FR: U.S. vs. CBR

	N	10th	50th	80th	90th	95th	99th	Mean
PSR	3,506	1.273	2.324	5.731	11.016	26.194	131.500	7.810
FR: U.S.	3,727	1.261	2.087	4.754	8.486	18.374	131.500	6.970
CBR	3,997	1.188	1.741	2.986	4.855	7.764	116.726	4.115

Notes: PSR denotes the product-specific reference rule, FR the fixed reference rule with the United States as the reference country, and CBR the conservative baseline measure. With reference to the upper limit of the grid search in Broda and Weinstein (2006), all estimates are capped at $\sigma = 131.5$ after estimation.

7 Conclusion

Based on the theoretical framework established by Feenstra (1994) and Broda and Weinstein (2006) (the Feenstra/Broda–Weinstein, or F/BW, framework), and applying the estimation method of Soderbery (2015), this study has systematically estimated product-level elasticities of substitution σ for Japan's imports at the HS6-digit level. Its distinguishing feature is that it focuses on how the reference country selection rule affects the estimates and the range of estimable products, comparing and examining two methods: the product-specific reference rule (PSR) and the fixed reference rule (FR: U.S.).

First, sensitivity to reference country selection cannot be captured by the mean difference alone. Before trimming, the null hypothesis of a zero mean difference cannot be rejected, but this does not imply that the product-level estimates agree. After trimming based on σ, the median absolute difference is 1.470 and the median relative difference is 43.273%, and the difference is large for some products. Moreover, the stage-specific mean difference is positive in the first step and negative in the second step, so that the results also differ by estimation stage.

Second, reference country selection also affects the set of products for which estimation is feasible. Estimates are obtained for 3,506 products under PSR and 3,727 products under FR: U.S., and using the two rules together covers 3,997 products. The CBR proposed in this study adopts the smaller value when both estimates are available and the available value when there is only one. The label "conservative" refers to this selection rule; it does not guarantee an improvement in estimation precision or a lower bound on welfare effects.

These results are also relevant when assessing the degree of differentiation of imported products. In the CES framework of this paper, a low σ indicates low substitutability between origin-specific varieties within the same product. If σ for the same product changes with the choice of reference country, the degree of differentiation inferred from the estimates may change as well. σ alone,

however, cannot directly identify the quality of a good or an objective type of good.

In addition, in the CES price index framework of Feenstra (1994) and Broda and Weinstein (2006), holding other conditions and the change in expenditure shares associated with the expansion of variety constant, the smaller σ is within the range $\sigma > 1$, the larger is the fall in the price index due to the expansion of variety. The CBR's adoption of the smaller σ therefore does not mean that welfare gains are evaluated as smaller. Differences arising from reference country selection are a reason to examine the sensitivity not only of the interpretation of the degree of differentiation but also of welfare evaluation. Because this paper does not estimate the welfare effects of policy changes themselves, assessing their magnitude is left for future work.

Several issues remain for future research. First, methods that endogenise the choice of reference country, and estimation methods that use multiple reference countries, should be examined. Second, although this study uses annual data, higher-frequency data may make it possible to distinguish short-run shocks from structural changes more precisely. Third, using the estimated substitution elasticities to evaluate quantitatively the effects of tariff changes and trade policy shocks on economic welfare and on the stability of supply chains is also an important topic.

In light of the above, the CBR measure and the empirical findings on reference country selection presented in this study deepen the understanding of Japan's trade structure and can be expected to serve as a useful empirical basis for future theoretical research and policy analysis.

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