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Measuring China's trade liberalization: A generalized measure of trade restrictiveness index

Bo Chen [a,*], Hong Ma [b], Yuan Xu [b]

[a] School of International Business Administration, SHUFE, China
[b] School of Economics and Management, Tsinghua University, China

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ABSTRACT

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Neither simple average nor import-weighted average tariff indexes are ideal measures of tariff barriers. In this paper, we propose a generalized trade restrictiveness index (GTRI) that extends Feenstra's (1995) tariff restrictiveness index (TRI) by relaxing the crucial assumption of a small open economy. We show that the GTRI can be measured using import tariffs, import shares, and the corresponding import and foreign export elasticities. We then apply the GTRI to examine how trade restrictiveness has evolved in China from 1997 to 2008, the period in which China entered the WTO. The GTRI indicates a higher level of protection than simple and import-weighted averages, but lower than the TRI. We further show a negative correlation between tariffs and product export supply elasticity, indicating that strategic trade policy was being pursued prior to China's WTO accession. Finally, we calculate the welfare loss and terms-of-trade gain due to tariff protection. The overall tariff pass-through increases from around 28% to almost 47% because of the WTO. *Journal of Comparative Economics* **42** (4) (2014) 994–1006. School of International Business Administration, SHUFE, China; School of Economics and Management, Tsinghua University, China.

1. Introduction

A precise measure of trade restrictiveness is essential in order for researchers and policy makers to understand cross-country differences in trade protectionism, as well as countries' progress in trade liberalization. Because tariff rates vary substantially across thousands of imported products, we need an appropriate method of aggregation. A simple idea, as proposed in the pioneering work of Anderson and Neary (1994, 1996), is to find a uniform tariff that applies to all imported products such that it can achieve the same level of welfare as product-specific tariffs. Such a measure is conventionally called a trade restrictiveness index (TRI).

This paper proposes a generalized trade restrictiveness index (GTRI) that extends the conventional TRI by relaxing the "small open economy" assumption. We stress that an importer may face an upward-sloping supply curve and exert market

* Corresponding author. Fax: +86 21 6590 7458.
E-mail addresses: chen.bo@shufe.edu.cn (B. Chen), mahong@sem.tsinghua.edu.cn (H. Ma), xuyuan@sem.tsinghua.edu.cn (Y. Xu).

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power accordingly. The measure is then applied to China's trade liberalization as indicated by the country's tariff reductions during and after its entry into the WTO.[1]

Our model builds on Feenstra (1995), who provides a simplification to the computable general equilibrium framework of Anderson and Neary. Feenstra (1995) shows that TRI can be expressed as a weighted average of the squared values of individual tariffs and the weights reflect import shares and demand elasticities. This approach is adopted by Kee et al. (2008), who calculate the TRI of 88 countries. Though widely adopted, TRI does not consider the responses of foreign suppliers. Thus it is assumed that the tariff is completely passed through onto domestic buyers.

In this paper, we define the GTRI as a uniform tariff that generates the same aggregate deadweight loss to the world as a whole (i.e. domestic importers and foreign exporters) as product-specific tariffs. From the viewpoint of the WTO, the impact of a country's tariff barrier is not confined only to its domestic economy, due to the prevalence of incomplete tariff pass-through. The GTRI corrects the incomplete tariff pass-through problem ignored in the TRI: a tariff distorts not only the behavior of the domestic importers but also that of the foreign exporters. We show that the GTRI can be measured using import tariffs, import shares, and the corresponding harmonic means of foreign export supply and domestic import demand elasticities. Therefore, given the harmonic mean structure, the TRI is indeed a special case of the GTRI when the importing country is small and hence the foreign export supply facing it is infinitely elastic.[2]

Empirically, this paper complements existing literature by applying the GTRI to the world's largest developing country, China. The rise of China and its opening-up to global trade is one of the most important and influential event that has been ongoing for more than two decades. There is a large literature talking about the impact of the liberalization (Branstetter and Lardy, 2008). However, little attention has been paid to the progress of the liberalization itself. How much more liberalized is China after its accession to the WTO compared with before the accession? Has the WTO effectively reduced strategic protection? We show in this paper that neither conventional measures (i.e. the simple average or import-weighted average of tariffs) nor TRI are ideal measures for answering those questions. The GTRI that takes into account the price responsiveness and terms of trade effect is a better alternative.

We examine how trade restrictiveness has evolved in China from 1997 to 2008, a period covering China's entry into the WTO in 2001. The GTRI indicates a higher level of protection than simple and import-weighted averages, but lower than the TRI. For example, in 2000, the simple and weighted averages of tariffs were 16.95 and 14.68 percentage points, respectively, whereas the GTRI measure was higher (18.75), and the TRI measure was even higher at 27.53. Furthermore, using the GTRI, the tariff reduction after China's entry into the WTO is more pronounced than when measured using simple average tariff rates. In terms of tariff reduction, the GTRI moves closely with the import-weighted average of tariffs, particularly during the period following China's WTO accession. However, at the sector-level, we show that the two indexes do not always display similar patterns. Existing research provides cross-country measures of trade barriers instead of a time-series evolution of trade policies, with a notable exception by Irwin (2010).[3] Our paper therefore complements the literature in providing a country study over an important reform period (the WTO entry period).

Furthermore, the GTRI accounts for tariff distortions on foreign suppliers. It thus provides interesting implications to the literature on international trade policy. Following Kee et al. (2008), we divide the GTRI into the average tariff, the variance of tariffs, and the covariance between tariffs and the harmonic means of the trade (i.e. foreign export and domestic import) elasticities. We find that the covariance is large and negative before WTO entry, along with finding that tariffs are positively correlated with import demand elasticities. Hence we can infer that higher tariffs may be targeted at those products with a lower import/export elasticity ratio (i.e. smaller tariff pass-through). Recent literature on trade policy has emphasized the value of market power in determining the optimal import tariff (Broda et al., 2008) as well as the effect of market power on a country's trade negotiations (Ludema and Maria Mayda, 2010). Bagwell and Staiger (2011) demonstrated that negotiated tariff cuts required for entry into the WTO depend on pre-negotiation tariffs, import volumes and prices, and trade elasticities. Our findings can be viewed as supporting evidence for strategic tariff policies.

Finally, the GTRI has important implications for welfare and terms of trade. As in Kee et al. (2008), we construct a linear approximation for the deadweight loss (DWL) associated with tariff structure. The DWL to importers and to exporters both decline substantially after China's WTO entry. We also find that the overall tariff pass-through increases from around 28% to more than 47% due to the WTO. We further quantify the improving terms of trade situation to foreign exporters during our sample period.

This paper contributes to a growing body of literature discussing the measurement of trade restrictiveness (Cipollina and Salvatici, 2008; Coughlin, 2010) and studying the welfare impact of tariff reform using new measures (Falvey and Kreickemeier, 2009).[4] Kee et al. (2008) provide estimates of TRI for a cross-section of 88 countries while Irwin (2010) measures the changes in TRI for the US over the course of a century, from 1867 to 1961. Chen and Ma (2012a,b) adopted Kee et al.'s

[1] Calculating non-tariff measures is also an important direction, which falls out of the scope of this paper. Kee et al. (2009) provide estimates for ad-valorem equivalents of non-tariff barriers.

[2] It is true, however, that other alternative measures of trade restrictiveness are available. For example, Anderson and Neary (2003) propose a uniform tariff equivalent (MTRI) that would leave aggregate imports unchanged at their current level as the existing structure of product-specific tariffs. Kee et al. (2009) propose the so called "Market Access Overall TRI", which is a uniform tariff imposed on the exporting country and which achieves the same level of exports as the current tariff structure faced by this exporting country.

[3] Irwin (2010) provides an annual measure of TRI for the United States over nearly a century.

[4] Anderson and Neary (2005) provide a detailed and excellent review of their work.

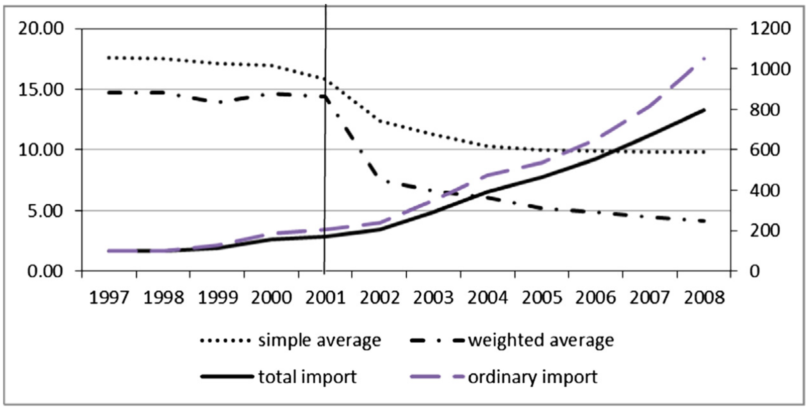

Fig. 1. Average import tariff and import growth: 1997–2008. *Note:* the right axis gives the relative annual import value from 1997 to 2008 (1997 = 100) for total import (solid line) and ordinary import (long dash). The left axis gives the simple average (dot) and weighted average (dot-dash) of tariffs. China gained its WTO membership in 2001, shown by the vertical line. *Source:* Authors' calculation based on trade data from the General Customs Administration of China.

(2008) method and computed the TRI for China. The inaccuracy of TRI when applied to large economies is pointed out in Dakhlia and Temimi (2006), who stress the importance of accounting for revenue motives and improving terms of trade. In contrast to our empirical emphasis, they just propose a theoretical extension to Anderson and Neary (1994, 1996) that reflects the deviation from the optimal tariff.

The rest of the paper is organized as follows. Section 2 reviews the concept of trade restrictiveness and introduces GTRI. Section 3 describes the Chinese import data. In Section 4, we briefly discuss the estimation strategy for import demand and foreign supply elasticities, construct a GTRI, and compute the DWL caused by import tariffs and changes in terms of trade from 1997 to 2008. We conclude our study in Section 5.

2. A generalized trade restrictiveness index

China has undergone significant growth in the international trade sector during the past two decades. In fact, China's annual imports have increased from US $55 billion in 1988 to over US $1.1 trillion in 2008. Import growth became especially drastic after China's accession to the WTO in 2001. Trade liberalization, particularly tariff reduction, is considered a key factor in explaining this rapid trade growth.

A key question thus presents itself: how much more liberalized was China in 2008 than in 1997, following seven years of WTO membership? Conventional answers opt for the simple or import-weighted average of import tariffs.[5] As shown in Fig. 1, the simple average of China's import tariffs dropped from 17.6% in 1997 to less than 10% in 2008, whereas the weighted average (where we use import share as weight) declined from 14.7% to 4.1%. Furthermore, in 2001, the year China entered the WTO, the average tariff rate dropped substantially. In practice, average tariff rates can be directly calculated using the country's import tariff data, which is widely adopted as a suitable proxy for trade protection (see, for example, Romalis (2007) and Goldberg et al. (2010).

Regardless of their simplicity, average tariff rates, whether or not weighted by import share, may be misleading when used in research or policymaking. First, a simple average of tariffs neglects the relative importance of different products (sectors). Second, although the import-weighted average of tariffs may account for the relative importance among *existing* products, the weights and corresponding tariffs may be negatively related because fewer goods are imported due to higher tariffs, resulting in lower weights. Therefore, the actual tariff barrier may be understated. Third, trade protection may be strategic, and as a result, it may favor certain industries. For example, Broda et al. (2008) showed that prior to obtaining WTO membership, countries tend to set higher import tariffs for goods with inelastic supplies. Ludema and Maria Mayda (2011) find that existing WTO countries tend to set higher import MFN tariffs for products with greater market power (i.e., less elastic supply).[6] Finally, average tariffs have no economic foundation (Anderson and Neary, 1996) and therefore cannot be used to measure the welfare costs of trade policy. This is particularly important when comparing trade restrictiveness across industries or nations.

The pioneering work of Anderson and Neary (1994, 1996) proposes a uniform tariff (i.e., the TRI) that can obtain the same welfare distortion for the importing country as its current tariff structure. Empirically, the Anderson–Neary methodology requires a computable general equilibrium (CGE) to solve for the TRI. Alternatively, Feenstra (1995) suggests that under a partial equilibrium environment and assuming linear demand,[7] the TRI can be simplified as:

[5] Another measure is output-weighted import tariff, which use the total output as weight to account for varying impact of tariffs for different sectors.

[6] Nunn and Trefler (2010) and Lin (2009) also emphasize that effective tariff interventions are likely to be correlated with skill-intensity or comparative advantages.

[7] Admittedly, a partial equilibrium method omits possible income and cross-price effects.

$$\mathrm{TRI} = \left[\frac{\sum_n s_n \sigma_n t_n^2}{\sum_n s_n \sigma_n}\right]^{1/2} \tag{1}$$

Thus, measuring TRI only requires knowledge of import demand elasticities (σ), import shares (s), and the tariff rates (t). This simplified TRI can be conveniently applied in econometric approaches that allow for highly disaggregated tariff lines.

However, Feenstra's (1995) TRI only considers a small open economy. That is, the underlying export supply is perfectly elastic (i.e., a horizontal export supply curve), such that the tariff pass-through is complete to domestic demanders. As noted by Feenstra (1995), few countries actually face such a scenario, given the prevalent monopolistic competition market structure. Thus, we propose a generalized trade restrictiveness index that takes into account not only the downward-sloping import demand, but the upward-sloping export supply as well, such that tariff burdens are partly shared by foreign export suppliers. That is, we relax the small open economy assumption and consider tariff imposition-related distortions to both foreign suppliers and domestic demanders.

The GTRI is defined so as to generate the same world-wide deadweight loss as China's existing tariff structure (thus holding world welfare constant). Therefore, when considering the total DWL, we should take into account the loss to domestic importers as well as the loss to foreign exporters:

$$\sum_n \mathrm{DWL}(\mathrm{GTRI}) = \sum_n (\mathrm{DWL}_{imp}(t_n) + \mathrm{DWL}_{\exp}(t_n)) \tag{2}$$

In a partial equilibrium setup, a second-order linear approximation to the deadweight loss is given by:

$$\Delta\mathrm{DWL}_{imp}(t_n) = \frac{1}{2} m_n \sigma_n \left(\frac{\varepsilon_n}{\varepsilon_n + \sigma_n} t_n\right)^2 \tag{3}$$

$$\Delta\mathrm{DWL}_{\exp}(t_n) = \frac{1}{2} m_n \varepsilon_n \left(\frac{\sigma_n}{\varepsilon_n + \sigma_n} t_n\right)^2 \tag{4}$$

where m_n is the imports of good n, t_n is the tariff levied on good n. σ_n, ε_n are the demand and supply elasticity, respectively. The DWLs to the importer and the exporter then depend on their respective tariff burden and the corresponding import demand and export supply elasticities. As derived in Appendix A, the GTRI can be written as:

$$\mathrm{GTRI} = \left[\frac{\sum_n \frac{\varepsilon_n \sigma_n}{(\sigma_n+\varepsilon_n)} s_n t_n^2}{\sum_n \frac{\varepsilon_n \sigma_n}{(\sigma_n+\varepsilon_n)} s_n}\right]^{1/2} = \left[\frac{\sum_n \frac{1}{(1/\sigma_n+1/\varepsilon_n)} s_n t_n^2}{\sum_n \frac{1}{(1/\sigma_n+1/\varepsilon_n)} s_n}\right]^{1/2} = \left[\frac{\sum_n \frac{\sigma_n}{(\omega_n\sigma_n+1)} s_n t_n^2}{\sum_n \frac{\sigma_n}{(\omega_n\sigma_n+1)} s_n}\right]^{1/2}, \tag{5}$$

where $\omega_n = 1/\varepsilon_n$ is the *inverse of* export supply elasticity, s_n is the import share of good n. Interestingly, compared to Feenstra's (1995) TRI, the GTRI is different only in the elasticity terms: it replaces the import demand elasticity (σ) with (one half of) the harmonic mean of import demand elasticity (σ) and export supply elasticity (ε), reflecting the fact that when a country considers its tariff policy, it may be concerned with not only the tariff distortion to domestic importers but also its market power to world suppliers. Apparently, when world supply is infinitely elastic, such as in the case of a small open economy, the GTRI degenerates to TRI:

$$\lim_{\omega_n\to 0} \mathrm{GTRI} = \lim_{\omega_n\to 0}\left[\frac{\sum_n \frac{\sigma_n}{(\omega_n\sigma_n+1)} s_n t_n^2}{\sum_n \frac{\sigma_n}{(\omega_n\sigma_n+1)} s_n}\right]^{\frac{1}{2}} = \left[\frac{\sum_n \sigma_n s_n t_n^2}{\sum_n \sigma_n s_n}\right]^{\frac{1}{2}} = \mathrm{TRI}$$

3. Data

This paper focuses on the reduction of China's trade restrictiveness in the period before and after its WTO accession in 2001. For this purpose, we use import data at the 8-digit HS level (HS-8), the most disaggregated level available. We obtain annual import data on values and quantities, as reported by the China Customs General, from 1997 to 2008.

Furthermore, a unique feature of our data is that it distinguishes processing from non-processing imports. Indeed, large shares of imports consist of intermediate inputs, which are processed and then exported as finished goods.[8] Imported intermediate inputs under the processing regime are exempt from import tax and VAT. Because of this, adding processing imports into our calculation of trade restrictiveness, including average tariff measures, would bias our estimation. Furthermore, because of the nature of processing trade, one may expect that the imported inputs are primarily used to produce exports. Thus, the impact of processing imports on a domestic economy systematically differs from ordinary imports. Therefore we exclude processing imports in our calculation of tariff weights.

[8] For the sake of precision, two subcategories exist within processing trade: (1) processing and assembly and (2) processing with imported inputs. Under the first category, firms do not pay import tax or VAT, whereas in the second, firms often pay the taxes first and then claim the rebates once the finished goods have been exported (the so called "collect first, and rebate later").

Ordinary imports account for about two-thirds of total imports and grow very fast due to trade liberalization. As shown in Fig. 1 (right axis, 1997 = 100), from 1997 to 2008, the total Chinese imports increased by a factor of 8, while ordinary imports increased even faster: compared with 1997, in 2008 the ordinary imports increased more than tenfold.

Focusing on ordinary imports, our dataset therefore contains 5624 six-digit HS products, which further includes more than 9000 eight-digit HS sub-categories. Treating each 8-digit HS goods from one specific source country as a variety à la Armington (1969), we are able to estimate the demand and supply elasticities.

The tariff data are MFN tariffs at the 6-digit HS level from the World Integrated Trade Solution (WITS). However, the WITS do not include tariff data from 2002. Thus, we supplement WITS data with data from the WTO when necessary. We merge HS-8 products into HS-6 and then match it with the MFN tariff.

4. GTRI and DWL

In this section, we explain in detail our strategy in estimating the elasticities of demand and supply. Then we discuss our construction of the GTRI.

4.1. Estimating elasticities

To obtain a precise measure of trade restrictiveness, as shown in equation (3), we first need appropriate measures of the elasticities of import demand and world export supply. However, estimating trade elasticity using a gravity equation is inappropriate because it assumes an infinitely elastic supply. Broda and Weinstein (2006) modified Feenstra's (1994) method to estimate reliable elasticities of substitution and supply elasticities, which solves the endogeneity problem by using a panel of import data at a highly disaggregate level. Although in theory elasticity of substitution is not the same as demand elasticity, they are equivalent under the Dixit and Stiglitz (1977) CES utility that is widely adopted in trade and many other fields. Therefore, we apply the technique of Broda and Weinstein (2006) to the Chinese ordinary import data at the 8-digit Harmonized System (HS) level, and estimate the (domestic) import demand elasticities and (foreign) export supply elasticities that are necessary in calculating China's GTRI.

Broda et al. (2006, henceforth BGW) estimated the import demand elasticities for 73 countries, including China, at the 6-digit HS level. However, they only report their elasticity estimates at the HS-3 level. Broda et al. (2008, henceforth BLW) used international trade flow data at the 6-digit HS level during the period of 1994–2003 to estimate the omegas for 15 countries, also including China. Unfortunately, they only report their estimates at the HS-4 level.[9] There are three reasons for estimating China's trade elasticities, rather than directly borrowing them from the existing literature. Firstly, the existing literature does not provide detailed estimates of China's elasticities that can match highly disaggregate tariff lines. Secondly, the existing literature does not estimate China's import and (foreign) export elasticities simultaneously, which may generate estimation inconsistency between these two types of elasticities. Thirdly, the existing literature does not exclude China's processing imports when estimating trade elasticities. This may cause estimation bias on trade elasticities and will bias the result of the GTRI, as processing imports, which account for more than 30% of China's total imports from 1997 to 2008, are duty free and thus may not suffer from such tariff distortion. Finally, our own estimation using 8-digit import data has its own advantages. Estimation at the 8-digit HS level, the most disaggregate level, can best capture the changes in unit value of imported varieties, and therefore reduce measurement error.

Since the estimation of elasticities is now standard in the literature, in what follows, we report our main estimation results, while describing the main steps of the estimation strategy in Appendix B. In practice, we have fewer elasticities estimated than the actual number of HS categories. First, we need a sufficient amount of observations for each imported HS-8 to obtain identification in our estimation: at least four supplying countries that survived for at least two years. Second, we set up a range for the grid search so our estimated σ's and ω's fall within a reasonable range.[10] The censoring of estimates due to the grid search leads to a further reduction in the number of estimated σ's and ω's. Following Broda and Weinstein (2006), we impute the missing elasticities as follows: an HS-8 product with missing elasticity is assumed to share with other HS-8 goods the same sigma and omega within the same HS-6 category. In other words, the elasticity of a new product is the weighted average of the elasticities of other goods within the same HS-6 category if this new product's elasticity is not available or is out of reasonable range. Similarly, a new HS-6 category shares the same elasticity with all other existing HS-6 products within the same HS-4 category.[11] Likewise, for the rest of the missing values, the same procedure applies to new HS-4 and HS-2 goods. The summary statistics are in Table 1, which shows the average estimated σ's and ω's for 16 broad HS categories.[12]

Columns (1) and (2) list the industry name and corresponding 2-digit HS code. Column (3) reports the import share of each category: minerals and machinery/electrical products comprise the largest value share in ordinary imports, at 23.7% and 31.46% of the total imports, respectively. Column (4) shows the number of 8-digit HS goods in each industry in which

[9] Detailed reports for import demand elasticities at HS-3 in BGW (2006) and export supply elasticities at HS-4 in BLW (2008) are available at http://www.columbia.edu/~dew35/TradeElasticities/TradeElasticities.html.

[10] To be concrete, we keep σ's in the range of (1,250) and ω's in the range of (0,250].

[11] After this step almost 90% of missing elasticities are available. At this aggregation level, it is reasonable to assume different HS-6 products within the same HS-4 category have same substitutability and supply elasticity.

[12] The trade elasticities are available at http://chenbo.weebly.com/research.html.

Table 1
Descriptive statistics of elasticities at sector level. *Source:* Authors' calculation based on trade data from the General Customs Administration of China.

HS-2 code (1)	Sector (2)	Import share (%) (3)	# HS8 (4)	Median # of varieties per HS8 (5)	Mean σ (6)	Mean ω (7)
01–05	Animal products	0.64	366	2.68	10.96	8.06
06–15	Vegetable products	4.01	622	2.84	10.10	8.74
16–24	Foodstuffs	0.94	324	3.32	12.83	7.79
25–27	Mineral products	23.74	245	3.30	11.24	3.49
28–38	Chemicals	9.64	1330	4.03	9.23	4.64
39–40	Plastics/rubbers	4.55	304	5.02	10.22	4.02
41–43	Leather and furs	0.27	158	2.92	9.53	7.06
44–49	Wood products	3.40	462	3.54	12.09	6.74
50–63	Textiles	1.66	1311	3.45	6.55	8.09
64–67	Footwear/headgear	0.05	70	3.75	6.25	8.84
68–71	Stone/glass	0.72	307	3.87	6.21	6.43
72–83	Metals	8.30	878	4.08	8.36	6.46
84–85	Machinery/electrical	31.46	1822	4.19	3.75	7.77
86–89	Transportation	5.95	360	3.19	6.85	13.60
90–97	Miscellaneous	4.69	616	4.33	4.51	9.26
Median value across all sectors					3.54	2.22

Note: This table reports summary statistics for estimated demand and (inverse) supply elasticities. Column (3) report the import share for each sector. Column (4) reports the number of eight-digit HS goods in each sector. Column (5) reports the median number of varieties (source countries) for each HS-8 good. Column (6) reports the mean value of demand elasticity estimates while Column (7) reports the mean value of inverse export supply elasticity. The last row gives the median value for two elasticities across all 8-digit HS8 products.

we obtained σ's. More differentiated sectors, such as machinery/electrical products, textile, and chemicals, have relatively more 8-digit HS product categories. In practice, we define variety as a specific 8-digit HS product from a particular country. Column (5) shows the median number of varieties per 8-digit HS category. The median number ranges from 2.68 for animal and animal products to 5.02 for plastics and rubbers. Finally, we report the estimated mean for the σ's and the ω's in Columns (6) and (7), respectively. The machinery/electrical sector has the lowest average σ at 3.75, whereas the food sector has the highest, at 12.83. On the supply side (Column (7)), the transportation sector has the highest average ω at 13.6, whereas the mineral sector has the lowest at 3.49. Across all sectors, the overall median values for σ's and ω's are 3.54 and 2.22, with simple averages of 7.69 and 7.10, respectively.

To show the robustness of our trade elasticities, we perform the following two steps. First, we compare our results to some prior results. According to Rauch (1999), commodities (HS 1–27, 44–49, 72–83) are often sold on organized exchanges, therefore those products are on average more substitutable than differentiated goods. As shown in Table 1, the mean sigma for commodities is 10.93, significantly higher than the mean sigma of 7.01 for other goods.

We then compare our results with the existing literature. BGW (2006) estimated the median import elasticity of China at about 3.4 and the simple average at about 6.2. Kee et al. (2008) developed a production-based, semi-flexible GDP function and used a panel estimation approach to estimate the parameters for computing elasticities at the 6-digit HS level. They reported that the average import elasticity for China is 7.26. BLW (2008) report the median omega for China as 2.1. Our elasticity estimates are close to those of the three studies mentioned above.

Next, we aggregate the σ's and ω's at the HS-8 level to the 6-digit level to match the tariff data, using import shares as weights. In the end, we obtained demand and supply elasticities for 5624 HS-6 products.

4.2. Constructing GTRI

With σ's and ω's for each HS-6, we can directly derive the TRI and the GTRI based on Eqs. (1) and (5). Furthermore, as suggested by Kee et al. (2008), the GTRI can be further divided into three components, as follows:

$$\text{GTRI} = \left[\sum_n s_n \tilde{\gamma}_n t_n^2\right]^{1/2} = \left[E(\tilde{\gamma}_n t_n^2)\right]^{1/2} = \left[\bar{t}^2 + \delta^2 + \rho\right]^{1/2} \tag{6}$$

where $\bar{t}$ denotes import-weighted tariffs; $\bar{t} = \sum_n s_n t_n$; δ^2 denotes the variance of tariffs; $\delta^2 = \sum_n s_n (t_n - \bar{t})^2$; $\rho = Cov(\tilde{\gamma}_n, t_n^2)$ denotes the covariance between the tariffs and corresponding elasticities, where the adjusted trade elasticity $\tilde{\gamma}_n \equiv \frac{\gamma_n}{\bar{\gamma}}$ with $\gamma_n = \frac{\sigma_n}{\omega_n \sigma_n + 1}$ and $\bar{\gamma}_n = \sum_n s_n \gamma_n$. Note that although individual elasticity is time invariant, the average and adjusted elasticities are time variant because the weights change over time.

As indicated by Eq. (6), to fully account for the trade restrictiveness an import-weighted average of tariffs is not enough. We also need to take into account the variance of tariffs, and the covariance between the elasticities of each product and the corresponding tariffs. The variance of tariffs reflects the heterogeneity associated with tariff imposition. The covariance term may reflect the strategic role of government intervention. The GTRI should be higher than the value suggested by the import-weighted average tariff if tariff variance is larger or higher tariff rates are imposed on products with larger harmonic means

Table 2
Measures of trade restrictiveness in China: 1997–2008.

Year	Simple average tariff	Weighted average tariff	TRI	Generalized TRI	Decomposition		
					Variance	Covariance	
						TRI	GTRI
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
1997	17.59	14.71	31.46	20.81	322.56	468.86	−119.07
1998	17.55	14.74	30.77	18.87	320.20	426.14	−193.89
1999	17.12	13.91	27.44	17.63	269.06	297.32	−155.73
2000	16.95	14.68	27.53	18.75	345.23	228.31	−227.88
2001	15.88	14.42	27.23	18.72	344.61	224.77	−235.67
2002	12.36	7.53	17.48	11.42	89.82	140.95	−7.00
2003	11.27	6.59	15.08	9.99	72.72	95.05	−10.64
2004	10.36	6.06	14.65	10.40	75.71	91.87	−2.69
2005	9.97	5.15	11.91	9.26	54.32	47.01	6.88
2006	9.94	4.88	11.29	9.02	49.02	41.76	6.68
2007	9.87	4.43	10.05	8.35	38.38	31.88	27.21
2008	9.86	4.13	9.83	7.83	35.40	30.28	27.74

Note: Columns (1)–(4) present four measures of trade restrictiveness. Columns (5)–(7) present the components of TRI and GTRI: the variance of tariff, and covariance of tariff (in square) and elasticities.

of trade elasticities. It is worth noting that the GTRI differs from the TRI only in the covariance term: the covariance of TRI is between the tariffs and adjusted import demand elasticities, whereas the covariance of GTRI also considers the harmonic means of not only import demand but also (foreign) export supply elasticities.[13]

In Table 2, we report different measures for the trade restrictiveness of China from 1997 to 2008. Columns (1) and (2) report the simple and import-weighted averages of tariffs. Although both measures exhibit the same trend of declining tariff barriers, particularly after 2001, the weighted average tariff is consistently smaller, indicating higher tariffs are in general associated with lower imports. Columns (3) and (4) show that the TRI and the GTRI are systematically higher than those suggested by the simple and weighted average tariffs prior to China's accession to the WTO, indicating that the correlation between tariffs and elasticities may play an important role.

Interestingly, though all four of the indexes exhibit similar dynamic patterns after 2001, they differ from each other prior to WTO entry. Before China's entry into the WTO in 2001, China's import tariff barrier, if measured by the simple average tariff, was slightly declining. In contrast, the import-weighted average was stable at around 14%, and even slightly increased from 1999 to 2001. The divergence of these two indexes implies that China's tariff reductions before 2001 were mainly on less important products (i.e. with relatively smaller import value) whereas more important products (i.e. with relatively higher import values) received little tariff reduction or in some cases even increased tariff rates.

Furthermore, both the TRI and GTRI also indicate that the overall tariff barrier did increase before 2001. However, the GTRI shares a similar pattern with the import-weighted average tariff whereas the TRI indicates a much higher rate of protection before 2001 and consequently a much more striking reduction in protection after WTO entry. Compared to its 1997 benchmark, the import-weighted average tariff decreased to 14.42% in 2001 from 14.71% and the TRI decreased to 27.23% from 31.46%, whereas the GTRI decreased to 18.72% from 20.81%. Such a pattern is also shown in Fig. 2.

Using the decomposition approach described in Eq. (6), we can take a closer look at the differences among measures. As shown in Columns (5)–(7) in Table 2, the TRI is much larger than the weighted average tariff mainly due to a large variance of tariffs and large and positive covariance between squared tariffs and elasticities. Products with larger demand elasticity were charged higher duties. Since larger demand elasticity (and substitutability) implies that a market is more competitive, the positive correlation between tariff and demand elasticity implies that a market is more government protected.

For GTRI, however, the covariance between squared tariffs and the harmonic means of trade elasticities is negative before WTO accession and converges to nearly zero after WTO accession. The negative covariance before 2001, along with the finding that tariffs are positively correlated with import demand elasticities, suggests that higher tariffs may have been targeted at those products with lower import/export elasticity ratios (i.e. smaller tariff pass-through) before China's ascension to the WTO in 2001. After WTO accession, the strategic behavior is significantly reduced. Our GTRI therefore indicates that before 2001, China may have strategically protected the products that had domestic monopolistic competitors and/or had market power in the negotiations regarding WTO membership. Nevertheless, all of the barrier measures dropped significantly after 2001, confirming the WTO's effectiveness in removing tariff barriers as well as strategic protection policies.

When comparing the average tariff measures with the GTRI (as well as the TRI), it seems the former serves as a good proxy to capture the progressive liberalization of import restrictions. However, the weighted average systematically understates the import restrictiveness due to the negative correlation between tariffs and import values and simple average systematically understates the magnitude of trade liberalization due to WTO accession. Furthermore, at the sector-level, the import-weighted average tariff may diverge from GTRI in measuring the level of protection. This is shown in Table 3.

[13] That is, for TRI, $\rho = Cov(\tilde{\sigma}_n, t_n^2)$. where $\tilde{\sigma}_n \equiv \frac{\sigma_n}{\bar{\sigma}}$.

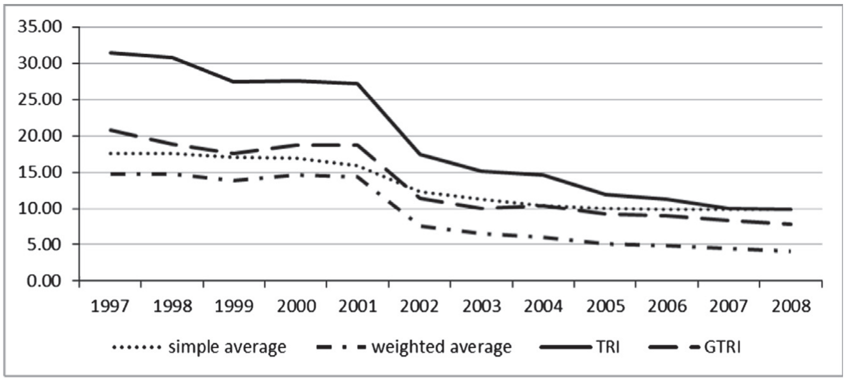

Fig. 2. Measures of trade restrictiveness: 1997–2008. *Note:* the figure gives the annual tariff rates for 1997–2008 by four measures: simple average (dot), weighted average (dash-dot), TRI (solid), and GTRI (long dash). *Source:* Authors' calculation based on trade data from the General Customs Administration of China.

It can be seen from Table 3 that: first, for most sectors, average tariff measures and GTRI are at a similar level, and they all consistently capture the trend and pattern of trade liberalization due to WTO entry; second, all measures (simple average, weighted average, and GTRI) find that agricultural products (animal, vegetable, and foodstuffs), textiles, and the transportation sector were well protected before WTO accession; third, after WTO entry protection for agricultural products and transportation has been reduced substantially, while protection for textiles has not, if we use the GTRI.

4.3. Deadweight loss and terms of trade

Finally, we calculate the linear approximation to the deadweight loss (DWL) and the terms of trade (TOT), and its gains in China due to tariff barriers, based on Eqs. (7)–(10), respectively:

$$\mathrm{DWL}_{imp} = \frac{1}{2} IMP \sum_n s_n \frac{\sigma_n}{(\omega_n \sigma_n + 1)^2} t_n^2 \tag{7}$$

$$\mathrm{DWL}_{\exp} = \frac{1}{2} IMP \sum_n s_n \left(\frac{\omega_n \sigma_n}{\omega_n \sigma_n + 1} \right)^2 \frac{1}{\omega_n} t_n^2 \tag{8}$$

$$\mathrm{TOT} = \sqrt{\sum\nolimits_n s_n \left(\frac{\omega_n \sigma_n}{\omega_n \sigma_n + 1} \right)^2 \frac{1}{\omega_n} t_n^2} \tag{9}$$

Table 3
Measures of trade restrictiveness across sectors.

Sector	Before WTO			After WTO		
	Simple average (1)	Weighted average (2)	GTRI (3)	Simple average (4)	Weighted average (5)	GTRI (6)
Animal products	22.2	16.8	18.6	12.9	10.8	11.5
Vegetable products	25.3	75.2	76.4	15.7	11.1	19.8
Foodstuffs	29.8	18.1	34.4	19.5	14.6	18.7
Mineral products	4.2	5.8	7.7	3.6	1.4	4.0
Chemicals	10.5	9.6	10.4	7.0	7.4	12.5
Plastics/rubbers	16.2	17.2	21.6	10.4	9.5	10.4
Leather and furs	17.6	10.1	12.7	13.2	8.0	12.4
Wood products	12.9	6.0	9.3	5.8	1.3	3.4
Textiles	24.5	18.4	21.5	13.2	22.3	31.8
Footwear/headgear	24.0	24.8	24.7	18.7	15.5	16.1
Stone/glass	17.4	15.9	16.3	13.3	7.8	10.7
Metals	10.5	8.4	10.1	7.7	4.1	5.5
Machinery/electrical	15.2	12.7	13.0	9.0	4.3	6.0
Transportation	23.4	18.2	36.3	12.9	14.7	22.9
Miscellaneous	17.2	12.3	13.6	11.7	6.2	7.8

Note: the left panel (Columns (1)–(3)) gives the average trade restrictiveness for sectors before WTO accession, while the right panel (Columns (1)–(3)) gives the parallel results after WTO.

Table 4
Deadweight loss and terms of trade gain in China: 1997–2008.

Year	Tariff pass-through (%) (1)	DWL to importers (2)		DWL to foreign exporters (3)	TOT gain (4)	TOT (%) (5)
1997	28.3	55.0	(0.058)	571.4	9137.4	14.9
1998	20.6	54.9	(0.055)	479.5	9371.3	15.0
1999	19.9	67.4	(0.063)	531.3	11205.7	14.1
2000	20.3	97.7	(0.083)	812.5	15975.8	14.9
2001	21.7	105.7	(0.081)	895.8	18327.0	14.7
2002	33.1	56.1	(0.039)	449.0	11938.8	7.6
2003	32.6	68.2	(0.042)	507.4	15224.7	6.7
2004	40.3	99.3	(0.052)	783.5	19031.3	6.2
2005	43.3	103.6	(0.046)	698.1	18302.8	5.2
2006	44.8	136.8	(0.051)	842.1	21020.2	5.0
2007	46.5	135.7	(0.040)	740.4	23780.0	4.5
2008	46.9	147.2	(0.034)	821.0	28532.3	4.2

Note: a. Deadweight losses and terms of trade gain are measured in nominal million US dollars.
b. Numbers in bracket of Column (2) are the GNI ratios (in one thousandth, ‰) of the DWL to China's Importers.
c. TOT is the abbreviation of "terms of trade". TOT (%) is defined as a uniform rate that foreign exporters must concede (compared to the prices they would otherwise charge in a tariff-free scenario) in order to enter China's market. TOT gain refers to the gains (in terms of tariff revenue) from the foreign exporters due to their price concession (i.e. tariff burden) under existing tariffs.

$$\text{TOT gain} = \sum_n IMP_n \left(\frac{\omega_n \sigma_n}{\omega_n \sigma_n + 1} \right) t_n \tag{10}$$

In particular, the TOT defined in Eq. (9) is a uniform rate that foreign exporters must concede (compared to the prices they would otherwise charge in a tariff-free scenario) in order to enter China's market when facing tariff barriers. The TOT gain aggregates the linear approximation of China's gains from the existing variety of imports due to the corresponding tariffs on them (as shown in Fig. A.1 in Appendix A). It is worth noting that given estimates on TOT, China's import tariff pass-through (TPT) can also be estimated as: TPT = $(1 - \text{TOT}/\text{GTRI}) * 100\%$.

The general results are shown in Table 4. Column (1) shows China's import tariff pass-through. The tariff pass-through of Chinese imports has increased from 28.3% in 1997 to 46.9% in 2008. This pattern reflects the term of trade changes due to trade liberalization. Although the overall rate of trade restrictiveness is reduced substantially, more reduction took place in imports with lower export supply elasticities (relative to import demand ones), so that Chinese importers now carry a larger share of the whole tariff burden. Column (2) shows that the DWL, due to the tariff barrier to China's consumers, rose to US $105.7 million in 2001, drastically dropped in 2002, and resumed its increase after 2003. In 2008 the losses amounted to US $147.2 million.[14] Considering the decreasing GTRI after 2001, the larger loss is mainly attributed to the rapid increase in China's imports after 2001. That is, the base for calculating DWL has significantly expanded. The alleviation of DWL resulting from tariff reduction can be better measured by the deadweight loss-gross national income ratio, as reported in the brackets in Column (2). China's income/welfare loss resulting from the existence of tariff barriers is reduced from 0.058‰ in 1997 to 0.034‰ in 2008. In other words, China has saved about 0.024‰ in income from tariff distortion as a result of the WTO's effective removal of tariff barriers. Although the direct gains to China's consumers seem trivial, tariff reduction does benefit foreign suppliers and China's government. China's government has seen a substantial net increase in its terms of trade thanks to increased imports. As shown in Column (3), world suppliers overall pay a higher cost than China's importers. It first increased from US $571.4 million in 1997, peaked at US $895.8 million in 2001, then dramatically dropped to US $449 million in 2002 and eventually increased to US $821 million in 2008. Similar to the increase in the losses to importers, the increase in the losses to world suppliers after 2001 is again mainly attributed to a surging export base (or import base to China). Although China has given up much of its tariffs, it nevertheless collected more gains from terms of trade owing to a surging import base. Column (4) shows that China's gains from terms of trade increased steadily from US $9137.4 million in 1997 to US $28532.3 million in 2008. The terms of trade situation reported in Column (5) offers a finer measure for world suppliers. World suppliers needed to lower prices by as much as 15.0% of what they would otherwise charge under a free trade environment in 1998. However, this concession shrank to only 4.2% in 2008.

5. Concluding remarks

The simple and import-weighted average tariffs are two measures of trade barriers that are widely adopted in trade and development literature. However, neither method is theoretically sound. The simple average tariff measure ignores the vast differences in imported goods, and the import-weighted average tariff measure ignores the correlation between import values and tariffs. Though the TRI addresses the above-mentioned problems, the caveat is that it is based on the assumption of a small open economy. Built on Feenstra's (1995) study, this paper derives a generalized trade restrictiveness index to measure the trade barrier, which allows for an upward-sloping export supply. The GTRI is a uniform tariff that generates the same

[14] The currency unit is in current dollars. The pattern will not change if we use real dollars.

aggregate deadweight loss to the world as the product-specific tariffs. That is, to correctly measure the tariff barriers, one should not only take into account the tariff distortion to domestic importers, but also that to world exporters. We show that our GTRI has desirable empirical tractability and requires only information on tariffs, import shares, and import as well as export elasticities.

We apply the GTRI to China to examine its trade liberalization during the WTO accession. Prior to joining the WTO in 2001, the GTRI was higher than the simple and import-weighted average tariff, but lower than the TRI. Thus it is important to account for not only tariff levels, but also tariff variance and covariance between tariffs and trade elasticities. Furthermore, the difference between the GTRI and the TRI indicates that if one only takes into account the tariff distortions to importers by assuming complete tariff pass-through as TRI suggests, it may result in a biased measure of tariff barriers, especially in large countries in which the tariff pass-through is typically incomplete. Nevertheless, all of the measures dropped substantially after 2001 and eventually converged, confirming the WTO's effectiveness in removing tariff barriers. Finally, we calculate the welfare loss and terms-of-trade gain due to tariff protection. The overall tariff pass-through increases from around 28% to almost 47% due to the WTO.

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Appendix A. Deriving GTRI

When an *ad volarem* tariff, t, is imposed, the tariff incidences shared by consumers (denoted by τ_d) vs. suppliers (denoted by τ_s) depend on the relative demand and supply elasticities,

$$\frac{\tau_d}{\tau_s} \approx \frac{\varepsilon}{\sigma} \tag{A.1}$$

where ε is the supply elasticity and σ is (in absolute value) demand elasticity.

Alternatively, if p^0 denotes C.I.F. price (i.e. no tariff), then we have

$$\tau_d = \frac{\varepsilon}{\varepsilon + \sigma} p^0 t \tag{A2.a}$$

$$\tau_s = \frac{\sigma}{\varepsilon + \sigma} p^0 t \tag{A2.b}$$

Then the deadweight loss of any goods "n" to demanders and suppliers, as shown in Fig. A.1, are respectively given by the following two equations:

$$\begin{aligned} \int_0^t \tau_d \frac{dC_n}{dp_n^d} \frac{dp_n^d}{dt_n} dt_n &= \int_0^t \left(p_n^0 \frac{\varepsilon_n}{\varepsilon_n + \sigma_n} \right)^2 \frac{dC_n}{dp_n^d} t_n dt_n = IMP \cdot \int_0^t \left(\frac{\varepsilon_n}{\varepsilon_n + \sigma_n} \right)^2 \frac{dC_n}{dp_n^d} \frac{p_n^0}{C_n} \frac{p_n^0 C_n}{IMP} t_n dt_n \\ &= IMP \cdot \int_0^t \left(\frac{\varepsilon_n}{\varepsilon_n + \sigma_n} \right)^2 \sigma_n s_n t_n dt_n = \frac{1}{2} IMP \cdot \left(\frac{1}{\omega_n \sigma_n + 1} \right)^2 \sigma_n s_n t_n^2 \end{aligned} \tag{A3.a}$$

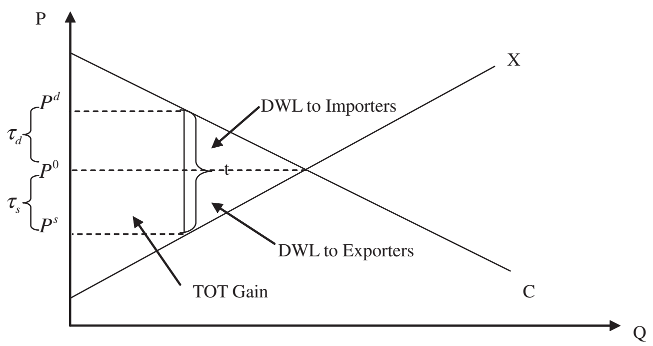

Fig. A.1. The decomposition of an import tariff.

where $\sigma_n = \frac{p_n^0}{C_n}\frac{dC_n}{dp_n^d}, s_n = \frac{p_n^0 C_n}{IMP}$, and IMP is aggregate import value.

$$\int_0^t \tau_s \frac{dX_n}{dp^s}\frac{dp^s}{dt}dt = \int_0^t \left(p_n^0 \frac{\omega_n\sigma_n}{\omega_n\sigma_n+1}\right)^2 \frac{dX}{dp^s}tdt = IMP\cdot\int_0^t \left(\frac{\omega_n\sigma_n}{\omega_n\sigma_n+1}\right)^2 \frac{p_n^0}{X_n}\cdot\frac{dX_n}{dp_n^s}\cdot\frac{p_n^0X_n}{IMP}tdt$$
$$= IMP\cdot\int_0^t \left(\frac{\omega_n\sigma_n}{\omega_n\varepsilon_n+1}\right)^2 \frac{1}{\omega_n}s_n tdt = \frac{1}{2}IMP\cdot\left(\frac{\omega_n\sigma_n}{\omega_n\sigma_n+1}\right)^2\frac{1}{\omega_n}s_n t_n^2 \tag{A3.b}$$

where $\frac{1}{\omega} = \frac{p_n^0}{X_n}\cdot\frac{dX_n}{dp_n^s}$ and $s_n = \frac{p_n^0C_n}{IMP} = \frac{p_n^0X_n}{IMP}$.

And the total DWL of goods n to both suppliers and consumers is:

$$\text{DWL}_n = \frac{1}{2}IMP_n\left(\frac{1}{\omega_n\sigma_n+1}\right)^2\sigma_n s_n t_n^2 + \frac{1}{2}IMP_n\left(\frac{\omega_n\sigma_n}{\omega_n\sigma_n+1}\right)^2\frac{1}{\omega_n}s_n t_n^2 = \frac{1}{2}IMP_n\left(\frac{\sigma_n}{\omega_n\sigma_n+1}\right)s_n t_n^2$$

Similar to TRI, GTRI is defined as a uniform tariff rate such that the world including both domestic demanders and foreign suppliers) would be indifferent in having GTRI or the existing various tariff structure. In other words, the aggregate deadweight loss generated by GTRI should be the same as that caused by existing heterogeneous tariff rates. That is, $\sum \text{DWL(GTRI)} = \sum_n \text{DWL}(t_n)$. Therefore we can derive the GTRI as follows:

$$\text{GTRI} = \left[\frac{\frac{1}{2}IMP\sum_n \frac{\sigma_n}{(\omega_n\sigma_n+1)}s_n t_n^2}{\frac{1}{2}IMP\sum_i \frac{\sigma_n}{(\omega_n\sigma_n+1)}s_n}\right]^{\frac{1}{2}} = \left[\frac{\sum_n \frac{\sigma_n}{(\omega_n\sigma_n+1)}s_n t_n^2}{\sum_n \frac{\sigma_n}{(\omega_n\sigma_n+1)}s_n}\right]^{\frac{1}{2}} \tag{A.4}$$

where ω the inverse supply elasticity. And when the tariff imposition country is "small", the export supply curves it faces is infinitely elastic, i.e. $\omega_i = 1/\varepsilon_i = 0$, then

$$\lim_{\omega_n\to 0}\text{GTRI} = \lim_{\omega_n\to 0}\left[\frac{\sum_n \frac{\sigma_n}{(\omega_n\sigma_n+1)}s_n t_n^2}{\sum_n \frac{\sigma_n}{(\omega_n\sigma_n+1)}s_n}\right]^{\frac{1}{2}} = \left[\frac{\sum_n \sigma_n s_n t_n^2}{\sum_n \sigma_n s_n}\right]^{\frac{1}{2}} = \text{TRI}$$

In addition, the terms of trade improvement due to tariff is exactly the tariff incidence to foreign suppliers, τ_s,

$$\tau_s = \frac{\sigma}{\varepsilon+\sigma}p^0 t = \frac{\omega\sigma}{1+\omega\sigma}p^0 t,$$

And hence the terms of trade gain (as shown by the lower rectangle in Fig. A.1) is given by

$$\text{TOT gain} = \sum_n IMP_n\left(\frac{\omega_n\sigma_n}{\omega_n\sigma_n+1}\right)t_n \tag{A.5}$$

Similar to the GTRI, the overall TOT to China is defined as a uniform TOT which generates the same TOT gain as the existing thousands of TOTs shown by Eq. (A.5):

$$\text{TOT}\cdot\sum_n IMP_n\left(\frac{\omega_n\sigma_n}{\omega_n\sigma_n+1}\right) = \sum_n IMP_n\left(\frac{\omega_n\sigma_n}{\omega_n\sigma_n+1}\right)t_n \Rightarrow \text{TOT} = \frac{\sum_n IMP_n\left(\frac{\omega_n\sigma_n}{\omega_n\sigma_n+1}\right)t_n}{\sum_n IMP_n\left(\frac{\omega_n\sigma_n}{\omega_n\sigma_n+1}\right)} \tag{A.6}$$

Appendix B. Estimating trade elasticities

In this appendix, we borrow the econometric methods proposed by Feenstra (1994) and Broda and Weinstein (2006) to estimate the (domestic) import demand elasticities and (foreign) supply elasticities.

As is widely applied in trade and many other fields in economics, we assume that a country's welfare on imports can be summarized by a constant elasticity of substitution (CES) function initially introduced by Dixit and Stiglitz (1977). That is, we assume that the elasticity of substitution between varieties, σ (sigma), within the same goods, g, is constant.[15] A remarkable feature of such CES functional form is that the elasticity of substitution between varieties, the sigma, can also be interpreted as the price elasticity of demand for a given imported good.

As is standard in macro-level studies, a variety as defined by Armington (1969) is a country-goods pair. Particularly, a good in this paper is an HS-8 category, and varieties of it are its exporting countries. For instance, "safety headgear" is a typical HS-8 product ("HS 65061000"). Suppose China imports this product from six different countries, then we shall treat "safety headgear" as a good with six imported varieties. A typical import demand function derived from the CES welfare maximization problem is shown as,

[15] Intuitively, the elasticities, which reflect productivity or tastes, should not significantly change in a short period. For example, Broda et al. (2006) find that the elasticities of 77 countries do not significantly change during the two sub-periods: 1994–1998 and 1999–2003.

$$\Delta \ln s_{gvt} = \varphi_{gt} - (\sigma_g - 1)\Delta \ln p_{gvt} + \varepsilon_{gvt} \quad \text{(A2.1)}$$

where s_{gvt} is the imports share of variety v of goods g[16]; φ_{gt} acts as a random effect to capture the special characters of demand on goods g overtime; p_{gvt} is the price of variety v of goods g; ε_{gvt} is the error term; σ_g is the time invariant elasticity of substitution between varieties of good g, and it is assumed to be bigger than unity to ensure a convex welfare. Finally, the difference operator "Δ" is applied between years to phase out goods-fixed effects.

However, Eq. (A2.1) has two problems, which result in biased estimation for the sigmas. First, there is a simultaneity problem. That is, supply curves facing the importing countries may be upward-sloping, which result in importing prices to increase with the higher imports demand. Second, there is a measurement error problem. The prices of imports are usually unavailable; hence, they are approximated by unit prices. Therefore, prices and demand may still be correlated.

To solve the simultaneity problem, we follow Broda and Weinstein (2006) and assume an upward sloping supply curve as Eq. (A2.2).

$$\Delta \ln p_{gvt} = \psi_{gt} + \frac{\omega_g}{1+\omega_g}\Delta \ln s_{gvt} + \delta_{gvt} \quad \text{(A2.2)}$$

where ψ_{gt} is a random effect to capture the special characters of supply on goods g overtime; $\omega_g \geqslant 0$ is the inverse supply elasticity, and δ_{gvt} is the error term that captures any random changes in the production technology.

Considering that both φ_{gt} and ψ_{gt} are unobserved random effects, we further difference Eqs. (A2.1) and (A2.2) with a base country "b".[17] The "difference in difference" of the demand and supply equations is respectively given by Eqs. (A2.3) and (A2.4):

$$\Delta^b \ln s_{gvt} = -(\sigma_g - 1)\Delta^b \ln p_{gvt} + \varepsilon^b_{gvt} \quad \text{(A2.3)}$$

$$\Delta^b \ln p_{gvt} = \frac{\omega_g}{1+\omega_g}\Delta^b \ln s_{gvt} + \delta^b_{gvt} \quad \text{(A2.4)}$$

where $\Delta^b x_{gvt} = \Delta x_{gvt} - \Delta x_{gbt}$. For the sake of identification, we assume that $E\left(\varepsilon^b_{gvt}\delta^b_{gvt}\right) = 0$. That is, demand and supply errors are uncorrelated once good and time specific effects are controlled for.

By multiplying (A2.3) and (A2.4), we obtain a "reduced form" as Eq. (A2.5)

$$(\Delta^b \ln p_{gvt})^2 = \theta_1(\Delta^b \ln s_{gvt})^2 + \theta_2(\Delta^b \ln p_{gvt}\Delta^b \ln s_{gvt}) + u_{gvt} \quad \text{(A2.5)}$$

where $\theta_1 = \frac{\omega_g}{(1+\omega_g)(\sigma_g-1)}$, $\theta_2 = \frac{1-\omega_g(\sigma_g-2)}{(1+\omega_g)(\sigma_g-1)}$, and $u_{gvt} = \varepsilon^b_{gvt}\delta^b_{gvt}$.

Note that Eq. (A2.5) provides the relationship between equilibrium prices (measured by unit prices) and quantities (measured by share) without the simultaneity problem as we assume $E(u_{gvt}) = E\left(\varepsilon^b_{gvt}\delta^b_{gvt}\right) = 0$. However, Eq. (A2.5) still suffers from measurement error problems, which result in the OLS estimates of $\beta_g = \begin{pmatrix}\sigma_g \\ \omega_g\end{pmatrix}$ inconsistent. Feenstra (1994) proposes that consistent estimates can still be obtained if we exploit the panel nature of the data set and assume constant supply and demand elasticities for the same good over time. Particularly, averaging Eq. (A2.5) overtime, the error term $\overline{u_{gv}}$ is independent of the regressands given σ_g and ω_g is time invariant. The unbiased estimates can then be obtained from Eq. (A2.6).

$$\overline{(\Delta^b \ln p_{gv})^2} = \theta_1\overline{(\Delta^b \ln s_{gv})^2} + \theta_2\overline{(\Delta^b \ln p_{gv}\Delta^b \ln s_{gv})} + \overline{u_{gv}} \quad \text{(A2.6)}$$

where $\bar{x}$ denotes the time average.

We use the generalized method of moments (GMM) to exploit the independence of the unobserved demand and supply disturbances for each country over time. According to Feenstra (1994), we can define a set of moment conditions such that

$$G(\beta_g) = E_t(u_{gvt}(\beta_g)) = 0 \forall v \quad \text{(A2.7)}$$

as long as all countries exporting good g satisfy the following condition:

$$\chi^2_{\varepsilon^b_{gv}} \Big/ \chi^2_{\varepsilon^b_{gv}} \neq \chi^2_{\delta^b_{gv}} \Big/ \chi^2_{\delta^b_{gv}}$$

where χ^2_x is the variance of x. Eq. (A2.7), therefore, gives us V_g independent moment conditions for each good g to estimate the two parameters of interest. For each good g, the following objective function can be used to obtain Hansen's (1982) estimator:

$$\hat{\beta}_g = \arg\min_{\beta \in B} G^*(\beta_g)' W G^*(\beta_g) \quad \text{(A2.8)}$$

where $G^*(\beta_g)$ is the sample analog of $G(\beta)$; W is a positive definite weighting matrix; and B is the set of economically feasible β such that $\sigma_g > 1$ and $\omega_g \geqslant 0$ .Specifically, the weighting matrix, W, is related to the time span and the inverse of lagged

[16] Demand is expressed in terms of expenditure shares rather than quantities to avoid the potential measurement error imparted from the use of unit values.

[17] The base country varies across goods. Basically, the based country of goods "g" just needs to be the country that exports "g" every year or most frequently from 1997 to 2008.

import quantities as in Broda and Weinstein (2006). We use a grid search of β's over the space defined by B. In particular, we compute the minimized GMM objective function over $\sigma_g \in [1.05, 200.5]$ at intervals that are 5% apart. Standard errors of β_g in this case are obtained by bootstrapping the grid-searched parameters.

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