NORTH-HOLLAND

Journal of Policy Modeling
23 (2001) 621–635

Journal of Policy Modeling

Would the right tariff aggregator for policy analysis please stand up?

Christian F. Bach[a,1], Will Martin[b,*]

[a]Royal Danish Agricultural and Veterinary University, Copenhagen, Denmark
[b]Development Research Group, The World Bank, 1818 H Street Northwest, Washington, DC 20433, USA

Received 1 November 1999; received in revised form 1 September 2000; accepted 1 February 2001

Abstract

The conventional use of import-weighted averages in tariff aggregation has little theoretical basis and wastes valuable information typically available in the detailed structure of protection. We build on the Anderson–Neary Trade Restrictiveness Index (TRI) and define ways in which a detailed set of tariffs may be aggregated consistently to provide measures of the impact of tariffs at the sectoral level. Under the assumptions needed for aggregation, we provide distinct aggregators for expenditure, input costs, tariff revenues, and the overall restrictiveness of tariffs in particular commodity groups. We illustrate the nature of the differences between the measures and show how they may be used in applied general equilibrium models to avoid wasting the valuable information available below the high level of aggregation necessarily used in such models. © 2001 Society for Policy Modeling. Published by Elsevier Science Inc.

Keywords: Tariff aggregation; Protection; Tariff revenue; Trade policy

* Corresponding author.
E-mail addresses: cfb@KVL.DK (C.F. Bach), wmartin1@worldbank.org (W. Martin).
[1] Also corresponding author.

PII: S0161-8938(01)00077-1

1. Introduction

While economists are near unanimous in their support for tariffs and nontariff barriers that are relatively uniform in their protective effect, country trade policies have a strong tendency towards Byzantine complexity. Tariff schedules involving over 10,000 tariff lines are not uncommon, and protection rates frequently differ considerably between very similar products. Meaningful evaluation of trade policy reforms frequently requires approaches that take into account the impacts of changes occurring in very large numbers of finely differentiated trade distortions.

Clearly, summary measures are required to interpret the effects of changes in a large number of tariff lines on welfare, industry output, and other variables of interest. A conventional approach is to calculate the effects on simple summary statistics like the average tariff rate, perhaps supplemented by measures such as the dispersion of the tariff (Thomas, Nash, et al., 1991). Even sophisticated, model-based analyses of trade liberalization, such as Harrison, Rutherford, and Tarr (1997), tend to be based on extremely simple aggregates such as trade-weighted average tariffs for broad commodity groups. Given that quite detailed information on protection measures and trade is typically available, it seems desirable to make the best possible use of it.

The simplest aggregator for the protective effect of tariffs is the simple average tariff rate. It is clearly flawed in not taking into account the relative importance of particular tariffs in forming the average. Perhaps the most common approach is the weighted average rate of protection using the value of imports at border prices as weights. If we are concerned about the welfare costs of a tariff regime, this approach is clearly wrong for large changes. The weight applied to any individual tariff falls as the tariff increases, even though we know that the welfare cost of a tariff increases more than proportionately with the rate. This weakness is particularly obvious for a prohibitive tariff, which is assigned a zero weight even though its welfare cost is at a maximum.

Practical solutions to the problem have been sought by a number of authors. A common approach involves including measures of variability alongside those of the weighted average. In most cases, there is no obvious way to incorporate these two moments into a single measure of the restrictiveness of the trade regime.[2]

A major advance in aggregating protection measures into useful aggregates was the Trade Restrictiveness Index (TRI). It can be used to estimate, for any small country, the uniform tariff that would be equivalent, in terms of welfare, to any pattern of distortions (Anderson & Neary, 1994). Changes in the TRI can be used to track the welfare costs of changes in a large number of distortions, just as

[2] In the related case of intertemporal variability in rates of protection, Francois and Martin (1995) incorporate the mean and the variance of protection into a single measure of the expected cost of protection.

changes in the ideal consumer price index can be used to track changes in the welfare consequences of changes in many consumer prices. Using a simple numerical general equilibrium model, it can be shown that average tariffs generally underestimate the *level* of protection as described by the "uniform tariff equivalent." The degree of underestimation is positively correlated with the dispersion of the tariff structure (Anderson & Neary, 1994). Even more disturbing, it appears that the results obtained when using ordinary summary measures of trade restrictiveness to assess the consequences of policy reform are frequently wrong in sign (Anderson, 1993).

Like any index, the standard TRI is optimal only for a specific purpose—in this case, aggregating the welfare consequences of all trade barriers in a small open economy. If we are interested in other variables, such as volumes or values of imports and exports, different indexes will be required. If we wish to focus only on protection measures within a particular sector, then changes in the overall TRI may not give a reliable indicator of changes in assistance *within* the sector. As noted by Anderson and Neary (1992), for a large country, the full welfare consequences of trade reform will, in turn, depend upon the induced changes in imports and exports and their consequences for the country's terms of trade.

In this paper, we build on the insights of the TRI approach to suggest a series of indicators for use in policy analysis. First, we define a simple indicator of trade restrictiveness that can be applied for particular commodity aggregates. Secondly, we develop a modeling strategy and a set of indexes that can be used, without loss of information, in computable general equilibrium models that are necessarily more aggregated than the available tariff and trade data.

2. Methodology

A general representation of any competitive economy is provided by Eqs. (1) and (2):

the income – expenditure condition:

$$e(\mathbf{p},u) - r(\mathbf{p},\mathbf{v}) - (\mathbf{e_p} - \mathbf{r_p})'(\mathbf{p} - \mathbf{p}^{\mathrm{w}}) - f = 0 \tag{1}$$

and the vector of behavioral equations:

$$\mathbf{e_p}(\mathbf{p},u) - \mathbf{r_p}(\mathbf{p},\mathbf{v}) = \mathbf{m}. \tag{2}$$

In the income–expenditure condition, e is the expenditure required to achieve consumer utility level u at domestic price vector $\mathbf{p}$, r is the restricted profit function at domestic prices $\mathbf{p}$ for inputs and outputs attainable with the given resource vector $\mathbf{v}$, $\mathbf{e_p} - \mathbf{r_p}$ is the vector of net imports/exports at world prices $\mathbf{p}^{\mathrm{w}}$ and domestic prices $\mathbf{p}$, so that $(\mathbf{e_p} - \mathbf{r_p})(\mathbf{p} - \mathbf{p}^{\mathrm{w}})$ represents net revenue from tariffs and export taxes/subsidies, and f is the net financial inflow from abroad. In the behavioral equations, $\mathbf{m}$ is a vector of net imports, including nontraded goods (for which $\mathbf{m} \equiv 0$) and supplied and demanded factors.

The balance-of-trade function (Anderson & Neary, 1996) can be derived from Eq. (1) by reclassifying the level of utility as exogenous and introducing a new variable, $\boldsymbol{B}$, to measure the hypothetical financial inflow required to maintain a specified level of utility, u^0, in the face of an exogenous shock.

$$\mathbf{B}(\mathbf{p}, u^0) = e(\mathbf{p}, u^0) - r(\mathbf{p}, \mathbf{v}) - (\mathbf{e}_\mathbf{p} - \mathbf{r}_\mathbf{p})(\mathbf{p} - \mathbf{p}^{\mathrm{w}}) - f \tag{3}$$

The balance-of-trade function gives us the transfer required to maintain the same level of utility given a change in prices and is therefore a convenient measure of the compensation required to maintain national welfare at any specified level. Its use can be seen as a generalization of the use of the expenditure function to evaluate the impact on consumer welfare of price changes, which is the conceptual basis for the widely used consumer price index.

To best capture the impact of trade barriers on welfare, it is desirable that we work at the highest level of disaggregation that is consistent with the production technology and consumer preferences, the information available, and the computational constraints under which we operate. We typically have information on tariffs and (hopefully) trade at a very fine level of disaggregation. However, it is rare to have information on gross and net production patterns at anything approaching the same degree of disaggregation. Thus, if we want to construct models of our economy or need summary statistics for policy evaluation, we are forced to aggregate.

Economic theory provides guidelines for the construction of consistent aggregates. Deaton and Muellbauer (1980, pp. 122–130) show that weak separability allows the decomposition of the consumer's problem into the maximization of subutility functions over elements of each commodity group and maximization of total utility over the subutility functions. To be able to specify behavior at the higher level in terms of composite prices and quantities derived from the lower level optimization requires stronger restrictions, such as homotheticity of preferences at the lower level. Chambers (1988) and Lloyd (1994) discuss a range of conditions that allow aggregation of the production technology. On the production side, the parallel conditions are that the production function be weakly separable and each of the subaggregator functions be homothetic (Chambers, 1988).

In the remainder of the theoretical discussion, we will assume that the conditions needed for the formation of subaggregate price and quantity indexes have been satisfied and focus on the construction and use of these indexes. We first discuss the balance-of-trade function and its potential application to commodity groups and then define and apply tariff aggregators for each of the components of Eq. (3). Then, in Section 3, we consider applications — firstly, an illustrative numerical example, and then the issues involved in applying the procedure in real-world computable general equilibrium models. Conclusions are given in Section 4.

2.1. The balance-of-trade function

Anderson and Neary's (1994) TRI uses an equation like Eq. (3) to define a uniform tariff equal in its welfare impacts to the observed tariff regime. Formally, the TRI for a tariff change that changes domestic prices from $\mathbf{p}^0$ to $\mathbf{p}^1$ is defined as the uniform scaling factor by which Period 1 prices must be deflated to maintain the utility of the representative consumer at a given level, such as u^0.

$$\Delta = [\Delta : \boldsymbol{B}(\mathbf{p}^1/\Delta, u^0) = \boldsymbol{B}(\mathbf{p}^0, u^0)] \tag{4}$$

The TRI can be used to calculate the uniform price reduction that would be welfare equivalent to a move from an initial, distorted equilibrium to free trade. This yields a value, Δ^{f}, which can be transformed into the uniform tariff, τ^B, which would be welfare-equivalent to the initial vector of tariffs.

$$\tau^B = 1/\Delta^{\mathrm{f}} - 1$$

Inserted in Eq. (4), this yields an expression for the welfare-equivalent uniform tariff rate (Eq. (5)):

$$\tau^B = [\tau^B : \boldsymbol{B}(\mathbf{p}^{\mathrm{d}}, \mathbf{p}^{\mathrm{w}}(1+\tau^B), u^0) = \boldsymbol{B}(\mathbf{p}^{\mathrm{d}}, \mathbf{p}, u^0)] \tag{5}$$

where the price vector is partitioned into a vector of prices on domestic exportable goods $\mathbf{p}^{\mathrm{d}}$, a vector of world prices $\mathbf{p}^{\mathrm{w}}$, and of domestic prices $\mathbf{p}$ for importables given the disaggregated set of tariff rates. To be consistent, the TRI must be derived from the disaggregated set of tariffs in a fully general equilibrium model with specified consumption and production structures (Anderson, 1993). With typically from 5 to 6000 tariff lines plus bilateral trade flows, this necessarily implies a highly simplified model structure and even then may be difficult to implement.

In many cases, there will be considerable interest not only in the cost of protection but also in the behavior of outputs and demands for particular groups of commodities. Assuming the conditions for two-stage analysis have been satisfied, each group of import goods might be associated with a single composite domestic good that can be treated as the numeraire for that particular composite.[3] This allows us to define aggregator functions for the commodity groups.

[3] As both the expenditure function and the tariff revenue will be homogenous of degree 1 in a uniform tariff equivalent, this problem can only be solved with a domestic good as numeraire, which implies setting expenditure equal to total expenditure on both imported commodities and the domestic good. The price of the domestic good is treated as exogenous in the formation of the commodity aggregates, although domestic goods' prices may be endogenous at the higher level.

With the domestic good differentiated along Armington (1969) lines from all of the imported goods and output and exports of the domestic good determined at the aggregate level, the output supply level, $\mathbf{r_p}$, and the revenue from production are constants and hence can be omitted from the balance-of-trade function. This allows us to define a simplified balance-of-trade function, $\boldsymbol{B}_j$, for each commodity group as the difference between total domestic expenditure and tariff revenue.

$$\begin{aligned} \boldsymbol{B}_j(\mathbf{p}_j, u_j) &= e_j(\mathbf{p}_j^{\mathrm{d}}, \mathbf{p}_j, u_j^0) - (\mathbf{p}_j - \mathbf{p}_j^{\mathrm{w}})\mathbf{e}_{\mathbf{p}_j} \\ &= e_j(\mathbf{p}_j^{\mathrm{d}}, \mathbf{p}_j, u_j^0) - \mathrm{t}\,\mathrm{r}_j(\mathbf{p}_j, \mathbf{p}_j^{\mathrm{w}}, u_j^0) \end{aligned} \tag{6}$$

where $\mathbf{p}_j^{\mathrm{d}}$ is the price of the single domestic good and $\mathbf{p}_j$ is the vector of domestic prices for importable with the corresponding world price vector $\mathbf{p}_j^{\mathrm{w}}$ (Eq. (6)).

This leads us to a summary indicator of trade restrictiveness for group j given by

$$\tau_j^B = \left[\tau_j^B \mid \boldsymbol{B}_j\left(\mathbf{p}_j^{\mathrm{d}}, \mathbf{p}_j^{\mathrm{w}}, \left(1 + \tau_j^B\right), u_j^0\right) = \boldsymbol{B}_j\left(\mathbf{p}_j^{\mathrm{d}}, \mathbf{p}_j, u_j^0\right)\right]. \tag{7}$$

This summary indicator of trade restrictiveness within a particular commodity group may be useful when considering sectoral liberalization policies. However, it does not give us an aggregator suitable for use in general equilibrium models. Clearly, this subaggregator is not the appropriate aggregator for the expenditure functions used to define expenditure on each commodity aggregate—the expenditure function is concave in tariff rates, while the balance of payments function underlying the TRI is convex in tariff rates. In finding a way around this problem, we found it useful to consider each of the components of Eq. (3) separately.

2.2. The expenditure function

The expenditure function for commodity group j may be defined as (Eq. (8)):

$$e_j(\mathbf{p}_j, u_j^0) = e_j(\mathbf{p}_j^{\mathrm{d}}, \mathbf{p}_j, u_j^0). \tag{8}$$

If we consider the impact of tariffs on the cost to consumers of achieving a particular level of utility, the tariff aggregator for expenditure can then be defined as a uniform tariff that requires the same level of expenditure as the observed vector of tariffs,

$$\tau_j^e = [\tau_j^e \mid e_j(\mathbf{p}_j^{\mathrm{d}}, \mathbf{p}_j^{\mathrm{w}}(1 + \tau_j^e), u_j^0) = e_j(\mathbf{p}_j^{\mathrm{d}}, \mathbf{p}_j, u_j^0)]. \tag{9}$$

Assuming the conditions for two-stage budgeting have been satisfied, changes in this aggregate tariff rate can be used to evaluate impacts on the demand for commodity *j*.

2.3. The profit function

If an aggregator over produced goods and intermediated inputs is required, the basis for aggregation is the restricted profit function (Dixit & Norman, 1980). For the case of a single domestic output and many imported inputs, the tariff aggregator for commodity group *j* is given by:

$$\tau_j^{\mathrm{r}} = [\tau_j^{\mathrm{r}} \mid r_j(\mathbf{p}_j^{\mathrm{d}}, \mathbf{p}_j^{\mathrm{w}}(1+\tau_j^{\mathrm{r}}), \mathbf{v}_j^0) = r_j(\mathbf{p}_j^{\mathrm{d}}, \mathbf{p}_j, \mathbf{v}_j^0)] \tag{10}$$

where $\mathbf{p}_j^{\mathrm{d}}$ is the price of the composite domestic good, $\mathbf{p}_j^{\mathrm{w}}$ is the vector of world prices of imported intermediates, $\mathbf{p}_j$ is the domestic prices of these inputs, and $\mathbf{v}_j^0$ is an indicator of the available quasi-fixed resources (Eq. (10)).

Assuming the conditions for two-stage aggregation are satisfied, this aggregator may be used to assess the implications of changes in an aggregate tariff on the composite quantity of imports of intermediate goods of type *j*.

2.4. Tariff revenue

Finally, for the last part of Eq. (3), the tariff revenue, we can proceed equivalently. Assuming the assumptions for two-stage budgeting have been satisfied, the tariff revenue aggregator for good *j* may be defined as:

$$\tau_j^{\mathrm{tr}} = [\tau_j^{\mathrm{tr}} \mid \mathrm{tr}_j(\mathbf{p}_j^{\mathrm{w}}(1+\tau_j^{\mathrm{tr}}), \mathbf{p}_j^{\mathrm{w}}, u_j^0, \mathbf{v}_j^0) = \mathrm{tr}_j(\mathbf{p}_j, \mathbf{p}_j^{\mathrm{w}}, u_j^0, \mathbf{v}_j^0)]. \tag{11}$$

2.5. The behavior of the different aggregators

The differences between the conventional fixed-weight indicator, the tariff revenue aggregator, and the aggregators for final expenditure or the costs of intermediate inputs are readily illustrated in the case of a single, specific tariff in an otherwise undistorted economy. Starting from a zero tariff level, a small increase in the price of the imported good has an equal impact on required expenditures measured using the Leontief expenditure function underlying the conventional fixed-weight aggregator, an expenditure function reflecting price-responsive behavior, and a tariff revenue aggregator. With a fixed-weight aggregator, the marginal impact of a change in the tariff rate stays the same as the tariff rate increases. Its slope is given everywhere by the slope of the dashed line through the initial point A in Fig. 1.

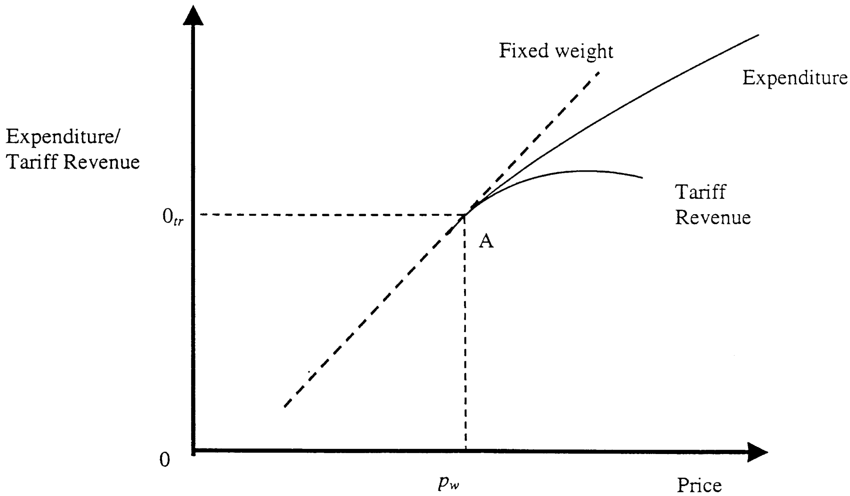

Fig. 1. Impacts of tariff increases on consumer expenditure and on tariff revenues.

With an expenditure (or input cost) aggregator, the slope at point A is the same as in the case of fixed weights. The derivative of the expenditure function with respect to price *i* is, by duality, equal to the quantity demanded, which is the same at point A whichever aggregator is used. However, as the tariff on this good is raised and the price of the good goes higher, the impact on expenditure progressively becomes smaller, simply because the quantity of the good demanded declines. The expenditure function plotted against the tariff in Fig. 1 illustrates these features. At point A, it is tangent to the straight line whose slope is given by the base quantity of the good. However, its slope diminishes as the tariff rises above a zero level because the expenditure function is concave in the prices of its component goods.

The tariff revenue aggregator is tangent to the fixed weight and expenditure function aggregators at point A in Fig. 1. Starting from a zero tariff, the first incremental tariff increases will reduce demand but cause no revenue loss. The impact of subsequent tariff increases on tariff revenues diminishes more rapidly than the impacts on (compensated) expenditures because the quantity reductions associated with subsequent tariff increases are associated with increasingly large marginal reductions in tariff revenues.[4] Thus, the tariff revenue curve is more strongly concave than the expenditure function in Fig. 1.

Fig. 1 also highlights the source of the convexity of the balance-of-trade function. In simple cases such as the one considered above, this function is

[4] With expenditure function $e=e(\mathbf{p},\mathrm{u})$, the impact of an increase in the tariff on expenditure is given by the first derivative of e wrt the price of good i, e_i. In this single-distortion case, tariff revenues are given by $e_i(\mathbf{p}_i - \mathbf{p}_i^{\mathrm{w}})$ and the marginal impact of an increase in $\mathbf{p}_i$ by $e_i + e_{ii}(\mathbf{p}_i - \mathbf{p}_i^{\mathrm{w}})$.

simply the expenditure function *minus* the tariff revenue function. The more pronounced concavity of the tariff revenue function overcomes the concavity of the expenditure function to create an overall balance-of-trade function that is convex in tariff rates.

3. Applications

3.1. A numerical example

Having established that we can use different aggregators for different parts of Eq. (3) and explored the behavior of the different indexes, we illustrate the properties of the aggregation approach using a simple numerical example of a tariff reform involving a sharp reduction in both the mean and the variance of the tariffs on six items.[5]

For this numerical example, we chose the constant elasticity of substitution (CES) function (Arrow, Chenery, Minhas, & Solow, 1961) widely used in computable general equilibrium models. Our expenditure function for commodity group j then becomes (Eq. (12)):

$$e_j(p_j^{\mathrm{d}}, p_j, u_j^0) = \left(\beta_j^{\mathrm{d}} p_j^{\mathrm{d}} + \sum_i \beta_{ij} p_{ij}^{1-\sigma}\right)^{\frac{1}{1-\sigma}} u_j^0. \tag{12}$$

With the initial domestic prices of all goods normalized at unity, the parameter β is equal to the initial values of the expenditure shares (domestic and import) in the base data and is held constant.

The expression for our modified balance-of-trade function defined for each commodity group is then (Eq. (13)):

$$\boldsymbol{B}_j = \left(\beta_j^{\mathrm{d}} \mathbf{p}_j^{\mathrm{d}} + \sum_i \beta_{ij} (p_{ij})^{1-\sigma}\right)^{\frac{1}{1-\sigma}} u_j^0 - \sum_i \beta_{ij} \left(\frac{p_j}{p_{ij}}\right)^{\sigma} (p_{ij} - p_{ij}^{\mathrm{w}}) u_j^0, \tag{13}$$

with the price index:

$$p_j = \left(\beta_j^{\mathrm{d}} p_j^{\mathrm{d}} + \sum_i \beta_{ij} (p_{ij})^{1-\sigma}\right)^{\frac{1}{1-\sigma}}.$$

With all domestic prices equal to 1 and u_i equal to the total expenditure (domestic and imports) in the group, the initial value of the modified balance-of-

[5] For a large-scale example using a popular general equilibrium model, see Bach, Martin, and Stevens (1996).

trade function for each commodity group with the disaggregated set of tariff rates becomes

$$\boldsymbol{B}_j^0 = u_j^0 - \sum_i \beta_{ij}(p_{ij} - p_{ij}^{\mathrm{w}})u_j^0,$$

which is simply total expenditure less tariff revenue.

The proposed version of the TRI, τ_j^B, for each commodity group is obtained from Eq. (7) by setting the value of the balance-of-trade function with a uniform tariff equivalent equal to the value with the disaggregated tariff set, $\boldsymbol{B}_j^0$:

$$\left(\beta_j^{\mathrm{d}} + \sum_i \beta_{ij}\left(p_{ij}^{\mathrm{w}}(1+\tau_j^{\beta})\right)^{1-\sigma}\right)^{\frac{1}{1-\sigma}} u_j^0 - \left(\sum_i \beta_{ij}\left(\frac{p_j}{p_{ij}^{\mathrm{w}}(1+\tau_j^B)}\right)^{\sigma} p_{ij}^{\mathrm{w}}\tau_j^B\right)u_j^0 = \boldsymbol{B}_j^0,$$

with the price index:

$$p_j = \left(\beta_j^{\mathrm{d}} + \sum_i \beta_{ij}\left(p_{ij}^{\mathrm{w}}(1+\tau_j^B)\right)^{1-\sigma}\right)^{\frac{1}{1-\sigma}}.$$

The uniform tariff equivalent in the expenditure and tariff revenue cases are found quite equivalently by setting the value of the function with a uniform tariff level equal to the value with the disaggregated tariff set (see Eqs. (9) and (11)).

With all domestic prices equal to 1 in the base equilibrium, the uniform tariff equivalent in the expenditure case has the closed-form solution (Eq. (14)),

$$\tau_j^e = \left(\frac{1-\beta_j^{\mathrm{d}}}{\sum_i \beta_{ij}(p_{ji}^{\mathrm{w}})^{1-\sigma}}\right)^{\frac{1}{1-\sigma}} -1. \qquad (14)$$

The base data for the numerical example consist of six tariff lines with a highly dispersed initial tariff structure, expenditure on the domestic good equal to 2000, total expenditure on imports at domestic prices of 1230, and tariff revenue equal to 630 in the initial equilibrium (Table 1).

From the initial equilibrium, we can calibrate the CES expenditure function, derive the expenditure and tariff revenue, at constant utility, after the tariff reform, and compare them with the expenditure and tariff revenue using the Leontief functional form underlying a conventional trade-weighted average. The results of these calculations are presented in Table 2.

There are two main points to notice. The first is that use of the CES aggregator results in lower estimated expenditure on imports at domestic prices (629 compared with 720) than is the case with constant weights. This is because the

Table 1
Dataset for numerical example

	Tariffs (%)		Imports[a]
Good	Before	After	Before
1	10	10	100
2	10	10	100
3	10	10	100
4	200	30	100
5	200	30	100
6	200	30	100

[a] At world prices.

expenditure function captures the substitution by consumers towards the commodities whose prices fall the most—the substitution that underlies the concavity of the expenditure function in prices. Similarly, tariff revenues (133 compared with 120) are higher than would be predicted by the conventional constant import-weighted index because consumption increases most for the goods whose prices decrease the most. In sum, allowing for substitution within our disaggregated tariff set gives an additional welfare gain (less expenditure and more tariff revenue) compared with the constant weights. This gain is reflected in the modified balance-of-trade function after trade reform (496 instead of 600 with constant weights). Also, it is reflected in the modified TRI, τ_j^B, equal to 1.78 in the initial equilibrium and 0.29 after tariff reform, compared with 1.05 and 0.2 for the conventional import-weighted average.

Table 2
Aggregated tariffs — different procedures

	Before	After
Expenditure on imports, domestic prices		
Leontief expenditure function	1230	720
CES expenditure function[a]	1230	629
Expenditure on imports, world prices		
Leontief expenditure function	600	600
CES expenditure function[a]	600	496
Tariff revenue		
Leontief expenditure function	630	120
CES expenditure function[a]	630	133
Uniform tariff equivalents		
Conventional	1.050	0.200
Expenditure[a]	1.490	0.273
Tariff revenue[a]	0.963	0.269
Simple version of TRI	1.780	0.289

[a] Elasticity of substitution = 2.

The gain occurs due to the reduction in the dispersion present in the initial tariffs and would not be present if there had been a uniform initial tariff rate and a uniform cut. In this case, relative prices would remain constant and the constant weights and any functional form would yield the same result. Thus, the additional welfare gain reflects the reduction in the variability within the tariff set.

The second point to notice from Table 2 is that, if we use simple import-weighted averages, with the same set of weights for the original and the new tariffs, one single price aggregator can enter both the expenditure part and the tariff revenue part of our model. If we use a functional form allowing for substitution, this will not be the case. Keeping expenditure at world prices constant (equal to 600), a uniform tariff equivalent for the expenditure part of our model will not yield the right change in tariff revenue (629 – 600 = 29 instead of 133). At the same time, the uniform tariff equivalent that gives the right tariff revenue after the tariff cut will not, at constant world prices, yield the right domestic (600 + 133 = 733 instead of 629). Thus, if we wish to reflect the changes in domestic expenditure and tariff revenue with the help of shocks to a price variable, it is necessary to apply different shocks to the expenditure and the tariff revenue parts of our model (see Bach et al., 1996).

3.2. Using the aggregators in large-scale models

The previous sections of the paper have defined aggregators that can be used for the different parts of the economy characterized by Eq. (3). Uniform tariff equivalents for each of the three components of Eq. (3), which are for the expenditure function, the revenue function, and the tariff revenue function, can be used to hold the overall balance-of-trade constant in the initial equilibrium and to trace through the consequences of reforms. In a single-country model, a single tariff aggregator (a TRI) or set of tariff aggregators defined using balance-of-trade function(s) may also be used in the expenditure, profit, and tariff revenue components of the overall balance-of-trade function.

It is important to note that the balance-of-trade function can be used in two different ways to obtain a money measure of welfare changes. In one approach, the utility level is held constant throughout the function and the tariff changes are implemented, causing the function to read off the amount of compensation from the rest of the world needed to hold utility at its chosen level. In another approach, the change in utility ground out by the model as a consequence of the change in tariffs is first observed, and the balance-of-trade function, with fixed prices, is used to estimate the amount of additional income that would be equivalent to this change in utility. Anderson and Martin (1996) term the first approach the compensation approach and the second the money metric approach. The two approaches are identical in the consumer expenditure case in the absence of distortions, but Anderson and Martin show they may be quite different in the presence of distortions. Although both are valid measures of welfare change, Anderson and Martin argue strongly for the compensation approach because it allows comparison with measures of the benefits of public goods.

In the small-country case, it is possible to use either the compensation approach or the money metric approach to capture the welfare implications of tariff changes. Either approach may be implemented using either the balance-of-trade function aggregators throughout or the appropriate aggregators in each part of the model. If there is interest in the impacts of reform on volumes of trade, then it becomes important to use the individual aggregators for each component of the model because the trade restrictiveness aggregators are not designed to aggregate quantities.

In the large-country case, it becomes important to use the appropriate aggregator in each component of the behavioral model. This is because, in the large-country case, the prices received for exports and imports depend on quantities imported and exported, and these quantity changes can only be adequately captured using the appropriate aggregators. Once these component aggregators have been applied throughout the model, the overall impact on welfare may be calculated using either the money metric or compensation approaches. Assuming the compensation approach is used, the resulting balance-of-trade function used for the welfare evaluation is the following (Eq. (15)):

$$\boldsymbol{B} = e(\tau^{e}, p^{\mathrm{w}}, u) - r(\tau^{r}, p^{\mathrm{w}}, v) - \mathrm{tr}(\tau^{\mathrm{tr}}, p^{\mathrm{w}}, u, v). \tag{15}$$

Once we move to a fully global model, however, we encounter a difficulty. Clearly, for the reasons outlined in the large-country case, we should use the appropriate aggregators in the expenditure and revenue functions and their derivatives. However, if this is done in the tariff revenue part of the model, it brings us into violation of Walras' law at the global level. The welfare gains being derived from tariff reforms accrue as tariff revenue gains, and hence expenditure gains, which are unmatched by changes in production, and financial inflows cannot be used as the balancing item the way they can be in single-country models.

We see no ideal solution to this problem. One potential approach in applied work is to develop a global model that uses the expenditure and revenue function aggregators throughout an aggregate model (see Rutherford for an example of this approach). Clearly, this will not allow the model to replicate the initial value of tariff revenues, and some data-balancing procedure may be needed to obtain a balanced initial dataset. From such an initial dataset, the resulting global model will satisfy Walras' law and be able to solve for changes in prices and quantities and an estimate of the impact on welfare. The resulting balance-of-trade function is

$$\boldsymbol{B} = e(\tau^{e}, p^{\mathrm{w}}, u) - r(\tau^{r}, p^{\mathrm{w}}, v) - \mathrm{tr}(\tau^{e}, \tau^{r}, p^{\mathrm{w}}, u, v), \tag{16}$$

which clearly misspecifies the tariff revenue impacts of trade policy changes on welfare.

One approach to dealing with this problem is to adjust Eq. (16) to correct for the error in its evaluation of the tariff revenue impacts, yielding Eq. (17):

$$\boldsymbol{B} = e(\tau^e, p^{\mathrm{w}}, u) - r(\tau^r, p^{\mathrm{w}}, v) - \mathrm{tr}(\tau^e, \tau^r, p^{\mathrm{w}}, u, v) - (\mathrm{t\,r}(\tau^t, p^{\mathrm{w}}, u, v) + \mathrm{t\,r}(\tau^e, \tau^r, p^{\mathrm{w}}, u, v)). \tag{17}$$

As long as this adjustment is done in a separate welfare evaluation exercise that is causally posterior to the solution of the global model, it will not violate Walras' law in the model solution. It will, however, allow the welfare impact obtained from the aggregated global model to be adjusted to take into account the information available in the original, disaggregated information on tariff barriers.

4. Conclusions

The purpose of this paper is to discuss and evaluate the use of different aggregators for tariff aggregation. A simple message is that the choice of aggregator when evaluating tariff changes should depend on the purpose for which it is to be used. For the behavioral responses of an economy, the conventional trade-weighted averages are the proper aggregators for representing small changes in trade barriers if we do not know the exact functional forms. If we do, exact indexes based on the underlying expenditure or revenue functions allow the consequences of large tariff changes to be more accurately captured.

If the analysis is to reflect the welfare effects of a given tariff level or of tariff reforms, then the aggregation should be based on the balance-of-trade function rather than the expenditure or revenue functions from which the behavioral equations are derived. A modified version of the TRI is developed as a summary indicator of the welfare costs of protection within particular commodity groups. It is easy to implement and demands only information on tariffs, import values, and total expenditure on each commodity. It reflects both the level and the variability of the disaggregated tariff information and provides a useful summary of the structure of protection in a particular sector.

When analyzing trade reforms using CGE models, appropriate aggregators should be used to represent the impacts of expenditure, revenue, and tariff revenue functions. In single-country models, this modification requires little adjustment other than to the specification of the tariff revenue equations in the income–expenditure conditions. In global models, some adjustments are needed to avoid violation of Walras' law, and we suggest an approach for dealing with this problem.

Acknowledgments

We are grateful to Thomas W. Hertel and Tony Sihsobhon for valuable assistance and to Mary E. Lovely, James E. Anderson, Eric Bond, and the participants at a seminar in the World Bank for helpful comments. Any remaining errors are ours.

References

Anderson, J. E. (1993). *Aggregation of trade restrictions in a simple CGE model.* Mimeo, Boston College.

Anderson, J. E., & Martin, W. J. (1996). *The welfare analysis of fiscal policy: a simple unified account* (Working Paper 316). Department of Economics, Boston College.

Anderson, J. E., & Neary, J. P. (1992). Trade reform with quotas, partial rent retention, and tariffs. *Econometrica*, *60*, 57–76.

Anderson, J. E., & Neary, J. P. (1994). Measuring the restrictiveness of trade policy. *World Bank Economic Review*, *8* (2), 151–170.

Anderson, J. E., & Neary, J. P. (1996). A new approach to evaluating trade policy. *Review of Economic Studies*, *63*, 107–125.

Armington, P. A. (1969). A theory of demand for products distinguished by place of production. In: *IMF Staff Papers*, (Vol. 16, pp. 159–178). Washington, DC: International Monetary Fund.

Arrow, K., Chenery, H. B., Minhas, B., & Solow, R. M. (1961). Capital–labor substitution and economic efficiency. *Review of Economics and Statistics*, *43* (3), 225–250.

Bach, C. F., Martin, W., & Stevens, J. A. (1996). China and the WTO: tariff offers, exemptions and welfare implications. *Weltwirtschaftliches Archiv*, *132* (8), 409–431.

Chambers, R. G. (1988). *Applied production analysis. A dual approach*. Cambridge: Cambridge University Press.

Deaton, A., & Muellbauer, A. (1980). *Economics and consumer behavior*. Cambridge: Cambridge University Press.

Dixit, A. K., & Norman, V. (1980). *Theory of international trade*. Cambridge: Cambridge University Press.

Francois, J. F., & Martin, W. (1995). *Multilateral trade rules and the expected cost of protection* (Discussion Paper No. 1214). London: Center for Economic Policy Research.

Harrison, G., Rutherford, T., & Tarr, D. (1997, September). Quantifying the Uruguay round. *Economic Journal*, *107*, 1405–1430.

Lloyd, P. J. (1994). Aggregation by industry in high-dimensional models. *Review of International Economics*, *2* (2), 97–111.

Thomas, V., & Nash, J. (1991). *Best practices in trade policy reform*. Oxford: Oxford University Press.