Measuring the Benefits of Global Liberalization with a Consistent Tariff Aggregator

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1 Introduction

Economists have long been aware that the standard approaches used to assess the implications of large-scale reforms, such as WTO agreements, potentially seriously understate their benefits because of excessive aggregation of the protection measures. The problem is potentially very important because border protection rates applied to finely differentiated products frequently differ greatly.[1] It is difficult to resolve because the information on production and demand structures needed to make a full assessment of the implications of reform is available at a much higher level of aggregation than the information on tariffs and trade flows.

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[1] Anderson [2008] indicates that the problem may also arise for other policy measures such as the income tax in industrial countries because the effects of these taxes are also finely differentiated once specific exceptions are taken into account.

Historically, measures such as the arithmetic or the trade-weighted average tariffs have been employed, but they are without theoretical foundation and in addition, they may introduce significant biases in estimation. More recently, new approaches with rigorous theoretical foundations for the aggregation problem have emerged. Anderson and Neary [1994] proposed a uniform tariff that yields the same welfare as the original differentiated tariff structure. In subsequent work (1996, 2003, 2005), they developed uniform tariff measures that are equivalent in their effects on the value of exports.

Building on the Anderson-Neary approach, Bach et al. [1996] and Bach and Martin [2001] proposed an approach to aggregation in the context of large-scale models that mitigated many of the problems—and showed that the implications of aggregation could be large. However, they were only able to apply their approach to individual countries or regions. Martin et al. [2003] applied this methodology to additional countries and confirmed that the impact on the results could be substantial. Manole and Martin [2005] developed the approach further, showing that it should be applied in specific ways, and establishing the relationship between the different tariff indexes. Anderson [2008] made an important breakthrough in identifying an approach that enables consistent aggregators to be used in global models.

The purpose of this paper is to apply aggregation approaches developed in this literature to ex ante assessment of global economic reforms. We first seek to establish whether it is feasible, and then move to examining some of the key issues involved in applying aggregation techniques in a global general equilibrium model.

2 The Aggregation Approach

An important lesson from index theory generally, and particularly from the papers by Anderson and Neary on tariff index theory, is that such indexes should be based on a model that relates the index to an economic objectives. In this paper, we focus primarily on economic welfare, although we are interested in other variables such as trade levels, partly for their own sake, and partly because they influence welfare through terms-of-trade effects. Like Bach and Martin [2001], we assume that the structure of such a competitive, small open economy can be captured by the income-expenditure condition:

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

and the set of behavioral equations[2],

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

where $e(\mathbf{p}, u)$ is the expenditure function of the representative household, p is a given vector of domestic sectoral price aggregates, u is domestic utility, $r(\mathbf{p}, \mathbf{v})$ is domestic revenue from production, and $\mathbf{v}$ is a vector of productive resources; $\mathbf{m}$ is the vector of imports, and f is the exogenously-determined net financial inflow from abroad. We can define B as the balance-of-trade function, which captures the financial inflow necessary to keep utility u constant when prices $\mathbf{p}$ change (Anderson and Neary [1996]) and provides a money measure of welfare changes in welfare in a small open economy.

Based on equation 1 and considering world prices p^w and the level of utility u^0 as exogenous, B can be written as:

$$B(\mathbf{p}, u^0) = e\left(\mathbf{p}, u^0\right) - r(\mathbf{p}, \mathbf{v}) - (\mathbf{e}_p - \mathbf{r}_p)' (\mathbf{p} - \mathbf{p}^w) - f = 0 \tag{3}$$

The majority of papers that use the balance-of-trade approach use a single-level model to specify a single aggregator that captures all the relevant information. Here, by contrast, we use a two-stage modeling approach that allows us to bring in information - such as information on the structure of production and demand - that is contained in economic models where a higher level of aggregation is feasible or desirable - such as in calibrated general equilibrium models or econometrically estimated national models such as Kohli [2004]. In the first stage we compute indices that capture the information about tariffs within groups. In the second stage, we use these

[2] We use bold letters for vectors.

aggregates to solve a more aggregated model.

Deaton and Muellbauer [1980] provide the theoretical underpinnings for two-stage modeling approach from the consumption side. If weak separability exists, then the consumer's maximization problem can be decomposed into the maximization of sub-utility functions over categories of products, and at a higher level, maximization of total utility over the sub-utility functions. If another condition—that of homotheticity of preferences at the lower level—is satisfied, then two stage-budgeting based can be used, with decisions at a higher level of aggregation based on aggregate prices and quantities passed up from the lower level. In a similar fashion, Chambers [1988] and Lloyd [1994] similarly show that weak separability of the production function, and homotheticity of the sub-aggregator functions allow aggregation of multi-stage production technologies.

In the rest of the paper we assume that the conditions needed for the formation of sub-aggregate price and quantity indexes have been met - a ubiquitous assumption in virtually all quantitative analysis of international trade - irrespective of whether the aggregators used are grounded in economic theory. We construct two different types of aggregators one that is optimal for decisions regarding expenditure levels and the demand for consumption goods, and another that is optimal for aggregating tariffs when estimating tariff revenues.

We further assume, following Armington [1969], that domestic products are differentiated from imported products for any given composite good, such as "crops". If the prices of domestically-produced goods are determined by returns on export markets, then $r(\mathbf{p}, \mathbf{v})$ will be invariant to changes in tariffs, and import demand will equal $e_p(\mathbf{p} - \mathbf{p}^w)$, allowing further simplification of the model. Like Hummels and Klenow [2005], we focus on aggregation from a fine level of disaggregation, such as the six-digit level of the Harmonized System. As noted by Manole and Martin [2005], it is likely to be useful to follow standard practice in the computable general equilibrium modeling, and to use a two-level approach in which purchasers first substitute between imported and domestic goods, and then between different imported goods. In the following section, we develop aggregators for the two components of the model - the expenditure and tariff revenue functions - needed to capture the welfare impacts of tariffs in a small, open economy.

2.1 Aggregators for Expenditures and Quantities

Based on the assumptions listed above, we can define an expenditure function for each of the sub-utility functions used in the analysis. Let e_i be the expenditure function for commodity group i:

$$e_i = e_i \left(\mathbf{p}_i, u_i^0\right) \tag{4}$$

where p_i is the vector of domestic price for goods in set i and ${u_i}^0$ is the utility level associated with consumption of goods in set i. Like Bach and Martin [2001], we define the tariff aggregator for expenditure on commodity group i as the uniform tariff, ${\tau_i}^e$, which requires the same level of expenditure on imported commodities in the group as the observed vector of tariffs to maintain sub-utility level ${u_i}^0$. Anderson [2008] terms this aggregator the true average tariff. Since we are assuming homotheticity of the aggregator function, $e_i = p_i.u_i$ where p_i is the price of the composite good, and u_i the volume of its consumption aggregated at domestic prices.

We can define the tariff aggregator for expenditure on commodity group j as the uniform tariff τ_i^e:

$$\tau_i^e = \left[\tau_i^e \mid e_i \left(p_i^d, p_i^w \left(1+\tau_i^e\right), u_i^0\right) = e_i \left(p_i^d, p_i^t, u_i^0\right)\right] \tag{5}$$

Since the commodity aggregators that we use are defined only over traded goods, we can use homogeneity of degree one of the expenditure function in prices to solve for ${\tau_i}^e$, obtaining, $\tau_i^e = e_i(p_i^d, p_i^t, u_i^0)/e_i(p_i^d, p_i^w, u_i^0) - 1$. Associated with this price aggregator is a quantity aggregator for domestic consumption.

2.2 Tariff revenue aggregation

Bach and Martin [2001] propose a tariff revenue aggregator defined in a similar fashion to the expenditure aggregator. A tariff revenue aggregator for commodity group i may be defined as the uniform tariff that will yield the same tariff revenue as the observed vector of disaggregated tariffs for that particular group of commodities, conditional on the utility level underlying the expenditure function and the resource endowments underlying the domestic revenue function:

$$\tau_i^R = \left[\tau_i^R \mid tr_i\left(p_i^d, p_i^w\left(1+\tau_i^R\right), p_i^w, u_i^0, v_i^0\right) = tr_i\left(p_i^t, p_i^w, u_i^0, v_i^0\right)\right] \qquad (6)$$

Manole and Martin [2005] identify a closed-form solution for this aggregator in the case where preferences are represented by a CES function and only imported goods are included in the aggregator.

Anderson [2008] uses a simpler approach of identifying the tariff revenue aggregator with the weighted average tariff. At the initial tariff, this weighted average is the same as the conventional fixed-weight average. As tariffs change, however, the weights in Anderson's aggregator are updated using the specified import demand functions. When multiplied by the value of imports at external prices, this weighted average returns the correct value of tariff revenues for any given vector of tariff rates and import demands. This approach defines a weighted average tariff for composite good i, ${\tau_i}^{wa}$. This measure should be quite similar to the tariff aggregator of Manole and Martin [2005], except that the tariff aggregator is defined with respect to the volume of domestic consumption, while the weighted average tariff is defined with respect to the volume of imports.

2.3 Global Model Solution

In a single-country model, a different tariff aggregator can be introduced into the expenditure and the tariff revenue functions without any difficulty. When this is done in a global model, however, a major difficulty arises because Walras' Law is no longer satisfied at the global level. When, for instance, a reduction in a particularly high tariff in one country results in a more rapid decline in expenditures than in tariff revenues, the country experiences a gain in welfare without there being any corresponding increase in income elsewhere.

Anderson [2008] resolved this problem ingeniously by recognizing that quantity indexes at domestic prices are different from the quantity indexes at world prices. To take account of this, he notes that expenditure on aggregate good j at domestic prices must equal expenditure on the good at border prices plus the value of the tariff. In our terminology, this means that

$$u_i(1+\tau_i^e)p^w = x_i^*(1+\tau_i^{wa})p^w \tag{7}$$

and hence

$$u_i = x_i^*(1+\tau_i^{wa})/(1+\tau_i^e) \tag{8}$$

where u_i is the quantity of aggregate i consumed in the country; x_i^* is the quantity aggregate (at world prices) exported from the rest of the world to the country of interest; and all other terms are as previously defined.

2.4 What Might we Expect?

Theory tells us a good deal about what we might expect when considering changes in a dispersed pattern of tariffs. To see this, it is useful to consider the very simple case when only one commodity is subject to a tariff, a case which provides more general insights into the implications of reforms that reduce the variance of tariffs. In this case, it is helpful to begin at an initial tariff of zero, as in the center of the horizontal axis in Figure 1. At this point, the slope of the expenditure function, e_p is equal to the quantity demanded.

If we use the traditional approach of assuming fixed weights, then the impact of tariff increases on expenditures and/or revenues increases linearly with the tariff. In reality, however, the slope of the expenditure function

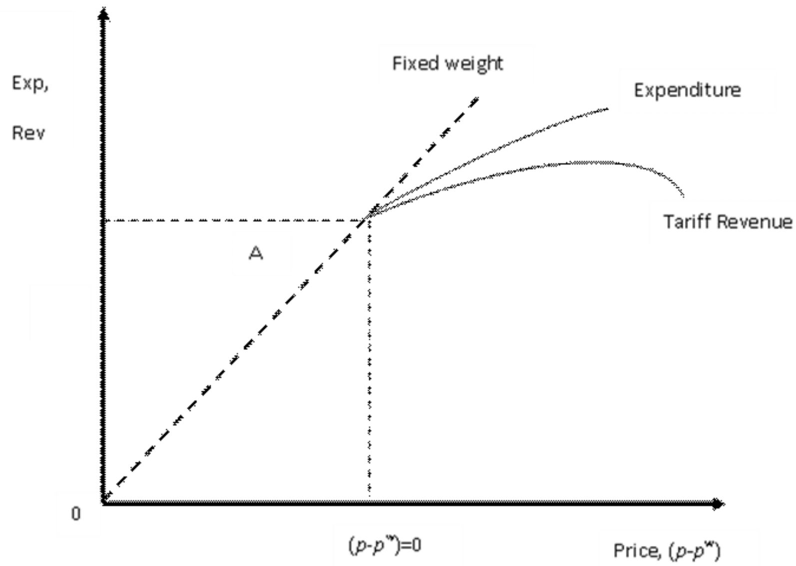

Figure 1: Impacts of a tariff on consumer expenditure and tariff revenues

declines as the tariff on this good increases (and the quantity consumed declines), as is indicated by the concave curve denoted "Expenditure". The slope of the tariff revenue aggregator is given by $e_p(p - p*)e_{pp}$, which is equal to the impact on expenditures, e_p, when the tariff is zero, but declines as the tariff rate rises. The relationships between these variables are shown in Figure 1. If we begin a reform that reduces tariffs that are initially above zero, it is clear that the reduction in the cost of expenditures will be greater than the loss of tariff revenues, a gain that is missed when using the traditional fixed-weight approach to aggregation.

Our key interest in this study is in the relationship between the expenditure and tariff revenue aggregators, and in the impact of the relationship between these two variables for national and global welfare. The expenditure aggregator is appropriate for aggregation with respect to expenditures and with respect to quantities. It therefore influences both the efficiency and - via induced effects on the terms of trade - real income effects resulting from changes in external prices.

3 Implementation

We use a two-tier strategy to implement this approach in the global CGE Linkage. First, we aggregate the tariffs outside the CGE to generate:

- the exact trade weighted tariff, τ^{wa}, that provides the right tariff revenue;
- the True Price Index, TPI, that generates the right domestic price and volume of imports.

In a second step, we modify the standard CGE equations to take into account both of these items as inputs in running the baseline and simulations.

3.1 The aggregation procedure

We first present a simple illustration based on a one level aggregation problem: HS6 products should be aggregated to the model sectoral aggregation. Then, we deal the realistic case where in the CGE both importing and exporting countries may be aggregated into regions too.

We note i the index for aggregated good, $hs6$ the index for detailed products, r the exportring country index and s the importing country index.

3.1.1 Basic case

We first illustrate our approach with a basic case where one country imports goods from only one partner.

Assuming CES, we have the price index at domestic price of imported goods equal to (countries index are dropped):

$$P = \left(\sum_{hs6} \alpha_{hs6}^{\sigma} (pcif_{hs6} \times (1 + t_{hs6}))^{1-\sigma} \right)^{\frac{1}{1-\sigma}} \tag{9}$$

t_{hs6} is the ad valorem tariff for the product $hs6$ at a bilateral level. In addition with endogenous world prices as well as CIF costs, we need to assume that the evolution of the CIF price, $pcif_{hs6}$, for each variety (origin) of a detailed product (HS6) follows the evolution of the CIF price of the sectoral aggregate. Thanks to the homotheticity assumption, we can still solve the aggregation issue outside the CGE.

We define $pcif_{hs6} = PCIF_i \ \forall hs6 \in i$.

$$P = PCIF_i \times \left(\sum_{hs6} \alpha_{hs6}^{\sigma} (1 + t_{hs6})^{1-\sigma} \right)^{\frac{1}{1-\sigma}} \tag{10}$$

We note with a 0 exponent, the initial values and with a 1 exponent the final values. For calibration purpose, we assume that $P^0 = PCIF_i$, $pcif_{hs6}^0 = PCIF_i \ \forall hs6$ at the initial time and thus:

$$\begin{aligned} \alpha_{hs6} &= \frac{pcif_{hs6}^0}{P^0} \times (1 + t_{hs6}^0) \left(\frac{\frac{trade_{hs6,r,s}^0}{pcif_{hs6}^0}}{\frac{V_i}{P^0}} \right)^{\frac{1}{\sigma}} \\ &= (1 + t_{hs6}^0) \left(\frac{trade_{hs6,r,s}^0}{V_i^0} \right)^{\frac{1}{\sigma}} \end{aligned} \tag{11}$$

with $x_{hs6} = trade_{hs6,r,s}^0$ and $V_i = \sum_{hs6} (1 + t_{hs6}^0) trade_{hs6,r,s}^0$ the aggregated domestic value for sector i.

Finally, we have

$$
\begin{aligned}
P^0 &= PCIF_i^0 \times \left(\sum_{hs6} (1+t_{hs6}^0)^{\sigma} \left(\frac{trade_{hs6,r,s}^0}{V_i^0} \right) (1+t_{hs6}^0)^{1-\sigma} \right)^{\frac{1}{1-\sigma}} \\
&= PCIF_i^0 \times \underbrace{\left(\sum_{hs6} \left(\frac{trade_{hs6,r,s}^0 (1+t_{hs6}^0)}{V_i^0} \right) \right)^{\frac{1}{1-\sigma}}}_{=TPI^0=1} \qquad (12) \\
&= PCIF_i^0 \\
P^1 &= PCIF_i^1 \times \underbrace{\left(\sum_{hs6} \left(\frac{1+t_{hs6}^0}{1+t_{hs6}^1} \right)^{\sigma} \left(\frac{trade_{hs6,r,s}^0}{V_i^0} \right) (1+t_{hs6}^1) \right)^{\frac{1}{1-\sigma}}}_{TPI^1} \qquad (13)
\end{aligned}
$$

It is obvious that we can compute what TPI using an aggregation module based on the MAcMApHS6 database (Laborde [2008]) and the tariff experiment. No input from the CGE is needed.

3.1.2 The exact trade weighted average

As noted above, if we are using the weighted average approach for tariff revenues, we also need to compute trade weighted tariffs using ex-post trade weights:

$$
\tau_1^{wa}(i,r,s) = \frac{\sum_{hs6 \in i} trade_{hs6,r,s}^1 \times t_{hs6,r,s}^1}{\sum_{hs6 \in i} trade_{hs6,r,s}^{1.}} \qquad (14)
$$

Since we assume that $pcif_{hs6} = PCIF_i \ \forall hs6 \in i$, we can omit this price, and its evolution, from both numerator and denominator. We just need to compute the evolution of quantities from the final consumer:

$$
\begin{aligned}
\tau_0^{wa}(i,r,s) &= \frac{\sum_{hs6 \in i} x_{hs6,r,s}^0 \times t_{hs6,r,s}^0}{\sum_{hs6 \in i} x_{hs6,r,s}^{0.}} \qquad (15) \\
\tau_1^{wa}(i,r,s) &= \frac{\sum_{hs6 \in i} x_{hs6,r,s}^1 \times t_{hs6,r,s}^1}{\sum_{hs6 \in i} x_{hs6,r,s}^{1.}} \qquad (16)
\end{aligned}
$$

Based on the CES preferences, we know that:

$$
\begin{aligned}
x_{hs6} &= \frac{\alpha_{hs6}^{\sigma}\left(pcif_{hs6}(1+t_{hs6})\right)^{-\sigma}}{\sum_{hs6}\alpha_{hs6}^{\sigma}\left(pcif_{hs6}(1+t_{hs6})\right)^{1-\sigma}} V_i \\
&= \frac{\alpha_{hs6}^{\sigma}(1+t_{hs6})^{-\sigma}}{\sum_{hs6}\alpha_{hs6}^{\sigma}(1+t_{hs6})^{1-\sigma}} V_i \qquad (17)
\end{aligned}
$$

In particular:

$$
\begin{aligned}
x_{hs6}^{0} &= \frac{\alpha_{hs6}^{\sigma}(1+t_{hs6}^{0})^{-\sigma}}{\sum_{hs6}\alpha_{hs6}^{\sigma}(1+t_{hs6}^{0})^{1-\sigma}} V_i^{0} \qquad (18) \\
x_{hs6}^{1} &= \frac{\alpha_{hs6}^{\sigma}(1+t_{hs6}^{1})^{-\sigma}}{\sum_{hs6}\alpha_{hs6}^{\sigma}(1+t_{hs6}^{1})^{1-\sigma}} V_i^{1} \qquad (19)
\end{aligned}
$$

And

$$
\begin{aligned}
\tau_0^{wa}(i,r,s) &= \frac{\sum_{hs6\in i}\alpha_{hs6}^{\sigma}(1+t_{hs6}^{0})^{-\sigma}\times t_{hs6,r,s}^{0}}{\sum_{hs6\in i}\alpha_{hs6}^{\sigma}(1+t_{hs6}^{0})^{-\sigma}} \\
&= \frac{\sum_{hs6\in i} trade_{hs6,r,s}^{0}\times t_{hs6,r,s}^{0}}{\sum_{hs6\in i} trade_{hs6,r,s}^{0}} \qquad (20) \\
\tau_1^{wa}(i,r,s) &= \frac{\sum_{hs6\in i}\alpha_{hs6}^{\sigma}(1+t_{hs6}^{1})^{-\sigma}\times t_{hs6,r,s}^{1}}{\sum_{hs6\in i}\alpha_{hs6}^{\sigma}(1+t_{hs6}^{1})^{-\sigma}} \\
&= \frac{\sum_{hs6\in i}(\frac{1+t_{hs6}^{0}}{1+t_{hs6}^{1}})^{\sigma} trade_{hs6,r,s}^{0}\times t_{hs6,r,s}^{1}}{\sum_{hs6\in i}(\frac{1+t_{hs6}^{0}}{1+t_{hs6}^{1}})^{\sigma} trade_{hs6,r,s}^{0}} \qquad (21)
\end{aligned}
$$

Once again, this value can be computed in an aggregation module independently of the CGE. It is important to notice that it requires solution of a partial equilibrium at the tariff line level for the whole dataset to determine the new trade pattern.

3.2 Extension

In an actual application, it is important to notice that the geographical dimension may also include regional aggregation. Therefore, a one-level

CES across products will lead to substitution across products, importers and exporters. We need to implement a nested structure for the aggregation procedure. As noted previously, we rely on separable and homothetic preferences.

3.2.1 Structure

At the first level, we assume Cobb Douglas preferences accross importers (countries $n \in s$):

$$
\begin{aligned}
M(i,r,s) &= \prod_{n \in S} M\_1_{i,r,n}^{\gamma_{i,r,n}} && (22)\\
P(i,r,s) &= \prod_{n \in S} \left(\frac{P\_1_{i,r,n}}{\gamma_{i,r,n}}\right)^{\gamma_{i,r,n}} && (23)\\
\gamma_{i,r,n} &= \frac{P\_1_{i,r,n} \times M\_1_{i,r,n}}{M(i,r,s) \times P(i,r,s)} && (24)\\
M\_1_{i,r,n} &= \gamma_{i,r,n} \frac{M(i,r,s) \times P(i,r,s)}{P\_1_{i,r,n}} && (25)
\end{aligned}
$$

At the second level, we assume CES preferences accross HS6 products ($hs6 \in i$)

$$
\begin{aligned}
P\_1_{i,r,n} &= \left(\sum_{hs6 \in i} \beta_{hs6,r,n}^{\sigma_1} \times P\_2_{hs6,r,n}^{1-\sigma_1}\right)^{\frac{1}{1-\sigma_1}} && (26)\\
M\_1_{i,r,n} &= \left(\sum_{m \in r} \beta_{hs6,r,n} \times M\_2_{i,r,n}^{\frac{\sigma_1 - 1}{\sigma_1}}\right)^{\frac{\sigma_1}{\sigma_1 - 1}} && (27)\\
\beta_{hs6,r,n} &= \left(\frac{M\_2_{i,r,n}^0}{M\_1_{i,r,n}^0}\right)^{1/\sigma_1} \frac{P\_2_{hs6,r,n}^0}{P\_1_{hs6,r,n}^0} && (28)\\
M\_2_{i,r,n} &= \beta_{hs6,r,n}^{\sigma_1} \left(\frac{P\_1_{i,r,n}}{P\_2_{hs6,r,n}}\right)^{\sigma_1} M\_1_{i,r,n} && (29)
\end{aligned}
$$

At the third level, we assume CES preferences accross exporters ($m \in r$)

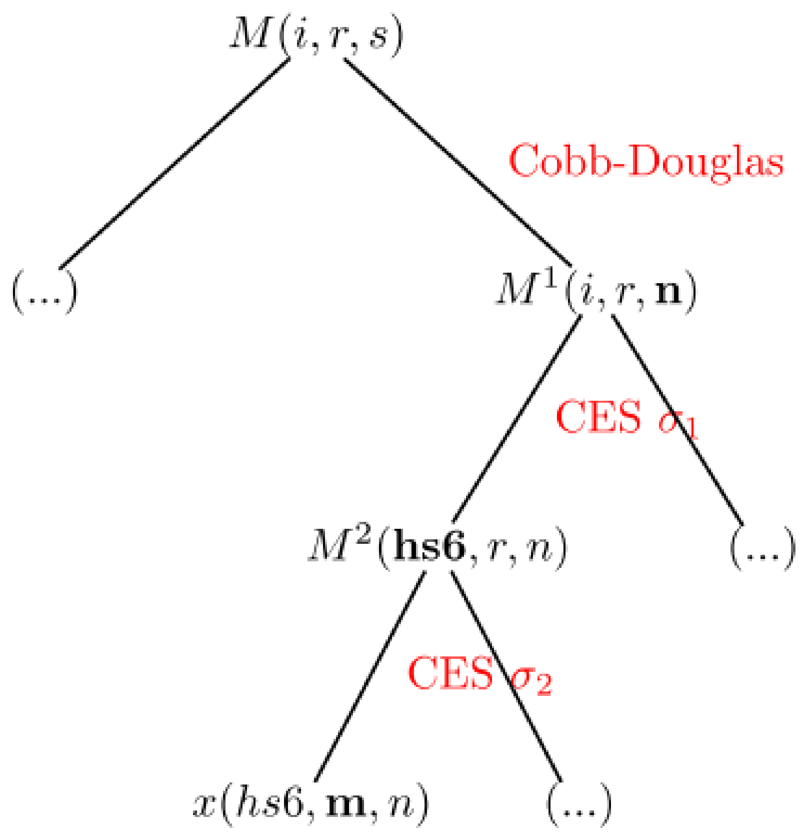

Figure 2: Nested structure

$$P\_2_{hs6,r,n} = \left(\sum_{m\in r} \alpha_{hs6,m,n}^{\sigma_2} \times ((1+t_{hs6,m,n}) \times pcif_{hs6,m,n})^{1-\sigma_2}\right)^{\frac{1}{1-\sigma_2}} \quad (30)$$

$$M\_2_{i,r,n} = \left(\sum_{m\in r} \alpha_{hs6,m,n} \times x_{hs6,m,n}^{\frac{\sigma_2-1}{\sigma_2}}\right)^{\frac{\sigma_2}{\sigma_2-1}} \quad (31)$$

$$\alpha_{hs6,m,n} = \left(\frac{x^0_{hs6,m,n}}{M\_2^0_{i,r,n}}\right)^{1/\sigma_2} \frac{(1+t^0_{hs6,m,n}) \times pcif^0_{hs6,m,n}}{P\_2^0_{hs6,r,n}} \quad (32)$$

$$x_{hs6,m,n} = \alpha^{\sigma_2}_{hs6,m,n} \left(\frac{P\_2_{hs6,r,n}}{(1+t_{hs6,m,n}) \times pcif_{hs6,m,n}}\right)^{\sigma_2} M\_2_{i,r,n} \quad (33)$$

At the initial point, we assume $pcif^0_{hs6,m,n} = 1$, $P\_2^0_{hs6,r,n} = 1$, $P\_1^0_{i,r,n} = 1$, $P^0(i,r,s) = 1$.During a simulation, we have $\frac{pcif^1_{hs6,m,n}}{pcif^0_{hs6,m,n}} = \frac{PCIF^1_{i,r,s}}{PCIF^0_{i,r,s}}$.

$$\alpha_{hs6,m,n} = (1+t^0_{hs6,m,n}) \left(\frac{trade^0_{hs6,m,n}}{\sum_{m\in r}(1+t^0_{hs6,m,n})trade^0_{hs6,m,n}}\right)^{1/\sigma_2} \quad (34)$$

$$\beta_{hs6,r,n} = \left(\frac{\sum_{m\in r}(1+t^0_{hs6,m,n})trade^0_{hs6,m,n}}{\sum_{m\in r,hs6\in i}(1+t^0_{hs6,m,n})trade^0_{hs6,m,n}}\right)^{1/\sigma_1} \quad (35)$$

$$\gamma_{i,r,n} = \frac{\sum_{m\in r,hs6\in i}(1+t^0_{hs6,m,n})trade^0_{hs6,m,n}}{\sum_{m\in r,hs6\in i,n\in s}(1+t^0_{hs6,m,n})trade^0_{hs6,m,n}} \quad (36)$$

3.2.2 New indicators

$$P(i,r,s) = PCIF_{i,r,s} \prod_{n\in S} \left(\sum_{hs6\in i} \left(\sum_{m\in r} \gamma_n^{\sigma_2-1} \times \beta_{hs6,r,n}^{\frac{1-\sigma_2}{1-\sigma_1}\sigma_1} \times \alpha^{\sigma_2}_{hs6,m,n} \times ((1+t_{hs6,m,n}))^{1-\sigma_2}\right)^{\frac{1-\sigma_1}{1-\sigma_2}}\right)^{\frac{\gamma_{i,r,n}}{1-\sigma_1}} \quad (37)$$

Average tariff rate is given by

$$
\begin{aligned}
\tau_1^{wa}(i,r,s) &= \frac{\sum_{m\in r, hs6\in i, n\in S} x_{hs6,m,n} t^1_{hs6,m,n}}{\sum_{m\in r, hs6\in i, n\in S} x_{hs6,m,n}} \\
&= \frac{\sum_{m\in r, hs6\in i, n\in S} x_{hs6,m,n} t^1_{hs6,m,n}}{\sum_{m\in r, hs6\in i, n\in S} x_{hs6,m,n}} \\
&= \frac{\sum_{m\in r, hs6\in i, n\in S} \begin{pmatrix} \sum_{hs6\in i}\left(\sum_{m\in r}\alpha^{\sigma_2}_{hs6,m,n}\times(1+t_{hs6,m,n})^{\frac{\sigma_1\sigma_2-\sigma_1}{\sigma_2-\sigma_1}}\right)^{\frac{\sigma_2-\sigma_1}{\sigma_2-1}} \\ \left(\sum_{m\in r}\beta_{hs6,r,n}^{-\sigma_1\frac{1-\sigma_2}{1-\sigma_1}}\times\alpha^{\sigma_2}_{hs6,m,n}\times((1+t_{hs6,m,n}))^{1-\sigma_2}\right)^{\frac{1-\sigma_1}{1-\sigma_2}} \end{pmatrix}^{-1} \times\gamma_{i,r,n}\alpha^{\sigma_2}_{hs6,m,n}\beta^{\sigma_1}_{hs6,r,n}\times t^1_{hs6,m,n}}{\sum_{m\in r, hs6\in i, n\in S} \begin{pmatrix} \sum_{hs6\in i}\left(\sum_{m\in r}\alpha^{\sigma_2}_{hs6,m,n}\times(1+t_{hs6,m,n})^{\frac{\sigma_1\sigma_2-\sigma_1}{\sigma_2-\sigma_1}}\right)^{\frac{\sigma_2-\sigma_1}{\sigma_2-1}} \\ \left(\sum_{m\in r}\beta_{hs6,r,n}^{-\sigma_1\frac{1-\sigma_2}{1-\sigma_1}}\times\alpha^{\sigma_2}_{hs6,m,n}\times((1+t_{hs6,m,n}))^{1-\sigma_2}\right)^{\frac{1-\sigma_1}{1-\sigma_2}} \end{pmatrix}^{-1} \times\gamma_{i,r,n}\alpha^{\sigma_2}_{hs6,m,n}\beta^{\sigma_1}_{hs6,r,n}}
\end{aligned} \tag{38}
$$

Parameters

In our application, we have to choose values for σ_1 and σ_2:

- σ_1 should be sector i specific and negatively correlated with the HS6 heterogeneity within the sector i;
- σ_2 should also be sector i specific, and negatively correlated with the geographical differentiation of products.

Due to the lack of estimates for these parameters, we have decided to take $\sigma_1 = 2$ in our core scenario. For $\sigma_{2,}$ we use σ_1 plus two time the elasticity of substitution[3] across imported varieties in the CGE.

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Equations 39 to 41 are the standard equations related to the Armington assumption in the Linkage model. WTF_r represents the import demand

[3] σ in equation 39

from region r (dropping the index for the importing country and the sector index). XMT is the aggregate level of import (from all regions), with a price of PMT. PM_r is the domestic price of imports that is equal to the landed (CIF) price from region r plus the domestic tariff, τ_r. Equation 39 is the standard CES function for import demand by region of origin where XMT is determined somewhere else. Equation 40 is the standard price equation for aggregate imports. And equation 41 represents the domestic price of imports from region r.

$$WTF_r = \alpha_r XMT \left(\frac{PMT}{PM_r}\right)^{\sigma} \tag{39}$$

$$PMT = \sum_r PM_r WTF_r / XMT = \left[\sum_r \alpha_r PM_r^{1-\sigma}\right]^{1/(1-\sigma)} \tag{40}$$

$$PM_r = (1+\tau_r)\, WPM_r \tag{41}$$

When we introduce the consistent aggregator methodology, the model with the consistent aggregator takes the following form:

$$WTF_r^a = \alpha_r XMT \left(\frac{PMT}{PM_r^a}\right)^{\sigma} \tag{42}$$

$$PMT = \sum_r PM_r^a WTF_r^a / XMT = \left[\sum_r \alpha_r (PM_r^a)^{1-\sigma}\right]^{1/(1-\sigma)} \tag{43}$$

$$PM_r^a WTF_r^a = PM_r WTF_r \tag{44}$$

$$PM_r^a = TPI_r\, WPM_r \tag{45}$$

$$PM_r = (1+\tau_r)\, WPM_r \tag{46}$$

Equation 39 is modified in equation 42 to take into account the new domestic price PM_r^a, defined as the CIF price multiplied by the True Price Index TPI_r to define the domestic quantity index WTF_r^a. At the same time, we check with equation 44 that imports at domestic prices using the TPI have the same value that in the case of the trade weighted average tariff. Tariff revenue is given by $\tau_r WPM_r WTF_r$. As explained previously, both $TPI_r$and τ_r are exogenous variables for the CGE generated by the aggregation procedure. The calibration procedure is also modified accordingly.

Combining equations 44 to 46, we find the equivalent of equation 8:

$$\frac{WTF_r^a}{WTF_r} = \frac{(1+\tau_r)}{TPI_r} \tag{47}$$

Because the TPI will be reduced by the a larger proportion than the trade weighted average, the liberalization effect will be magnified on the domestic volume due to the distortions reduction at domestic prices.

4 An illustration

In our initial experiment, we focus on global liberalization. To implement this simulation, we first calculate the TPI and the associated True Average Tariff for each sector used in the model, and the weighted average tariff. Because the shares used to weight the trade-weighted-average decline with the height of the tariff on any particular good, we would expect the trade-weighted average tariff to be lower than the True Average Tariff. Examples of these estimates are presented in Table 1 for five countries of interest.

Table 1: Tariff aggregators—the True Average Tariff and the Weighted Average Tariff

	Bangladesh		EU		USA		India		Japan	
	TAT	TW	TAT	TW	TAT	TW	TAT	TW	TAT	TW
	%	%	%	%	%	%	%	%	%	%
Beverages and Tobacco	32.5	32.5	16.2	5.0	1.8	1.4	49.2	17.6	41.4	35.5
Capital Goods	18.6	17.3	0.9	0.8	2.4	2.1	4.7	4.2	0.8	0.7
Chemicals rubber and plastics	17.8	17.0	0.8	0.7	4.9	4.4	4.6	4.2	1.3	1.2
Fossil fuels	28.3	27.3	0.1	0.1	0.4	0.4	1.0	0.9	0.5	0.5
Other grains	6.0	5.8	40.0	7.6	0.1	0.1	0.9	0.9	53.9	36.1
Iron and steel	9.8	9.0	0.0	0.0	0.2	0.2	4.5	4.1	0.5	0.5
Leather	9.6	7.4	2.0	1.6	7.5	6.6	2.2	2.0	13.1	12.6
Livestock	13.2	12.6	0.8	0.6	0.2	0.2	2.2	2.2	9.1	4.6
Dairy products	32.3	32.3	20.1	2.5	21.9	15.6	4.2	4.1	77.7	62.0
Motor vehicles and parts	20.4	20.0	0.8	0.6	0.6	0.6	14.6	12.5	0.0	0.0
Other crops	20.7	17.8	48.1	2.7	8.7	4.0	5.6	5.5	9.9	1.6
Other food	26.1	24.7	2.5	1.6	3.5	2.8	6.3	5.5	9.2	7.5
Other manufacturing	21.5	20.4	0.2	0.2	0.7	0.7	5.3	5.0	0.4	0.4
Other natural resources	10.9	9.1	1.0	0.9	0.0	0.0	4.6	4.3	3.4	3.2
Oil seeds	11.5	11.0	0.0	0.0	26.7	2.2	0.4	0.4	0.2	0.1
Plant-based fibers	0.5	0.4	0.0	0.0	10.7	9.6	0.0	0.0	0.0	0.0
Processed meats	19.3	17.3	53.5	9.4	9.9	6.8	3.8	3.8	89.7	71.9
Rice	21.8	21.4	109.9	56.6	4.0	3.8	18.1	17.5	450.9	425.0
Sugar	29.7	29.6	71.7	30.8	134.6	51.0	35.1	32.7	278.6	214.9
Services	22.5	22.5	0.0	0.0	0.0	0.0	1.9	1.8	0.0	0.0
Textile	25.8	25.3	1.0	0.9	4.4	3.9	6.3	6.1	129.6	84.1
Vegetables and fruits	15.3	13.1	30.3	5.3	0.5	0.4	2.8	2.8	5.7	5.5
Vegetable oils and fats	17.2	15.1	6.9	2.0	1.5	1.3	0.3	0.3	2.3	1.8
Wearing apparel	32.1	32.1	2.4	1.9	7.1	6.4	9.8	9.2	11.3	11.3
Average	19.3	18.4	17.0	5.5	10.5	5.2	7.9	6.1	49.6	40.9

The entries in Table 1 highlight some important points. The first is that the True Average Tariff is consistently (weakly) above the weighted average tariff. The final row of the table presents the simple average of the aggregates presented above[4] shows that the margin of difference between the two measures is particularly large for industrial countries such as the EU and the USA, where the average tariff is low, but the dispersion of tariffs is typically much higher (relative to the mean) than in developing countries.

Results

The results are presented in Table 2. The first column of the table shows the results obtained using a standard version of the model with conventional weighted average tariffs. The second shows the results obtained using the consistent aggregation approach with an assumed elasticity of substitution between tariff lines within each group and region of 2.0.

The average increase in the estimated welfare impacts is 41 percent at the global level. However, the effect of using consistent aggregation techniques varies a great deal from one country or region to another, reflecting the fact that the aggregators affect welfare gains both through efficiency and terms-of-trade impacts. Somewhat surprisingly, the gains are relatively small in proportional terms for many of the industrial countries, despite the large coefficient of variation of their tariffs noted above.

The gains are much larger for developing countries than for the industrial countries. For the industrial countries, the average increase in the measured welfare impact is about 20 percent while, for developing countries as a group, the corresponding gain is 100 percent. One troubling feature of the results is that the estimated welfare gains are much larger for regional aggregates than for individual countries - clearly this requires further investigation.

[4] A true aggregate across these commodity groups would ideally be used. This simple average is used purely for illustrative convenience.

Table 2: Real income impacts in 2025 relative to baseline, USD2004 billion

	Standard	**Consistent**
World total	*495.8*	*696.4*
Australia and New Zealand	16.1	16.8
EFTA	20.0	31.4
EU 27	135.3	174.6
United States	47.8	53.4
Canada	7.3	8.5
Japan	52.0	62.7
Korea and Taiwan	77.1	97.1
Hong Kong and Singapore	28.7	29.1
Chile	2.2	2.1
Bangladesh	-0.5	0.1
Brazil	21.7	30.6
China	-21.4	-15.2
Egypt	1.2	9.7
India	18.9	23.2
Nigeria	3.0	5.4
Pakistan	4.1	4.6
Indonesia	2.8	3.7
Thailand	6.6	7.6
Mexico	5.7	9.7
SACU	3.8	13.6
Turkey	8.2	11.1
Rest of Asia	6.8	22.2
Rest of LAC	11.8	17.9
Rest of the World	26.4	61.3
Morocco and Tunisia	3.5	5.8
Rest of Sub Saharan Africa	6.4	9.3
High income countries	*384.4*	*473.5*
Quad plus ANZ	*278.6*	*347.3*
Other high income countries	*105.8*	*126.2*
WTO developing countries	*217.2*	*349.1*
Low and middle income countries	*111.4*	*222.9*
Middle income countries	*72.6*	*158.1*
Low income countries	*38.7*	*64.9*
Low & middle income excl China and India	*109.8*	*201.5*
Low income excl India	*19.9*	*41.7*
Middle income excl China	*90.0*	*159.8*
Selected LDC countries	*12.7*	*31.6*
Latin America and the Caribbean	*41.5*	*60.3*
Sub Saharan Africa	*13.2*	*28.3*

5 Conclusions

In this study, we apply the consistent aggregation technique developed by Anderson [2008] to the assessment of global trade reform. This technique employs the broad approach to aggregation developed by Bach and Martin [2001] to deal with the problem of aggregation when protection rates vary substantially within the groups used in the analysis. It uses the technique developed by Anderson [2008] to allow this approach to be applied to a global model, rather than only to a single-country model as in earlier applications. This ingenious technique restores global market clearing by taking into account the fact that quantity aggregates at domestic prices differ from quantity aggregates at international prices.

We apply the technique in a modified version of the LINKAGE global general equilibrium model, taking into account the nested structure of import demand in that model. Using this aggregation procedure with a conservative estimate of the elasticity of substitution between six-digit tariff lines results in a substantial increase in the estimated welfare gains from complete liberalization of global trade barriers.

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