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Is the Devil in the Details?: Assessing the Welfare Implications of Agricultural and Non Agricultural Trade Reforms

by

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Abstract

The use of traditional trade-weighted average tariffs biases the estimated welfare benefits of trade reform downwards through averaging distortions and use trade weight bias. Decomposition of total tariff variation suggests that over half the variation in EU agricultural tariffs is lost in standard models, a loss compounded by weighting bias. The Bach-Martin aggregation procedure is used to avoid this loss of information in an analysis of EU and Indonesian tariff reform. The results increase the estimated global benefits of EU agricultural trade reform by over 150%. Inappropriate aggregation may be causing very substantial underestimation of the global gains from agricultural trade reform. For Indonesia, the underestimation of the benefits using a weighted average approach is much more serious for nonagricultural products, where the variation in tariffs within groups is more important.

Is the Devil in the Details?: Assessing the Welfare Implications of Agricultural and Nonagricultural Trade Reforms

1. Introduction

Tariffs vary a great deal across commodities, and this variation in tariffs is known to have major implications for the costs of protection. Variation in tariffs is particularly serious in the industrial countries, where the variation of tariffs is typically higher, relative to average tariffs, than in developing countries (Hoekman and Olarreaga 2001). However, when economists turn to assessing the implications of trade reforms, they typically undertake a great deal of aggregation before evaluating the welfare impacts of reform—typically reducing the detailed information available for thousands of tariff lines to perhaps 20 or 30 aggregate commodities used in a standard computable general equilibrium model analysis. As is frequently the case in trade policy, the devil may be in the details. We may have been greatly underestimating the welfare costs of protection by aggregating away the detailed information available at the tariff-line level.

These problems are particularly intense in agricultural trade policy, because agricultural trade policies frequently involve highly variable rates of protection once the protective impacts of specific tariffs are taken into account. Further, some current proposals, such as those made under the Doha Agenda by the Cairns Group and the United States, involve very large reductions in the mean and the variance of protection rates. These reductions would involve sharp reductions in the variability of tariffs within categories, as well as across them, and their impacts are likely to be poorly estimated using only aggregated data.

Numerous studies have experimented with changing the level of aggregation in their models, and many have found that higher degrees of disaggregation provide higher estimates of the welfare gains from liberalization. However, there are serious limits on this approach to assessing the implications of disaggregation. In the context of computable general equilibrium models, it is not feasible to exceed the degree of

disaggregation available in the input-output tables available for the analysis—perhaps 60 or 100 sectors, or 500 at most. This limit is typically greatly reduced by computational constraints, particularly when modeling is undertaken at a global level. An alternative would be to proceed with a model that allows a high degree of disaggregation of trade flows, but without a structural representation of production systems of the type provided by a computable general equilibrium model. However, this is not attractive in that it wastes critically important information about economic structure, such as the information about inter-industry product flows and final demand patterns contained in computable general equilibrium models.

There are strong reasons to expect that the resulting high levels of aggregation may substantially reduce the measured welfare benefits of trade reform. Working in a single-country context, Bach, Martin and Stevens (1996) concluded that the welfare implications of China's trade liberalization in the context of WTO Accession were roughly doubled if appropriate aggregators were used to take into account the implications of variations in tariffs. Bach and Martin (2001) subsequently outlined an approach to aggregation that could be used in a global modeling context.

In this paper, we apply the proposed approach to two regions where detailed data on tariffs are available—the EU and Indonesia. The EU is an interesting case because its submission to the WTO's Integrated Database includes the *ad valorem* equivalents of its agricultural tariffs, and because its agricultural tariffs are high and variable. Indonesia, by contrast, has relatively low and uniform agricultural tariffs. For nonagricultural tariffs, Indonesia's tariffs are high and variable and the EU has low tariffs.

The objective of this paper is to assess the extent to which using index-based approaches in the spirit of the Anderson-Neary Trade Restrictiveness Index (Anderson and Neary 1996) can help deal with the problems created by the necessary evil of aggregation when evaluating the welfare consequences of trade reform. In the next section of the paper, we provide some intuition into the nature of the problem. Then, we outline a potential solution, and discuss issues arising in its implementation. In the fourth section, we

present estimates of the aggregators needed to analyze the problem for two focus countries. In the fifth section, we present some results from implementation of the approach. Finally, we give some conclusions.

2. *The Nature of the Problem*

When we aggregate tariffs or any other price distortions using standard fixed-weight aggregation procedures, we lose potentially important information about their effects. This information loss has two distinct sources—an averaging problem and a weighting problem. The <u>averaging problem</u> follows from the fact that the costs of tariff distortions are related to the square of the tariff rate, and averaging two or more tariffs and taking the square of this average will underestimate the welfare impacts of the two distortions. the <u>weighting problem</u> arises when we use average tariffs based on fixed weights, as is invariably done in models used to evaluate policy reforms, we add another source of underestimation of the welfare effects—systematic underestimation of the weights on higher protection rates.

<u>The Averaging Problem</u>

We use a simple graphical approach to illustrate the averaging problem. Figure 1 shows a second-order approximation to the welfare costs of two different tariff rates. In the figure, the excess demand for imports is denoted by z_p , where z is the net expenditure function. This function is defined as $z=e(\mathbf{p},u) - r(\mathbf{p},\mathbf{v})$ in where $e(\mathbf{p},u)$ is the expenditure function of the representative household or a given vector of domestic prices, $\mathbf{p}$, and domestic utility,u, and $r(\mathbf{p},v)$ is the domestic revenue from production for prices $\mathbf{p}$, and a vector of productive resources, $\mathbf{v}$. By Shephard's Lemma, the first derivative of this function with respect to the domestic price of the good under consideration, $z_{\mathbf{p}}$, equals the compensated demand for imports of that good. Its second derivative with respect to prices, z_{pp} , gives the slope of this demand curve with respect to its own price.

Figure 1. Implications of aggregating two tariffs.
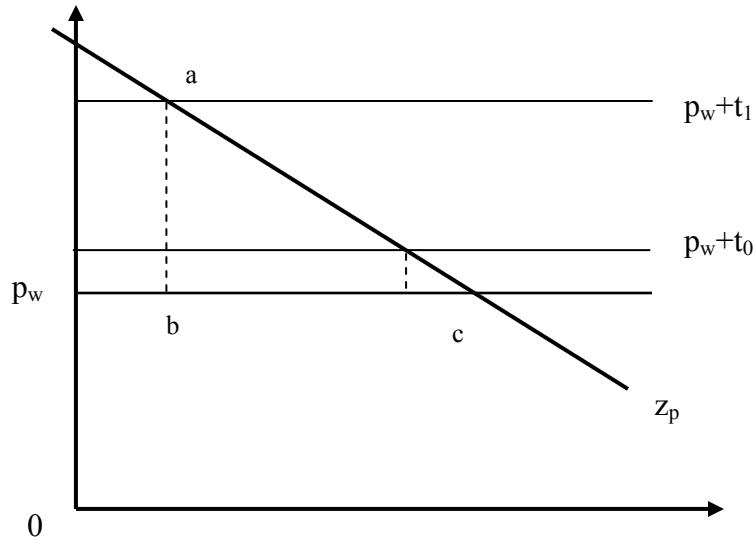
The welfare cost of each tariff is given by the conventional Marshallian welfare triangle, $\frac{1}{2} z_{pp} t^2$, where $t = (p - p^w)$. This cost is represented by the triangle abc for tariff t_1 . Comparison of this triangle with the corresponding triangle associated with t_0 shows that the cost of a tariff rises more than proportionately with the level of the tariff.

To illustrate the potentially serious implications of aggregation for welfare we first consider an extremely simple numerical example. For simplicity, we express the tariffs in *ad valorem* form, and specify the slope of the excess demand curve in terms of an import demand elasticity, η, so that the welfare triangle is given by $\frac{1}{2}.\eta.\tau^2$ where τ is the proportional equivalent of the tariff. If we consider proportional tariffs of 0.1 and 1 (ie 10 percent and 100 percent); an initial value of imports for each commodity of 100 ; and an elasticity of import demand equal to unity, then their welfare costs of each tariff are:
For $\tau_0 = 0.1$

$$\Delta W_0 = \frac{1}{2}.(0.1)^2.100 = 0.5$$

For Tariff $\tau_1 = 1$
$$\Delta W_1 = \frac{1}{2}.1^2.100 = 50$$

The average cost of the two tariffs would therefore be 25.25.

If, by contrast, we try to represent the effects of the two tariffs by taking their average, and then calculating the welfare impact t, we obtain:

$\Delta W_a = $ ½.$(0.55)^2$.100 $= 15.125$.

As is evident, aggregating the two tariffs before calculating the welfare impacts leads to a very substantial underestimation of the welfare consequences of the tariff. In this simple case, the result is underestimation of the welfare costs by more than 40 percent. The proportional degree of underestimation of the welfare impacts does not depend upon the elasticity of demand, although the absolute welfare impact would, of course, be higher if the elasticity were larger.

Clearly, we can generalize these stylized calculations to situations where there are many tariffs. If we maintain the assumption of equal elasticities, and equal pre-tariff import values, V, then the average welfare cost of n independent tariffs would be :

(1)
$$\Delta W = \frac{1}{n}\left(\frac{1}{2}\eta \cdot V \cdot \sum_{i=1}^{n}\tau^2\right)$$

We show in Appendix 1 that, as long as tariffs differ between products, the average welfare losses associated with these tariffs will exceed the welfare losses estimated at the average tariff.

We can use the logic of Analysis of Variance to obtain a useful decomposition of equation (1) into the square of the mean tariff and the deviations of individual tariffs about the mean. Using $\bar{\tau}$ to indicate the mean tariff, this expansion of equation (1) yields:

(2)
$$\Delta W = \frac{1}{2}\eta \cdot V\left[\frac{1}{n}\sum_{i=1}^{n}\left(\tau - \bar{\tau}\right)^2 + \bar{\tau}^2\right]$$

Equation (2) provides a convenient decomposition of the second moment of the tariff regime about the origin that will give an initial indication of the likely extent of error involved in using a single average tariff as a basis for estimates of the cost of a tariff regime. Clearly, equation (2) implies that aggregation will do little harm if the variation of the tariff about the mean is small. If, by contrast, the variation about the mean is large, then the welfare costs of a tariff regime are likely to be substantially under-estimated, as they were in our stylized example above.

In most modeling work, the tariff regime is analyzed using a number of aggregates, rather than simply the mean tariff. This increases the amount of the variation in tariffs captured, by including variations between groups as well as the squared mean of the tariff. Equation (2) can be generalized to this case by using tariff averages for different sub-groups of tariffs. Where m commodity aggregates are formed, each containing n_i individual tariff lines, and n is the total number of tariff lines, equation (2) can be generalized to:

$$(3) \qquad \Delta W = \frac{1}{2}\eta \cdot V\left[\frac{1}{n}\sum_{i=1}^{m}\sum_{j=1}^{n_i}(\tau_{ij} - \overline{\tau}_i)^2 + \sum_{i=1}^{m}\frac{n_i}{n}(\overline{\tau}_i - \overline{\tau})^2 + \overline{\tau}^2\right]$$

Equation (3) provides a potentially useful decomposition of the factors likely to determine the degree of underestimation of average welfare impacts associated with use of commodity aggregates. Analysis based on aggregates will capture the final term in equation (3) in the overall average tariff, and the second term, involving the variation of the commodity group means about the overall mean. However, it will not capture the effects of variations in tariffs within the commodity groups. If the commodity groups are sufficiently homogeneous, then most of the variation in tariffs will be captured by the variation between the aggregated groups of commodities. If, on the other hand, most of the variation in tariffs is within the commodity aggregates, then there will be potentially serious underestimation of the welfare implications of trade reform. Equation (3), modified to deal with different numbers of tariff lines in each commodity group, can provide at least a rough guide to the amount of variation missing when using particular approaches to tariff aggregation.

For a concrete example, we decomposed the agricultural and nonagricultural tariffs of EU and Indonesia, using the commodity aggregates (based on GTAP commodity groups) utilized in the this year's *Global Economic Prospects*. From table 1, looking at agricultural tariffs, it appears that, for the EU, use of a single average tariff would capture only 34% of the total sum of squares relevant to the welfare cost evaluation. For Indonesia, where the variation of tariffs about the mean is much greater, it would capture 68% of the sum of squares. Using the 10 agricultural commodity groups included in the model increases the amount of variation captured by including the variation between commodity groups. However, at least in these two cases, the increase in the sum of squares captured is relatively small—12% in the case of the EU, and 6% in Indonesia. In the case of European agricultural tariffs, more than half the variation remains within the commodity groups.

For nonagricultural tariffs, for both regions, use of a single tariff will capture around half of the total sum of squares relevant to the welfare cost evaluation. Using the 13 nonagricultural commodity groups increases the amount of variation captured by including the variation between commodity groups – 20% for the EU and 12% in Indonesia. For Indonesian nonagricultural tariffs, more than one third of the variation remains within the commodity groups.

Table 1. Decomposition of the second moments about zero of tariffs

	Region	Within - group variation	Between - group variation	Overall average	Total
		%	%	%	%
Agricultural	EU	54	12	34	100
tariffs	Indonesia	26	6	68	100
Nonagricultural	EU	26	20	54	100
tariffs	Indonesia	36	12	52	100

An obvious concern with this decomposition is that it ignores the interactions between tariffs. An increase in the tariff on one good creates a negative welfare impact in its own market. However, if this good has substitutes that are also subject to tariffs, there may be positive effect through increased tariff revenues in these markets (Martin 1997). These effects can be illustrated graphically for the effect of tariff t_2 on the market for good one in a simple, partial equilibrium diagram:

Figure 2. Impacts of tariff 2 on the market for good 1.
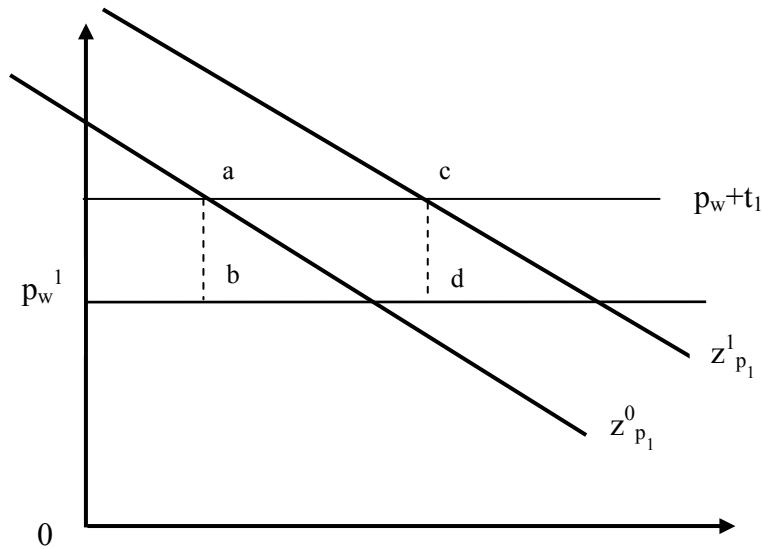
When the tariff on good 2 is raised, the excess demand for good 1 increases, because consumers shift their demands from good 2 to good 1, and because producers shift resources from good 1 to good 2. The outward shift in the excess demand curve for good 1, from $z^0_{p_1}$ to $z^1_{p_1}$, increases imports of good 1. The increase in imports increases welfare since the value of the additional units of the good to the countries is given by their tariff-inclusive price, while their cost to the economy is given by the world price. The additional revenue accrues to the government and may have an even higher social value if the marginal costs of government funds exceed unity (see Anderson and Martin 2003).

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The interactions between markets can, in principle, be taken into account by extending the welfare framework outlined above. This requires a generalization to take into account the interactions between markets. A second-order approximation to the costs of the trade regime becomes the quadratic form:

(4) $\Delta W = \frac{1}{2} \mathbf{t}' \mathbf{z}_{PP} \mathbf{t}$

where $\mathbf{t}$ is the vector of tariffs and $\mathbf{z_{pp}}$ is the matrix of compensated own and cross price effects of tariff changes on the demand for imports. the matrix $\mathbf{z_{pp}}$ is negative semi-definite by the concavity of the underlying expenditure and the convexity of the profit function. Thus, ΔW is negative for any well-behaved technology and positive tariff vector. However, it is less obvious to us how equation (4) might be used to form a simple, practical indicator of the amount of variation in tariffs captured in a given aggregation scheme.

The decomposition implied by equation (3) is inherently very simplistic in that it rests on the assumption that the free-trade value of imports for each commodity would be the same. While a serious problem, it should not be overstated. The same problem arises with simple tariff averages, which continue to be widely used as summary indicators of the restrictiveness of tariff policies.

The Weighting Problem

When we use fixed-weight indicators, a critical question is the choice of weights. If we use initial weights, as in Laspeyres price indexes, then the weights are likely to overstate the impact of price changes. If we use final-period price changes, such as Paasche price indexes, then the effects of price changes are likely to be understated. In considering tariff changes, we typically have no choice but to use indexes weighted by trade weights that reflect the impacts of existing distortions. As noted by Anderson and Neary (1996), trade-weighted tariffs have major deficiencies when some tariffs are prohibitive or near-prohibitive. High tariffs are typically associated with low trade values, and prohibitive tariffs are equivalent to zero tariffs in their effect on the weighted average tariff.

If, for instance, we are considering the effect of a tariff on the expenditure needed to maintain a given level of utility, then the impact is given by the concave function in Figure 1. As the tariff rises from zero, the expenditure on the good increases-- assuming it is in inelastic demand-- but expenditure rises at a lower rate than would be implied by the Leontief demand structure that underlies the fixed-weight index. The slope of the expenditure function, e_p , declines as the quantity demanded, which is also e_p , declines. Clearly, use of the expenditure weight obtained from a situation where a non-zero tariff is in place will underestimate the overall impact of the introduction of the tariff on the value of the expenditure function.

One might attempt to solve this problem by estimating the average slope of the expenditure function over the range from t=0 to the value of interest. However, estimating such parameters effectively involves specifying a complete model of the economy, and solving it for the interdependent changes in quantities associated with changes in trade regimes. Once such a model is available, a better approach is probably to solve it directly for the variables of interest.

Figure 3. Impacts of a tariff increase on consumer expenditure

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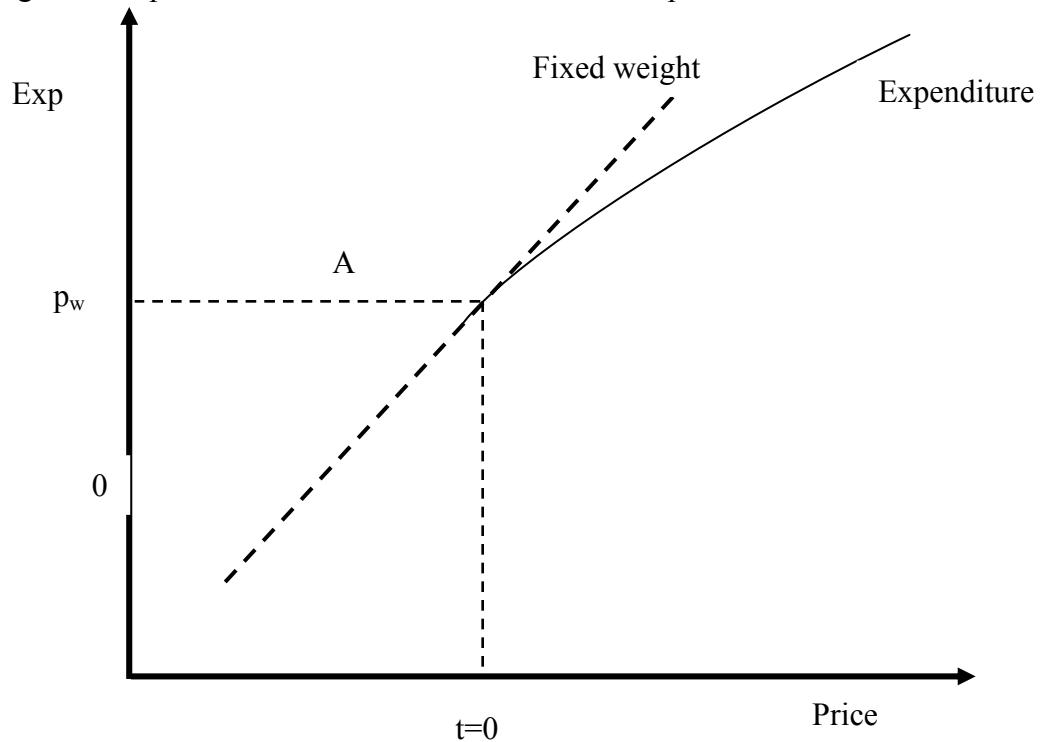
3. The Optimal Aggregation Approach

We proceed in the spirit of the Anderson-Neary Trade Restrictiveness Index, where exact aggregators are specified in a way that captures all of the relevant aspects of variations across tariffs. However, we do not attempt to solve in one step for a single index of the welfare costs of protection. Instead, we use a two-step approach. In the first step, we obtain indexes that summarize the information about tariffs within groups. Then, in the second step, we use this information in a higher level model. This approach lets us take advantage of the multi-sectoral economic models without suffering from the disadvantages, in terms of modeling both economic behavior and estimating welfare generally associated with the aggregation required for the use of such models.

Following Bach and Martin (2001), we begin with a general representation of a competitive, small open economy in two equations:

The income-expenditure condition,

$$(5) \qquad e(\mathbf{p}, u) - r(\mathbf{p}, \mathbf{v}) - (\mathbf{e_p} - \mathbf{r_p})'(\mathbf{p} - \mathbf{p}^w) - f = 0$$

and the vector of behavioral equations,

$$(6) \qquad \mathbf{e_p}(\mathbf{p}, u) - \mathbf{r_p}(\mathbf{p}, \mathbf{v}) = \mathbf{m}$$

where all variables except $\mathbf{m}$ and f are as previously defined. Variable $\mathbf{m}$ is a vector of imports, and f is the net financial inflow from abroad. I

The Balance-of-trade function (Anderson and Neary 1996) can be derived from equation (5) by reclassifying the level of utility as exogenous and introducing a new variable, B, to measure the hypothetical financial inflow required to maintain a specified level of utility, u^0 in the face of a change in $\mathbf{p}$.

$$(7) \qquad B(\mathbf{p}, u^0) = e(\mathbf{p}, u^0) - r(\mathbf{p}, \mathbf{v}) - (\mathbf{e_p} - \mathbf{r_p})(\mathbf{p} - \mathbf{p}^w) - f$$

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.

Economic theory provides guidelines for the construction of consistent aggregates. Deaton and Muellbauer (1980, pp. 122-30) show that weak separability allows the decomposition of the consumer's problem into the maximization of sub-utility functions over elements of each commodity group, and maximization of total utility over the sub-utility 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. On the production side, Chambers (1988) and Lloyd (1994) discuss a range of conditions that allow aggregation of the production technology. One such condition is that the production function be weakly separable, and the sub-aggregator functions are homothetic (Chambers 1988).

In the remainder of the theoretical discussion, we will assume that the conditions needed for the formation of sub-aggregate price and quantity indexes have been satisfied, and focus on the construction and use of these indexes. These conditions put restrictions on the matrix z_{pp} of equation (4) required to make analysis feasible. While strong, these assumptions are implicit in *any* use of two stage modeling approaches. Particularly, they are implicit in the ubiquitous use of fixed-weight aggregators in computable general equilibrium modeling. Thus, we are relaxing, rather than making more restrictive, the conditions generally used in current modeling approaches.

Most applications of the Anderson-Neary Balance-of-Trade approach have used a model of the entire economy to obtain a single index of the Balance-of-Trade. Our objective is to use a two-level approach that allows us to extend the single-level models based on aggregate data that are currently used for policy analysis. To do this, we need at least two different types of aggregator. The first type is optimal for decisions regarding

expenditure levels and the demands for consumption goods (and producer inputs if these are specified in the profit function). The second type is optimal for aggregating tariffs in estimating tariff revenues.

Our expenditure aggregator is like the widely-used consumer price index (CPI) in that it is intended to provide an estimate of the impact on welfare of a uniform change in all prices equivalent to a disparate set of price changes. Unlike the fixed-weight CPI, however, we use the properties of the expenditure function to capture the impacts of changes in prices on the expenditures required to achieve a specified level of utility. Under our maintained assumption of homotheticity of the utility function at the lower level, it also allows the formation of quantity aggregates—aggregates that are essential to making valid inferences about terms of trade effects.

3.1   *The expenditure function aggregator*

Under the two-stage budgeting approach, an expenditure function exists for each of the sub-utility functions used in the analysis. The expenditure function for commodity group j may be defined as:

(7) $$e_j(\mathbf{p}_j, u_j^0) = e_j(\mathbf{p_j^d}, \mathbf{p_j}, u_j^0)$$

where $\mathbf{p_j^d}$ is a vector of domestically produced goods not subject to tariffs that provide the numeraire. If we focus on the impact of tariffs on the cost to consumers of achieving a particular level of utility, the tariff aggregator for expenditure on this group can then be defined as the uniform tariff, τ_j^e, that requires the same level of expenditure on imported commodities in the group as the observed vector of tariffs to maintain utility level u_j^0,

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

3.2   *Tariff revenue aggregator*

For the last part of equation (5), the tariff revenue term, we can proceed in the same manner as for the expenditure function. A tariff revenue aggregator for good j, t may be

defined as the uniform tariff that will yield the same tariff revenue as the observed vector of tariffs for that group of commodities:

(9) $$\tau_j^R = [\,\tau_j^R \mid tr_j(\mathbf{p_j}^w(1+\tau_j^R),\ \mathbf{p_j}^w,\ u_j^0,v_j^0) = tr_j(\mathbf{p_j},\ \mathbf{p_j}^w,\ u_j^0,\ v_j^0)]$$

4   Calculating the Aggregators

Aggregation of domestic and imported goods, and imported goods from different sources is undertaken using a Constant Elasticity of Substitution (CES) functions in the LINKAGE model used in this analysis. For consistency with the model we can formulate the expenditure and tariff revenue functions using a Constant-Elasticity of Substitution functional form for the expenditure function and the import demand functions that underlie the tariff revenue function. Since we undertake no aggregation on the output side, and use the same CES aggregator for final demand and intermediate-input demand, we need only an expenditure and a tariff revenue function for composite good j:

$$10\ (a)\quad e_j = \left(\beta_j^d p_j^d + \sum_i \beta_{ij}(p_{ij})^{1-\sigma} \right)^{\frac{1}{1-\sigma}} u_j^0$$

$$10\ (b)\quad tr_j = \sum_i \beta_{ij}\left(\frac{p_j}{p_{ij}} \right)^{\sigma} (p_{ij} - p_{ij}^W)u_j^0$$

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

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

As Bach and Martin (2001) have shown, there is a closed-form solution for the expenditure aggregator. The expenditure index, τ^e, can be estimated by setting the value of the expenditure function 10(a) to the expenditure function with a uniform tariff and

solving for that uniform tariff. With all domestic prices equal to 1 in the base equilibrium, the uniform tariff equivalent in the expenditure case has the closed-form solution:

$$
(11) \qquad \tau^{e} = \left(\frac{1 - \beta^{d}}{\sum_{i=1}^{n} \beta_{i}(p_{i}^{w})^{1-\sigma}} \right)^{\frac{1}{1-\sigma}} - 1
$$

The tariff revenue index, τ^{R}, can be obtained by setting the tariff revenue function (10 b) equal to the corresponding expression with a uniform tariff, and solving for τ^{R}. This is similar to solving :

$$
(12) \qquad c = h(\tau^{R})
$$

where $h : R^{+} \to R^{+}$, $h(t) = t(1+t)^{-\sigma} \left[\beta^{d} + (1+t)^{1-\sigma} \sum_{i=1}^{n} \beta_{i}(p_{i}^{W})^{1-\sigma} \right]^{\frac{\sigma}{1-\sigma}}$ and c depends on

β and disaggregated tariffs. As τ^{R} cannot be factored out of (12), it must be estimated numerically.

5   *Properties of the aggregators*

The definitions given in equations (8) and (9) do not guarantee existence, uniqueness or economic meaning . This raises particular concerns these aggregators are to be generated on a routine basis using trade analysis software like the World Bank's WITS program. The closed-form equation for the expenditure index in the CES case guarantees existence and uniqueness, so the only question is whether the solution has economic meaning. We show that it is positive and so has economic significance. For the tariff revenue aggregator, we show that there are likely to be two solutions, and define the conditions needed to ensure that the estimated index is the economically relevant one.

Proposition 1. In the context of Formula 11, for $\sigma > 1$, the closed form solution for the expenditure aggregator, τ^{e}, is positive.

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Proof: In the context of the formula 11 and with the domestic prices set to 1 in the base equilibrium, world prices are $p_i^W = \dfrac{1}{1+\tau_i}$ and we notice that

$$\sum_{i=1}^{n} \beta_i (p_i^w)^{1-\sigma} = \sum_{i=1}^{n} \beta_i (1+\tau_i)^{\sigma-1} > \sum_{i=1}^{n} \beta_i \quad \text{because } \sigma > 1 \text{ (we assume that there is at least}$$

one positive tariff). As the denominator is $1 - \beta^d = \sum_{i=1}^{n} \beta_i$, the fraction is less than 1. With a negative power, the expression is greater than one, so the tariff revenue index is positive.

The situation is more complex with τ^R. We may or may not have existence and, if there is solution, the solution may not be unique.

Proposition 2. In the context of Equation 12, for certain values of parameter c, there are at least two solutions to the equation.

Proof: We sketch the ideas here, for a more detailed exposition, see Appendix 1. Analyzing the equation (12), we notice that the function h(t) is a continuous and positive function with h(0)=0, $\lim_{t\to\infty} h(t) = 0$ and has a maximum on its domain and it reaches this maximum at M. For any tariffs, imports and domestic consumption such that c<M we may apply the intermediate value property and find at least two solutions.

To better understand this, consider Figure 4:

Figure 4. Uniform tariff solutions for constant tariff revenue
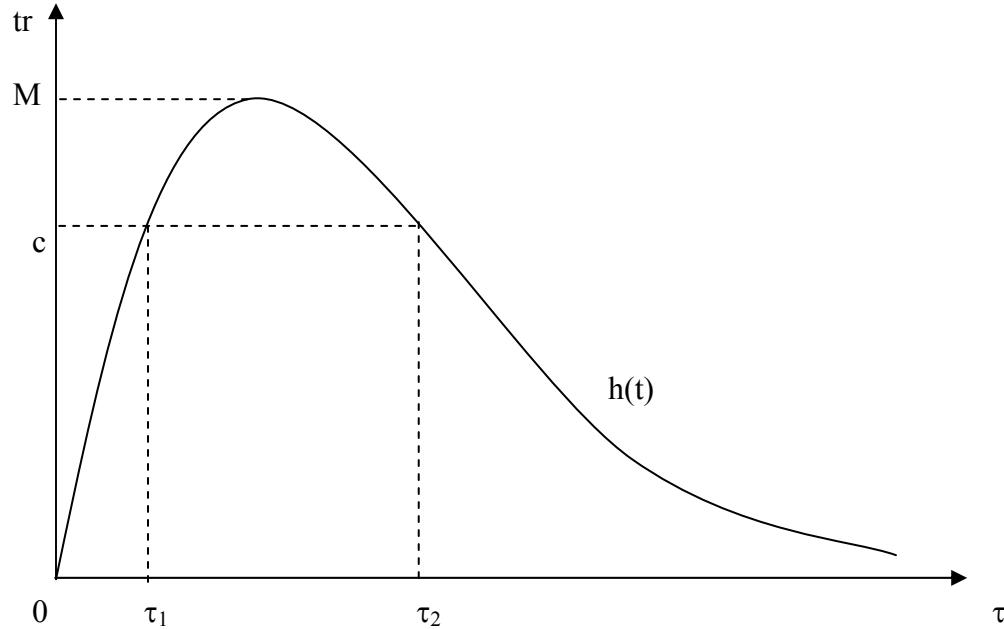
Figure 4 is the (in)famous Laffer Curve for tariff revenues. As tariff rates rise, tariff revenues increase until some point, like M, where they begin to decline because the reductions in import volumes associated with increased tariffs outweigh the revenue gains. If c<M, there are two values τ_1 and τ_2 such that $c=h(\tau_1)=h(\tau_2)$. However, only one of these tariff rates is in the economically relevant range. No well-informed government would set tariff rates beyond the revenue-maximizing level. Assuming that the objective is to keep tariff revenue constant and assuming economic rationality, we use the lowest uniform tariff that keeps tariff revenue constant. This aggregator has the property that tariff revenues are increasing in this range.

6   *Implementing the Aggregators*

For a single, small economy, the aggregators outlined above can simply be incorporated into the relevant parts of an economic model and the model solved to obtain the outcomes for quantities, revenues and welfare. There is an important issue as to whether the welfare implications should simply be inferred as money-metric equivalents of observed changes in utility, or whether they should be assessed using a compensation approach.

Anderson and Martin (2003) show that there are likely to be substantial differences between the two approaches when the supply of labor is responsive to change in income levels, but these differences are generally much smaller when, as in the present case, the aggregate supply of labor is not price responsive. Therefore, we follow the usual practice for models of this type and calculate welfare using the money metric approach.

A key constraint in the context of global general equilibrium modeling is the need to have a single aggregator throughout the model. If, a different aggregator is used in the tariff revenue function from that used in other parts of the model, Walras' Law will not be satisfied, and the model will not solve. The approach that we adopt to overcome this problem is to use the expenditure aggregator throughout the global model—including in the tariff revenue terms. This allows us to solve the global general equilibrium model, albeit by generating a tariff revenue term that does not exactly match actual tariff revenues even in the original equilibrium. The model does, however, accurately capture the price and quantity levels and impacts that are crucial to the operation of the model.

To obtain correct estimates of changes in tariff revenues, and in welfare, we add an additional term, outside the model, to capture the difference between the true tariff revenue and that estimated by the tariff revenue terms based on the expenditure aggregators.

$$(15) \quad \boldsymbol{B} = e(\tau^e, p^w, u) \ - r(\tau^r, p^w, v) \ - tr(\tau^e, \tau^r, p^w, u, v) - (tr(\tau^R, p^w, u, v) + tr(\tau^e, \tau^r, p^w, u, v))$$

The effect of using equation (15) is to adjust the welfare evaluation term by the difference between tariff revenues with the appropriate aggregator, and the tariff revenues derived using the aggregators which must be used, for consistency with Walras' Law and for appropriate aggregation of quantities, throughout the global model. The additional information obtained from the lower level of aggregation is effectively passed up to the more aggregated model to obtain an overall assessment of the welfare impact of the change. This adjustment is made only to the country reforming its own tariffs, since it reflects efficiency gains within the economy, rather than gains that will accrue to other countries, such as those arising from terms of trade changes. As previously noted, terms-

of-trade gains are best captured using the expenditure-based aggregators incorporated into the global model.

The expenditure aggregators for the model can be calculated using equation (15) with tariff rates and information on market shares (at domestic prices) for each good. A different aggregator was calculated for each supplying region because we have available information on differences in the composition of imports from each region, which allows us to include real-world differences in tariff rates for each supplier even when tariff-line level tariffs are the same across suppliers. Since we have no corresponding information on the composition of domestically-produced goods, we simply enforced the same share value share for the domestic good within each group.

Calculation of the tariff revenue based aggregator for the model is much less straightforward. Since utility is being held at the level in the aggregate model while product-group prices, and hence quantity aggregates, are changing, we need to reproduce the behavior of a large number of model equations when solving for the tariff revenue aggregators. The steps taken in this operation are reported in Appendix 2.

The tariff aggregators calculated for the European Union and for Indonesia are presented in Table 2 together with the trade-weighted averages for the same groups. In virtually all cases, the expenditure-based tariff indexes are above the standard trade-weighted averages. In most cases, the tariff revenue aggregators are higher again, although there are many exceptions to this pattern. The expenditure-based deal with the weighting problem discussed in section 2, and resolving this problem unambiguously raises the value of the index. The lack of a consistent pattern between the tariff-revenue based indexes and the weighted average is perhaps because the behavior of this index is more closely related to the averaging problem discussed in section 2, and hence more subject to specific interactions between tariffs. Averaging over all the categories (using a simple average), we find that the expenditure-based tariff index for agricultural products in the

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EU is, at 45.9%, more than 10 percentage points above the traditional weighted average. The tariff-revenue based index is substantially higher again, at 62.1 percent. For nonagricultural products in Indonesia, the expenditure based tariff index is 14.1%, almost 4 percentage points above the weighted average and comparable with the tariff revenue index, 13.6%.

Table 2. Comparing weighted average tariffs with the expenditure and revenue aggregators ($1997 millions)

	European Union			Indonesia		
	Weighted Average	Expenditure based Tariff Index	Tariff Revenue based Tariff Index	Weighted Average	Expenditure based Tariff Index	Tariff Revenue based Tariff Index
Rice	56.9	58.1	62.1	1.0	1.1	1.0
Wheat	67.7	71.1	74.3	0.0	0.0	0.0
Other grains	50.4	62.2	76.5	0.2	0.2	0.2
Oil seeds	0.0	0.0	0.0	8.8	11.8	8.0
Sugar	55.7	62.9	71.0	9.9	9.9	9.9
Other crops	15.1	48.8	154.8	3.3	4.3	3.2
Livestock	3.3	9.6	2.5	0.6	0.8	0.6
Other natural resources	0.0	0.0	0.0	2.5	2.8	2.4
Fossil fuels	0.1	0.1	0.1	0.1	0.1	0.1
Processed meats	44.4	63.2	84.4	11.4	13.2	10.4
Dairy products	48.4	68.5	88.0	8.3	12.5	7.6
Other foods	9.6	14.9	7.4	8.1	9.6	7.5
Textile	9.2	9.5	9.1	17.5	19.9	15.9
Wearing apparel	11.7	11.9	11.3	34.3	35.9	36.9
Leather	7.1	8.4	6.4	5.0	7.8	4.4
Refined oil	3.4	3.5	3.4	4.3	4.4	4.3
Chemicals rubber and plastics	4.0	4.2	4.0	6.7	7.8	6.5
Iron and steel	2.0	2.1	2.0	6.6	8.8	6.3
Motor vehicles and parts	7.4	8.0	6.5	30.3	59.6	72.9
Electronic equipment	1.1	1.4	1.1	10.0	12.5	9.4
Other machinery	1.7	1.8	1.7	8.6	11.1	8.5
Other manufacturing	2.2	2.4	2.2	9.6	13.0	8.4
Utilities	0.0	0.0	0.0	0.1	0.1	0.1
Simple average of above	17.5	22.3	29.1	8.1	10.7	9.8
Simple average of above agricultural	35.1	45.9	62.1	5.1	6.3	4.8
Simple average of above nonagricultural	4.0	4.1	3.7	10.4	14.1	13.6

Our simulation results given in Tables 3(a) and 3(b) indicate the real income impacts (equivalent variation) from full removal of tariffs in the agriculture sectors,

respectively nonagricultural sectors, by the European Union and Indonesia (individually), with no reciprocity. The impacts of the reforms are simulated using the World Bank's standard LINKAGE model in a comparative static framework.[1] The Armington elasticities are double those used in the standard GTAP model.

Four reform simulations are undertaken—one for each region—under a different set of assumptions regarding the base year tariff rates. The first simulation uses tariff rates aggregated from the 8-digit HS level using import weights. The second uses a different aggregation function—also using the same 8-digit HS information—designed to overcome the downward bias of using trade-weights and is a better reflection of the welfare impacts.

Columns 1,3 and 5 of Tables 3(a) and 3(b) reflect the impacts of European trade reforms. The first column shows the income impact of using import-weighted average tariffs. The third column shows the impact using the expenditure-based tariff aggregator function. And the fifth column shows the percent difference. Overall, for agricultural products, the first reform leads to a global gain of some $27 billion, of which about one-half accrues to the European Union. Using the expenditure-based aggregator yields global income gains of $54 billion, a 100 percent increase over the import-weighted average tariff. For nonagricultural products, there is not a significant difference on the measurements of gains from the trade reform for the EU.

The estimated welfare loss to the EU from cutting nonagricultural tariffs reflects a combination of second-best effects resulting from lowering tariffs that are below those in agriculture, and terms of trade losses when other countries do not reduce their nonagricultural protection. Moving to the expenditure-based measure exacerbates the second-best effect by widening the gap between agricultural and nonagricultural barriers, and the terms of trade effect by increasing the magnitude of Europe's nonagricultural distortions. When increased own-market efficiency effects from lowering European protection are factored in, the end result is very little change in the estimated welfare loss.

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[1] The results are to be interpreted as medium-term impacts, i.e. after all adjustments, but without taking into consideration dynamic effects.

This loss is, however, reduced, when the tariff aggregator is factored in, and the loss is reduced by $1.5 billion.

The results for Indonesian reforms are presented in columns 2, 4, and 6. For agricultural products, the elimination of protection yields quite small income gains—even for Indonesia, though they are somewhat higher when using the expenditure-based tariff aggregator. Use of the weighted average tariff results in an estimated loss of $534 million for Indonesia while use of the expenditure-based index will result in a gain of $468 million.

The numbers in parentheses beside the welfare gains using the expenditure-based aggregator are the total gains when the tariff revenue impacts are adjusted using the tariff revenue aggregator in the EU and Indonesia. For agricultural products, in Europe, the impact of these reforms is to add an additional welfare gain of $12.2 billion per year. In Indonesia, the effect is to add an additional $67 million per year. For nonagricultural products in Europe, adding this term additional welfare gain of $1.5 billion per year. In Indonesia, the effect is to add an additional $1.2 billion per year.

Table 3(a): Impact of agricultural tariff reform using different tariff aggregators

	Weighted average tariffs		Expenditure index tariffs		Percent difference	
	EU tariff reform	Indonesia tariff reform	EU tariff reform	Indonesia tariff reform	EU tariff reform	Indonesia tariff reform
	($1997 millions)					
OECD Cairns countries	2,229	17	3,486	21	56	28
European Union with EFTA	13,205	6	27,932 (40,972)	11	112	96
United States	543	46	1,382	60	155	31
Japan	-702	18	-1,129	22	61	20
High income Asia ag producers	-139	5	-228	6	64	15
High income Asia city states	54	2	125	3	133	36
Brazil	1,363	10	2,775	12	104	18
China	-164	-5	-290	-7	77	34
India	188	12	349	15	85	20
Indonesia	188	20	418	23 (90)	122	13
Russia	591	0	1,038	0	76	339
México	276	-1	501	-1	82	20
SACU	353	0	658	1	87	47
Vietnam	48	1	127	2	165	24
Rest of South Asia	98	1	165	2	68	25
Rest of East Asia	521	39	825	44	58	14
Rest of LAC	3,444	3	6,329	4	84	25
EU accession countries	1,589	0	2,642	1	66	29
Rest of ECA	530	1	1,324	1	150	25
Middle East	954	-3	1,809	-3	90	-4
North Africa	482	0	896	0	86	10
Rest of Sub Saharan Africa	971	2	1,820	2	87	39
Rest of the World	393	1	656	1	67	33
Total	27,017	177	53,610	220	98	24

[*] Numbers in parenthesis refer to the welfare gains with incorporation of the tariff aggregation.

Table 3(b): Impact of nonagricultural tariff reform using different tariff aggregators

	Weighted average tariffs		Expenditure index tariffs		Percent difference	
	EU tariff reform	Indonesia tariff reform	EU tariff reform	Indonesia tariff reform	EU tariff reform	Indonesia tariff reform
	($1997 millions)					
OECD Cairns countries	479	37	520	47	9	28
European Union with EFTA	**-11,368**	484	**-12,889 (-11360)**	619	13	28
United States	2,132	353	2,347	419	10	19
Japan	2,237	649	2,481	825	11	27
High income Asia ag producers	1,179	330	1,307	432	11	31
High income Asia city states	446	28	474	36	6	31
Brazil	352	11	396	16	12	41
China	1,861	-84	1,926	-102	3	21
India	913	-10	954	-10	5	4
Indonesia	331	**-534**	376	**468 (1727)**	14	-188
Russia	721	-17	759	-23	5	31
México	183	-8	199	-11	8	32
SACU	219	1	238	1	9	69
Vietnam	269	-3	293	-3	9	7
Rest of South Asia	626	-12	644	-14	3	14
Rest of East Asia	593	42	644	44	9	5
Rest of LAC	298	-28	332	-33	11	21
EU accession countries	3,034	-2	3,283	-2	8	18
Rest of ECA	1,358	-8	1,437	-8	6	12
Middle East	824	-51	883	-74	7	47
North Africa	1,024	-7	1,074	-10	5	43
Rest of Sub Saharan Africa	283	-3	305	-6	8	83
Rest of the World	220	1	232	11	6	1432
Total	8,214	1,169	8,216	2,620	0	124

[*] Numbers in parenthesis refer to the welfare gains with incorporation of the tariff aggregation.

7. Conclusions

In this paper, we examine the implications of the use of trade-weighted tariff averages in estimating the welfare impacts of trade reform. At the conceptual level, we find that this leads to two errors—an averaging error and a weighting error. For simple numerical examples, we show that the averaging error alone may lead to substantial underestimation of the welfare benefits of trade reform. This error is compounded by the weighting error, which reduces the weight on high tariffs below the desirable level and, in the limit, gives a zero weight to the most restrictive possible tariffs—those that prevent all trade.

We note that the magnitude of the tariff averaging problem is related to the second moments of tariffs about zero, and suggest that a decomposition of the sum of squared deviations of tariffs from zero may provide an initial screening device to indicate whether the tariff averaging problem is serious for a particular aggregation and set of policies. When tariffs are high and variable, as in EU agriculture, this decomposition suggests that over half the variation in tariffs is contained within the groups used in the widely-cited LINKAGE model of the world economy.

To deal with both the tariff averaging and tariff weighting problems while retaining the structural information contained in modern computable general equilibrium models, we use the tariff aggregation approach of Bach and Martin (2001). For the first time, we have applied this procedure in a full global equilibrium model, the LINKAGE model. This approach uses a two stage aggregation approach, where tariffs are aggregated from the tariff-line level up to the aggregates used in the computable general equilibrium (CGE) model, and then applied within the CGE model. Because it was not possible to automate the process of computing these aggregators, we have been able to analyze only two regions at this stage—the European Union and Indonesia.

We find that the tariff aggregators calculated using the expenditure function approach are considerably higher than traditional weighted average approach for both Europe and Indonesia. This reflects the fact that trade weighted averages are underestimates because the weights on high tariffs are systematically underestimated. The relationship between the tariff revenue aggregators and the weighted average was less clear, perhaps unsurprisingly since the tariff revenue terms involve cross-price effects whose sign is potentially ambiguous.

Use of the expenditure-based aggregator substantially increased the welfare impacts of agricultural trade reform in the European Union. The estimated global welfare gains doubled, from $27 billion to $54 billion per year, with $15 billion of this gain

accruing to the European Union, and the remainder distributed to other regions through improvements in their terms of trade. The adjustment made to incorporate the tariff revenue aggregator results in a further increase of $12 billion to the European Union. For Indonesia, where initial agricultural tariffs are lower and less variable, the additional gains are much smaller, although the global gains from Indonesia's agricultural reforms go up by 24 percent and the gains to Indonesia by 13 percent when the expenditure-based index is used.

For nonagricultural products, the abolition of tariffs in Indonesia yields a global gain of $1.2 billion. Using the expenditure-based tariff aggregator yields estimated global gains of $2.6 billion, almost 125% above the result with the import-weighted average tariff. Use of the weighted average tariff results in an estimated loss of $534 million for Indonesia while use of the expenditure-based index will result in a gain of $468 million. For EU nonagricultural trade reform, the global gains of $8.2 billion are similar for both aggregators, but there are major differences in the distribution of these benefits between countries.

Our analysis and results suggest that, in ignoring the important details within the distribution of protection, in almost all of our modeling work, we may have been greatly underestimating the costs of protection. This under-estimation appears to be most serious in those cases where protection is high and variable, the very cases where these costs are highest. We propose simple diagnostic procedures for evaluating when the omission of detailed information is likely to be most important for a given choice of commodity aggregates and policy regime. Finally, we demonstrate that the procedures suggested by Bach and Martin (2001) can be implemented in a global general equilibrium model. With the great increase in the availability and quality of data on protection policies, and increasing availability of analytical tools, we hope that these costs can be better estimated in the future.

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Appendix 1: Demonstration of Key Propositions

Proposition 1. We consider n tariffs t_1, t_2, ..., t_n and an average tariff t_a. The welfare cost for the n tariffs, $W_H = \sum_{i=1}^{n} W_i$ is higher than welfare cost for the average tariff, $W_A = nW_a$, $W_H \geq W_A$ and, if there is variation in tariff, the inequality is strict.

Proof: . We consider n tariffs t_1, t_2,...,t_n and the average tariff t_a. The welfare cost triangles associated with these tariffs are similar triangles (see Figure 1) and their surfaces are W_1, W_2, ... , W_n, respectively S_a. For similar triangles there is the following property: $\dfrac{t_i^2}{t_a^2} = \dfrac{W_i}{W_a}$ for every i, so $W_i = \dfrac{t_i^2}{t_a^2} W_a$. We wish to show that the welfare cost for all tariffs, $W_H = \sum_{i=1}^{n} W_i$ is higher than welfare cost for the average tariff, $W_A = nW_a$. We

$$W_H \geq W_A \iff \sum_{i=1}^{n} \frac{t_i^2}{t_a^2} W_a \geq nW_a \iff \sum_{i=1}^{n} t_i^2 \geq n \cdot t_a^2$$

have:

As $t_a = \dfrac{\sum_{i=1}^{n} t_i}{n}$, we can write the equivalence: $W_H \geq W_A \iff n \cdot \sum_{i=1}^{n} t_i^2 \geq \left(\sum_{i=1}^{n} t_i \right)^2$. Now if we

consider the Cauchy–Schwarz inequality, $\sum_{i=1}^{n} a_i^2 \cdot \sum_{i=1}^{n} b_i^2 \geq \left(\sum_{i=1}^{n} a_i b_i \right)^2$ $a_i \geq 0, b_i \geq 0$ $i = \overline{1,n}$

and take $a_i = 1$ and $b_i = t_i$ we obtain that $n \cdot \sum_{i=1}^{n} t_i^2 \geq \left(\sum_{i=1}^{n} t_i \right)^2$ and, from equivalence, that

$W_H \geq W_A$.

Observation. As a property of the Cauchy-Schwarz inequality, the equality is possible only if there is c>0 such that $b_i = c*a_i$. In our situation, $t_i = c$ for every i. In other words, if there is variation in tariffs and the average tariff is used, the welfare costs are underestimated, $W_H > W_A$.

Proposition 3. In the context of Equation 12, tariff revenue index, for $\sigma > 1$, for certain parameters, there are at least two solution to the equation.

Proof: An equivalent form for equation 12:

Equation 13

$$\frac{\sum_{i=1}^{n} \beta_i p_i^W \tau_i}{\sum_{i=1}^{n} \beta_i (p_i^W)^{1-\sigma}} = \tau^R (1+\tau^R)^{-\sigma} \left[\beta^d + (1+\tau^R)^{1-\sigma} \sum_{i=1}^{n} \beta_i (p_i^W)^{1-\sigma} \right]^{\frac{\sigma}{1-\sigma}}$$

We define the function $h: R^+ \to R^+$, $h(t) = t(1+t)^{-\sigma} \left[\beta^d + (1+t)^{1-\sigma} \sum_{i=1}^{n} \beta_i (p_i^W)^{1-\sigma} \right]^{\frac{\sigma}{1-\sigma}}$.

The function can be written *as h(t)=k(t)*m(t)*, with $k(t) = t(1+t)^{-\sigma}$ and

$m(t) = \left[\beta^d + (1+t)^{1-\sigma} \sum_{i=1}^{n} \beta_i (p_i^W)^{1-\sigma} \right]^{\frac{\sigma}{1-\sigma}}$. The function *k(t)* has the following properties:

1. *k(0)=0*

2. $\lim_{t \to \infty} \dfrac{t}{(1+t)^{\sigma}} = \lim_{t \to \infty} \dfrac{1}{\sigma(1+t)^{\sigma-1}} = 0$, where we applied l'Hospital.

3. $k'(t) = \dfrac{1-(\sigma-1)t}{(1+t)^{\sigma+1}}$, the derivative being positive for $t < \dfrac{1}{\sigma-1}$, zero for $t = \dfrac{1}{\sigma-1}$

   and negative for $t > \dfrac{1}{\sigma-1}$.

The function *k(t)* starts from zero, it is increasing until reaches the maximum in $t = \dfrac{1}{\sigma-1}$ and after that it is decreasing, converging asymptotically to zero.

The function *m(t)* has the following properties:

1. $m(0) = \left[\beta^d + \sum_{i=1}^{n} \beta_i (p_i^W)^{1-\sigma} \right]^{\frac{\sigma}{1-\sigma}}$ with *m(0)>0*. Similar with the proof of

   Proposition 2, $\beta^d + \sum_{i=1}^{n} \beta_i (p_i^W)^{1-\sigma} > 1$ so *m(0)<1*.

2. $\lim_{t \to \infty} m(t) = (\beta^d)^{\frac{\sigma}{1-\sigma}}$. As $\beta^d < 1$, $\lim_{t \to \infty} m(t) > 1$.

3. $m'(t) = \dfrac{\sigma}{1-\sigma} \left[\beta^d + (1+t)^{1-\sigma} \sum_{i=1}^{n} \beta_i (p_i^W)^{1-\sigma} \right]^{\frac{\sigma}{1-\sigma}-1} \sum_{i=1}^{n} \beta_i (p_i^W)^{1-\sigma} (1-\sigma)(1+t)^{-\sigma} > 0$,

   so *m(t)* is an increasing function.

We notice that the function h(t) is a continuous and positive function with h(0)=0,

$\lim_{t \to \infty} h(t) = 0$ and has a maximum on its domain and it reaches this maximum M. For any

tariffs, imports and domestic consumption such that $c = \dfrac{\sum_{i=1}^{n} \beta_i p_i^W \tau_i}{\sum_{i=1}^{n} \beta_i (p_i^W)^{1-\sigma}} < M$ we may

apply intermediate value property and find at least two solutions.

Appendix 2: Calculation of the Tariff Revenue Aggregator

The steps below describe the calculations for adjusting the welfare impacts of trade reform using the tariff-revenue aggregator approach. The country (region) index is dropped from all equations. The country (region) index in the equations below refers to the region of origin (i.e. the trading partner) where necessary.

1. Calculate the new set of domestic import prices, *PM*, using the tariff rate revenue index (τ^R)—i.e. the world price, *WPM*, adjusted by the alternative tariff rate. Then calculate the new aggregate import price, *PMT*, index using the CES dual price function.

$$(1) \qquad PM_{r,i} = \left(1 + \tau_{r,i}^{R}\right) WPM_{r,i}$$

$$(2) \qquad PMT_i = \left[\sum_r \beta_{r,i}^{w} \left(PM_{r,i}\right)^{1-\sigma_i^{w}}\right]^{1/(1-\sigma_i^{w})}$$

2. Calculate the new Armington price, *PA* and the consumer final demand price, *PAc*. The latter is equal to the Armington price adjusted for a sales tax.

$$(3) \qquad PA_i = \left[\beta_i^{d} PD_i^{1-\sigma_i^{m}} + \beta_i^{m} PMT_i^{1-\sigma_i^{m}}\right]^{1/(1-\sigma_i^{m})}$$

$$(4) \qquad PAc_i = \left(1 + \tau_i^{Ac}\right) PA_i$$

4. The next set of equations is needed to calculate the Hicksian compensated demand function, i.e. the demand function at the new set of import prices holding utility constant. Equation (5) calculates the expenditure function price index, *P*, and equation (6) measures utility, *u*.

$$(5) \qquad P = \exp\left[\sum_i \mu_i \ln\left(\frac{PAc_i}{\mu_i}\right) + \mu^{s} \ln\left(\frac{P^{s}}{\mu^{s}}\right)\right]$$

$$(6) \qquad u = \exp\left[\sum_i \mu_i \ln(XAc_i - \theta_i) + \mu^{s} \ln\left(\frac{S^{h}}{P^{s}}\right)\right]$$

5. This step calculates consumer's Hicksian demand for goods at the new set of prices. The consumer demand function, XAc^h, is derived from the expenditure function (see Varian). The aggregate demand for Armington goods, XA^h is equal to the standard Armington demand, plus the difference between the new consumer demand vector and the standard consumer demand vector. This explicitly assumes that there is no change in the government and investment demand generated by the change in prices.

$$(7) \qquad XAc_i^{h} = \theta_i + u.P.\frac{\mu_i}{PAc_i}$$

$$(8) \qquad XA_i^{h} = XA_i + XAc_i^{h} - XAc_i$$

6. The trade flow, WTF^h, can be derived using the double nested Armington structure.

$$(9) \quad WTF_{r,i}^{h} = \beta_{r,i}^{w} \left(\frac{PMT_i}{PM_{r,i}} \right)^{\sigma_i^{w}} \beta_i^{m} \left(\frac{PA_i}{PMT_i} \right)^{\sigma_i^{m}} XA_i^{h}$$

7. Finally, equation (10) determines the tariff revenue function.

$$(10) \quad TarY^{R} = \sum_{r} \sum_{i} \tau_{r,i}^{R} WPM_{r,i} WTF_{r,i}^{h}$$