Barriers to Trade and Comparative Advantage in Global Trade

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Abstract

Despite the accumulated knowledge about barriers to trade, debate still continues on the implications of barriers to trade on welfare and the environment. From a global perspective, barriers to trade preclude the allocation of production according to comparative advantage. Barriers to trade may have a systematic impact on the distribution of wealth among regions and possibly on the distribution of environmental degradation. For these reasons, models of global trade should include barriers to trade. This paper describes the inclusion of barriers to trade into the World Trade Model and demonstrates the implementation using several illustrative examples.

Keywords

World Trade Model; Input-output analysis; International trade; Sustainable development; Environmental impacts;

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1 Introduction

Economic theory has long been interested in barriers to trade; particularly tariffs and quotas. Despite the accumulated knowledge on barriers to trade, there is still considerable debate on the implications of barriers to trade. On an international level, barriers to trade alter the comparative advantage of production. Products are no longer produced in the region that can produce the good most efficiently relative to other goods. From this global perspective, most studies show that barriers to trade should be reduced. However, on a regional level, barriers to trade effect the distribution of wealth and possibly the environment. In this case, the political and social dimensions often make generalizations about barriers to trade difficult.

The term "barriers to trade" encompasses a variety of different barriers; some of which are unavoidable. In this paper, barriers to trade implies taxes and quotas imposed on import and export flows; however, many other barriers to trade exist. For instance, transportation is a barrier to trade, but it cannot be removed. Any model of global trade should consider the implications of transportation and its role as a barrier to trade. Other barriers to trade are difficult to quantify. For instance, slow and difficult customs regulations often act as a barrier to trade. Whilst these barriers to trade are important, they are often difficult to quantify. Often the most appropriate method of analysis is to estimate these barriers to trade in terms of equivalent tariffs or quotas. There are also some "non-intentional" tariffs. For instance, a physical capacity constraint at a port may act as an export and import quota; however, this is not usually an intentional governmental policy.

This paper shows how barriers to trade can be included into the World Trade Model (Duchin, 2005; Strømman and Duchin, 2005b). The World Trade Model was originally developed to study pathways to sustainable development. The model minimizes global resource use for an exogenous demand and given resource constraints. Currently, the World Trade Model has been applied to agriculture and trade (Juliá, 2004; Juliá and Duchin, 2005) and to the aluminum value chain (Strømman and Duchin, 2005a). The model is currently being extended with the intention of studying the dynamics of growth and resource availability.

This paper is structured as follows. The following section gives a brief review of the World Trade Model. The World Trade Model is then extended to include both tariffs and quotas. We then demonstrate the properties of the model using illustrative examples.

2 A brief description of the World Trade Model

The World Trade Model is a liner program that minimizes global production costs based on comparative advantage (Duchin, 2005). Each region has a distinct technology and distinct factor constraints. The model framework can be applied to m regions, n goods, and k factors of production. The model has been extended to include bilateral trade flows and transportation costs (Strømman and Duchin, 2005b). The model equations are briefly introduced here and the reader is encourage to refer to Duchin (2005) and Strømman and Duchin (2005b) for further elaboration on the model.

2.1 Model equations

The World Trade Model minimizes global factor costs,

$$\min_{x_i} \qquad \sum_i \pi_i' F_i x_i \tag{1}$$

where x_i is the vector of outputs of each good in each region i, F_i is a matrix of factor use intensities, and π_i is the factor price (wage) in each region. For more details on the notation see Table 1.

In each region production must meet regional demand,

$$(I - A_i)x_i \geq y_i + \sum_{j \neq i} e_{ij} - \sum_{j \neq i} (I - T_{ji})e_{ji} \qquad \text{for all } i \tag{2}$$

where A_i are the interindustry Leontief production coefficients in each region, y_i is the consumer demand in each region, e_{ij} is the export from region i to region j, and T_{ji} is the transportation requirement instigated by the importing region. Each region has factor endowments that can't be exceeded

$$F_i x_i \leq f_i \qquad \text{for all } i \tag{3}$$

A given region only enters into trade when income does not exceed autarky income,

$$\pi_i' F_i x_i \leq \pi_i' F_i x_i^* \qquad \text{for all } i \tag{4}$$

where x_i^* is the output in region i if it does not enter into trade. This constraint is called the Benefit of Trade (BOT) constraint and it states, for each region, that the income with trade must not exceed the income in autarky. The BOT can be thought of as a policy measure applied by the government in each region.

The dual linear program must also be presented for the analysis of tariffs and quotas to follow. The dual objective states

$$\max_{p_i, r_i, \alpha_i} \qquad \sum_i \left(y_i' p_i - f_i' r_i - y_i p_i^{*'} \alpha_i \right) \tag{5}$$

The dual constraint are

$$(I - A_i')p_i - F_i' r_i - F_i' \pi_i \alpha_i \leq F_i' \pi_i \qquad \text{for all } i \tag{6}$$

and

$$-p_i + (I - T_{ij}')p_j \leq 0 \qquad \text{for all } i,j \text{ such that } i \neq j \tag{7}$$

where p, r, and α are the dual variables; p is interpreted as the price, r is the scarcity rent for factor endowments and is non-zero when (3) is binding, and α is the BOT rent and is non-zero when (4) is binding.

In the World Trade Model the factor prices, π, and consumption, y, are given exogenously, while the outputs, x, and prices, p, are determined endogenously. When factor endowments are fully utilized in a given region, a portion of the factor incomes are given endogenously through the scarcity rents. This approach differs from most mainstream trade models where the utility or consumption, y, is maximized given factor endowment constraints. Since the World Trade Model seeks to minimize global factor use for a given consumer demand, it does not require that all factors be fully utilized. This implies the model is particularly relevant for modeling scenarios of sustainable development. This paradigm is the distinctive feature of the World Trade Model.

For more detailed description of the World Trade Model see Duchin (2005) and for more detail of the transportation model see Strømman and Duchin (2005b).

3 Tariffs and Quotas

This paper considers two broad categories of barriers to trade; tariffs are a tax applied to the traded good, while quotas limit the quantity of the traded good. Transport is already incorporated into the model (Strømman and Duchin, 2005b). Once the framework for tariffs and quotas has been developed, it can be applied to other barriers to trade; some of these are also discussed in this paper. Overall, the World Trade Model has been adapted to work with several different barriers:

- An *ad-valorem* tariff is a percentage of the value of the good; e.g. 10% tariff on imported clothes.
- A *specific tariff* is a value per unit of good; e.g. 2 cents per kg of imported orange.
- An *export tax* is applied by the exporting region, often "voluntarily"; e.g. 5% tax on exported cars.
- An *import quota* specifies the amount of good that can be imported in a given period; e.g. a given amount of sugar per year.
- A *voluntary export restriction* specifies the amount of good that can be exported in a given period; e.g. a given number of cattle per year.

There are many other non-tariff barriers to trade that exist; such as prohibitive legislation. These will not be modeled here and are assumed to be negligible. It is possible to estimate the effect of some non-tariff barriers in terms of an effective tariff or quota. There are also some "non-intentional" tariffs. A capacity constraint (for instance at a port) acts as an export or import quota, this is usually non-intentional. Capacity constraints are easily incorporated into the model through equivalent quotas.

3.1 Specific tariff

We will derive the model for a specific tariff first and this can easily be generalized to an ad-valorem tariff later. A specific tariff is a tax of fixed value per unit of the imported good and is collected by the government of the importing country. The tax constitutes value added and consequently can be modeled through the objective of the primal.

Consider region j importing a good from region i; this is expressed as e_{ij}. Suppose region j applies a tariff to region i, denoted by τ^s_{ji}. The income region j collects as a consequence of the tariff is $\tau_{ji}^{s'} e_{ij}$ and this government income enters the objective function of the primal

$$\text{Minimise} \qquad \sum_i \left(\pi_i' F_i x_i + \sum_{j \neq i} \tau_{ji}^{s'} e_{ij} \right) \tag{8}$$

The constraints for the primal do not change since the tariff only enters the objective function; however, the dual constraints are modified to include the tariff. The price setting equation becomes,

$$(I - A_i')p_i - F_i' r_i - F_i' \pi_i \alpha_i \leq F_i' \pi_i \qquad \text{for all } i \tag{9}$$

which is the same as for the World Trade Model and the transport price equation becomes,

$$-p_i + (I - T_{ij}')p_j \leq \tau_{ji}^s \qquad \text{for all } i,j \text{ such that } i \neq j \tag{10}$$

which now has the tariff structure on the right hand side. This equation corresponds to the variable e_{ij} (that is, it is the price equation for the exporting region i or the importing region j).

It is straightforward to determine the effect of a tariff on the price. If region j imports a good, α, from region i ($\{e_{ij}\}_\alpha > 0$) then the transport price equation, (10), becomes binding,

$$-\{p_i\}_\alpha + \left\{(I - T_{ij}')p_j\right\}_\alpha = \{\tau_{ji}^s\}_\alpha \qquad \text{for given } i,j \text{ and good } \alpha \tag{11}$$

Rearranging gives,

$$\{p_j\}_\alpha = \left\{(I - T_{ij}')^{-1}(p_i + \tau_{ji}^s)\right\}_\alpha \geq \left\{(I - T_{ij}')^{-1} p_i\right\}_\alpha \qquad \text{for given } i,j \text{ and good } \alpha \tag{12}$$

That is, the tariff causes an increase in the price of the good α compared to the price with zeros tariffs.

If each region applies tariffs equally to all other regions then

$$\tau_{ij}^s = \tau_i^s \qquad \text{for all } j \tag{13}$$

3.2 Ad-valorem tariff

It is straightforward to modify the formulation for a specific tariff to an ad-valorem tariff. An ad-valorem tariff is a percentage tax applied to the value of the imported good. Thus the specific tariff needs to be modified to include the price of the imported good.

Consider again region j importing a good from region i; this is expressed as e_{ij}. Region j applies a tariff to region i, and so the ad-valorem tariff is constructed as,

$$\tau_{ji}^s = \hat{\tau}_{ji}^a p_i \tag{14}$$

where p_i is the price paid for the good by region j before the price of transport is added and τ_{ji}^a is the ad-valorem tariff applied by region j to region i, and the hat, $\hat{\cdot}$, means diagonalization of the vector into a matrix with the vector on the diagonal. It is assumed that the tariff is applied to the region at the price without transportation. The alternative would be to apply the tariff to the price within the region applying the tariff; that is, the tax collected is given by $\hat{\tau}^a_{ji} p_j$, where p_j is the price of the good in region j (the region applying the tariff). There are two main problems in taking this approach. First, for consistency with transport, the tariff should be applied to the value of the good and not the transport on that good; transport is a separate tradeable good and so a tariff on transportation services can be applied directly if necessary. Second, more technically, linear variations applied to the objective function of a linear program gives piecewise linear variations in the objective (see for example, Theorem 4.6 in Sierksma, 2002). Calculations have shown this is not the case if the tariff is applied the price of the region applying the tariff. Both these points show that the tariff should be applied to the price of the good before transportation is added.

If the tariff is applied to the price of the good in the exporting region then the objective function for the primal becomes,

$$\text{Minimise} \qquad \sum_i \left(\pi_i' F_i x_i + \sum_{j \neq i} (\hat{\tau}^a_{ji} p_i^\dagger)' e_{ij} \right) \tag{15}$$

where τ^a_{ji} is a vector of the percentage tariff per good (ad-valorem tariff) applied to the import e_{ij} and valued with the price $p_i^\dagger$. This introduces the dual variable, $p_i^\dagger$, into the primal objective. To solve this system requires an iterative procedure; hence the † is used on the price to identify that it is from the previous iteration. This is discussed further below.

The constraints for the primal do not change since the tariff only enters the objective function; however, the dual constraints are modified to include the tariff. The price setting equation becomes,

$$(I - A_i')p_i - F_i' r_i - F_i' \pi_i \alpha_i \leq F_i' \pi_i \qquad \text{for all } i \tag{16}$$

which is the same as for the World Trade Model and the transport price equation,

$$-p_i + (I - T_{ij}')p_j \leq \hat{\tau}^a_{ji} p_i^\dagger \qquad \text{for all } i,j \text{ such that } i \neq j \tag{17}$$

which now has the tariff structure on the right hand side. This equation corresponds to the variable e_{ij}.

3.2.1 Iterative procedure

The inclusion of an ad-valorem tariff puts a dual variable (the price) into the primal, see (15). This is not solvable directly. To solve the system an iterative procedure is used. The price in the primal objective, $p_i^\dagger$, is taken as the price from a previous run and then new prices are generated. The new prices are then used in the primal objective. This iterative procedure is repeated until the solution from subsequent iterations converge. The initial price used in the first iteration is from the World Trade Model with zero tariffs. The iterations are not interpreted as new time periods, but rather as an iterative method of solving the linear program when the dual variable is in the primal. Calculations show that the solution converges to several significant digits after only two or three iterations.

3.2.2 Formulation through the price equation

It is appealing to derive the ad-valorem tariff formulation through the price equation; this may avoid the iterative procedure. However, this approach gives an unrealistic solution. To see this consider formulating the problem in the dual; rewrite (17) as

$$-(I + \hat{\tau}^a_{ji})p_i + (I - T'_{ij})p_j \leq 0 \qquad \text{for all } i,j \text{ such that } i \neq j \tag{18}$$

The primal can now be constructed, the objective remains as in (1). However, (2) becomes

$$(I - A_i)x_i \geq y_i + \sum_j (1 + \hat{\tau}^a_{ji})e_{ij} - \sum_j (I - T_{ji})e_{ji} \tag{19}$$

From this it can be seen that the tariff increases the export demand in each region by $\hat{\tau}^a_{ji}e_{ij}$. That is, the quantity e_{ij} is imported by region j from region i, but region i produces $(I + \hat{\tau}^a_{ji})e_{ij}$.

The same problem results if the tariff is applied to p_j to give,

$$-p_i + \left((1 + \hat{\tau}^a_{ji})I - T'_{ij}\right) p_j \leq 0 \qquad \text{for all } i,j \text{ such that } i \neq j \tag{20}$$

The same problem results, but this time on the imports,

$$(I - A_i)x_i \geq y_i + \sum_j e_{ij} - \sum_j \left(I + \hat{\tau}^a_{ji} - T_{ji}\right) e_{ji} \tag{21}$$

These two examples demonstrate that an ad-valorem tariff must be formulated through the objective and not the price equation in the dual linear program.

3.3 Export tax

An export tax is conceptually similar to a tariff, and thus requires little theoretical development. An export tax, t_{ij}, is applied to exports from i to j, that is, e_{ij}. Comparison to a tariff shows that

$$t^s_{ij} = \tau^s_{ji} \tag{22}$$

That is, if region i applies a export tax to region j, then it is equivalent to region j applying an import tariff to region i, but the income is earned by a different region. In terms of ad-valorem values,

$$\hat{t}^a_{ij}p_i = \hat{\tau}^a_{ji}p_i \tag{23}$$

If a region, i, applies the same export tax to all other regions, j, then

$$t^s_{ij} = t^s_i = \tau^s_{ji} \qquad \text{for all } j \neq i \tag{24}$$

This shows that region i applying an export tax to all other regions is the same as those regions applying an import tariff to i of the same magnitude.

3.4 Import quota

A common non-tariff barrier to trade is an import quota; the government places an upper bound on the amount of a given good that can be imported. This represents a new constraint in the primal,

$$e_{ji} \leq q_{ij} \qquad \text{for all } i,j \text{ such that } i \neq j \tag{25}$$

where q_{ij} is the quota that region i applies to imports from region j. Not all regions would apply a quota. This can be treated in two ways; first, the relevant constraint can be left out; second, the magnitude of the quota can be increased to a large number. While the former is mathematically more rigorous, the latter is chosen to allow for a more consistent mathematical framework. Hence each region has a q_{ij} and if a quota is not applied for a good, then the value of q_{ij} is made large enough so that it does not effect the solution; this can be determined by ensuring the corresponding dual variable for the constraint is zero.

Given the quota constraint above, the dual of the linear program is modified. The objective becomes

$$\text{Maximize} \qquad \sum_i \left(y_i' p_i - F_i r_i - y_i' p_i^* \alpha_i - \sum_{j \neq i} q_{ji}' s_{ij} \right) \tag{26}$$

The price setting equation remains the same,

$$(I - A_i')p_i - F_i' r_i - F_i' \pi_i \alpha_i \leq F_i' \pi_i \qquad \text{for all } i \tag{27}$$

and the transport price equation becomes

$$-p_i + (I - T_{ij}')p_j - s_{ij} \leq 0 \qquad \text{for all } i,j \text{ such that } i \neq j \tag{28}$$

By a simple rearrangement of this equation it is straightforward to show that the quota causes an increase in the price p_j, c.f. (12).

If the quota is applied differently to each region the quota introduces $m(m-1)$ new equations into the primal and hence $m(m-1)$ new dual variables. The mathematics is greatly simplified if a quota is applied to all imports of a good and not the imports from specific regions; that is,

$$q_i = \sum_j q_{ij} \tag{29}$$

Hence, the new primal constraint becomes

$$e_{ji} \leq q_i \qquad \text{for all } i \tag{30}$$

The dual objective becomes

$$\text{Maximize} \qquad \sum_i (y_i' p_i - F_i r_i - y_i' p_i^* \alpha_i - q_i' s_i) \tag{31}$$

where s_i is the new dual variable for the introduced quota inequalities. The price setting equation remains the same, but the transport price equation becomes

$$-p_i + (I - T_{ij}')p_j - s_j \leq 0 \qquad \text{for all } i,j \text{ such that } i \neq j \tag{32}$$

3.4.1 Is a quota equivalent to a tariff?

The effect of a quota is to introduce a new dual variable. By inspection of the dual objective it is seen that the new dual variable has units of price ($ per unit); analogous to a specific tariff. This essentially shows a "duality" between a quota and a specific tariff. Bhagwati (1965) showed that under some conditions of perfect competition, tariffs and quotas are equivalent "in the sense that a tariff rate will produce an import level which, if alternatively set as a quota, will produce an identical discrepancy between foreign and domestic prices". Can this hold in the model presented here?

If a region applies a non-zero quota to a given good, then that region may still import that good until the quota is reached. Consider region i importing from region j, $e_{ji} > 0$. There are two cases to consider: the quota is binding and the quota is not binding.

If the quota constraint is not binding, then there are no rents earned by region i, $s_{ji} = 0$. In contrast, if a tariff was applied, then that region would be collecting income from the tariff, given by $\tau_{ij}^{s'} e_{ji}$. In this case, it appears that a quota and tariff behave differently.

If the quota constraint is binding, then the region earns a rent, $s_{ji} > 0$. In this case it is possible that a quota and a tariff are equivalent. This warrants further investigation. Suppose that a quota and a tariff are equivalent. That is, given the right choice of τ_{ij}^{s} for a given q_{ij} the solutions of the two problems are be identical. In a linear program, at the optimal solution the primal and dual objectives are equal. Thus for tariffs,

$$Z = \sum_i \left(\pi_i' F_i x_i + \sum_{j \neq i} \tau_{ji}^{s'} e_{ij} \right) = \sum_i \left(y_i' p_i - F_i r_i - y_i' p_i^* \alpha_i \right) \tag{33}$$

and for quotas,

$$Z = \sum_i \pi_i' F_i x_i = \sum_i \left(y_i' p_i - F_i r_i - y_i' p_i^* \alpha_i - \sum_{j \neq i} q_{ji}' s_{ij} \right) \tag{34}$$

We assume that all the variables in both solutions are the same and so through manipulations it is possible to show that

$$\sum_i \sum_{j \neq i} \tau_{ji}^{s'} e_{ij} = \sum_i \sum_{j \neq i} q_{ji}' s_{ij} \tag{35}$$

For simplicity, assume that the tariff is applied from one specific region to another, let i and j be those regions,

$$\tau_{ji}^{s'} e_{ij} = q_{ji}' s_{ij} = s_{ij}' q_{ji} \tag{36}$$

We assumed that the quota is binding, this implies that $q_{ji} = e_{ij}$ and further assume that these are non-zero and arbitrary, therefor

$$\tau_{ji}^{s} = s_{ij} \tag{37}$$

That is, if a quota is binding, there exists an equivalent tariff, equal to the quota rent, that gives the same solution. A similar outcome can be obtained if is assumed that $\tau_{ji}^{s} = s_{ij}$ in (36); in that case, the quota is given by the export flow, $q_{ji} = e_{ij}$. These details are explored more in the illustrative example below.

3.5 Voluntary export restriction (VER)

This is analogous to incorporating an import quota. A constraint is added to the primal to limit the amount of exports of a given good. The new constraints in the primal are

$$e_{ij} \leq q_{ij}^{ex} \qquad \text{for all } i,j \text{ such that } i \neq j \tag{38}$$

The presentation of the dual is not shown here as it is very similar to the case of import quotas. The primary difference is that the dual variable will have the regional indices swapped; for example, $s_{ij} = t_{ji}$. Consequently, the properties of the model with VERs are similar to the properties of the model with import quotas.

3.6 A complete model for barriers to trade

By constructing all the barriers to trade through the primal it is possible to model them all simultaneously. Let τ_{ij}^a be an ad-valorem tariff, τ_{ij}^s be a specific tariff, and q_{ij} is an import quota.

The objective becomes

$$\text{Minimise} \qquad \sum_i \left(\pi_i' F_i x_i + \sum_{j \neq i} (\hat{\tau}_{ji}^a p_i^\dagger + \tau_{ji}^s)' e_{ij} \right) \tag{39}$$

and the constraints are the same as the World Trade Model, but an import quota is included,

$$e_{ji} \leq q_{ij} \qquad \text{for all } i, j \text{ where } i \neq j \tag{40}$$

It is also possible to put export taxes and export quotas into this model as well, although this is not pursued here.

4 Illustrative examples

In this section we apply the model to a variety of different illustrative examples to verify that the model behaves as expected. It must be emphasized that the results in this section are illustrative examples and do not reflect current real-world production patterns. At this stage the model data is only suitable for model testing and broad analysis, but has limited application in detailed studies. We are yet to incorporate detailed data on barriers to trade into the model and further the data set needs further updating and testing.

First the data is briefly introduced. Then we apply the show some properties of the model with the inclusion of a tariff and then a quota.

4.1 Data

The data set for the model was originally based on Duchin (2005) and modified slightly in Strømman and Duchin (2005b). The data from Strømman and Duchin (2005b) is used and it will not be described in detail here. The model consists of 11 regions, see Table 2. There are six tradeable goods—coal, oil, gas, mineral products, agricultural products, manufactured goods—and two non-tradable goods—electricity, services; see Table 3. There are four international transportation modes; crude oil transport, bulk transport, container transport, liquified natural gas (LNG) transport; see Table 3. Each region has six factors of production; land, labor, capital, coal, oil, gas; see Table 4. All the factors of production have a resource constraint. The data has been constructed to reflect the year 1990 and the price unit in the model is 1970 US dollars.

A further point relevant to barriers to trade is that subsidies are, not at this time, incorporated into the model. In reality, of course, tariffs are often accompanied by substantial subsidies to domestic producers. The influence of subsidies on world prices and outputs is not reflected in the model.

4.2 Ad-valorem tariff

4.2.1 Agricultural tariff in North America

To fully demonstrate how tariffs effect the solution of the model requires numerical methods. For this we apply a linearly increasing tariff on good α in region i,

$$\{\tau_i^a\}_\alpha (u) = \frac{u}{100} \tag{41}$$

where $u \geq 0$ is the percentage tariff and is applied equally to all regions. We then show the resulting shifts in production and changes in prices.

Consider a linear increase in the ad-valorem tariff on agriculture from 0 to 25% in North America. No other regions have a tariff applied. The results are shown in Figures 1-3. These results do not seek to represent the observed real-world tariffs, but rather demonstrate the implementation of tariffs in the model.

Figure 1 show the changes in agriculture output as the tariff increases. The tariff is binding at a low percentage and the first region to stop producing agriculture is Japan. As the tariff increases production is increasingly shifted from Europe to North America. As production shifts in the agriculture sector, there are also indirect effects on other sectors. Figure 2 shows the changes in manufacturing output as the agriculture tariff increases. As North America starts to produce more agriculture it must stop producing manufacturing to free up resources. Likewise, Western Europe can increase output of manufacturing as agriculture production shifts towards North America. The results in Figures 1 and 2 demonstrate the ability of the model to capture indirect effects. The tariff causes a shift in comparative advantage. Given the limited factor availability in each region, changes in output caused by a tariff have indirect effects on the output of all goods.

Figure 3 shows the changes in the agriculture price in each region due to the tariff in North America. Before the tariff was applied North America did not have a comparative advantage in agriculture, therefor as production shifts to North America, the price must increase. Since some agriculture production shifts to North America, the region with a comparative advantage in agriculture can produce more agriculture for other regions. As a consequence, the price of agriculture in the other regions decreases.

Figure 4 shows the difference in using a tariff and a quota. A decreasing quota was applied to North America from 100G\$US70 to 0G\$US70. On the same plot is the output for a tariff increasing from 0 to 25%. If a quota gives a certain output (point A) then the

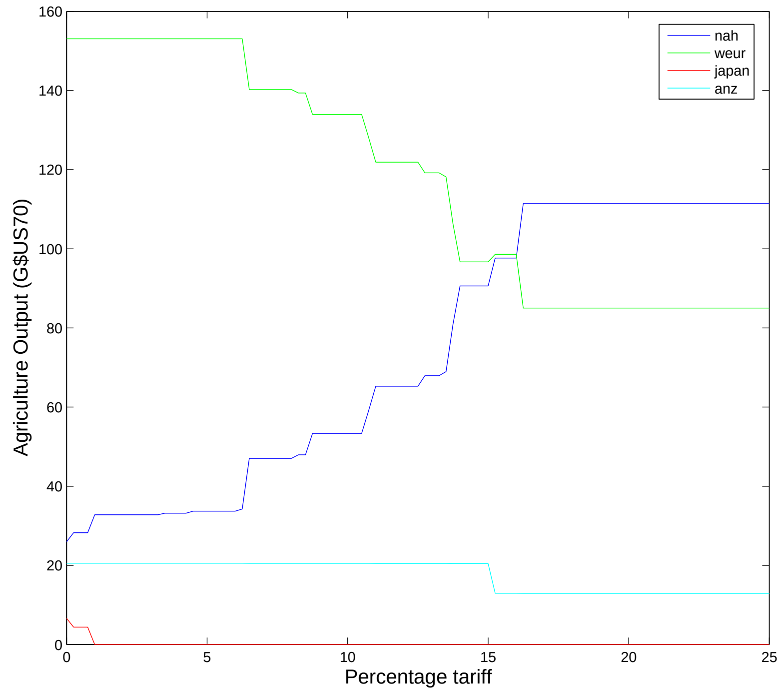

Figure 1: The output in the agriculture sector for an increasing tariff on agriculture in North America.

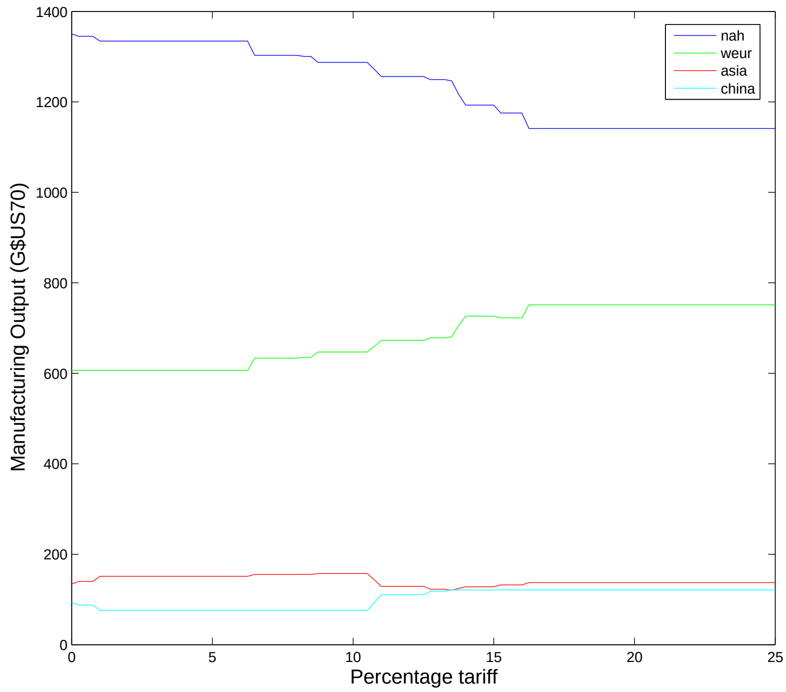

Figure 2: The output in the manufacture sector for an increasing tariff on agriculture in North America.

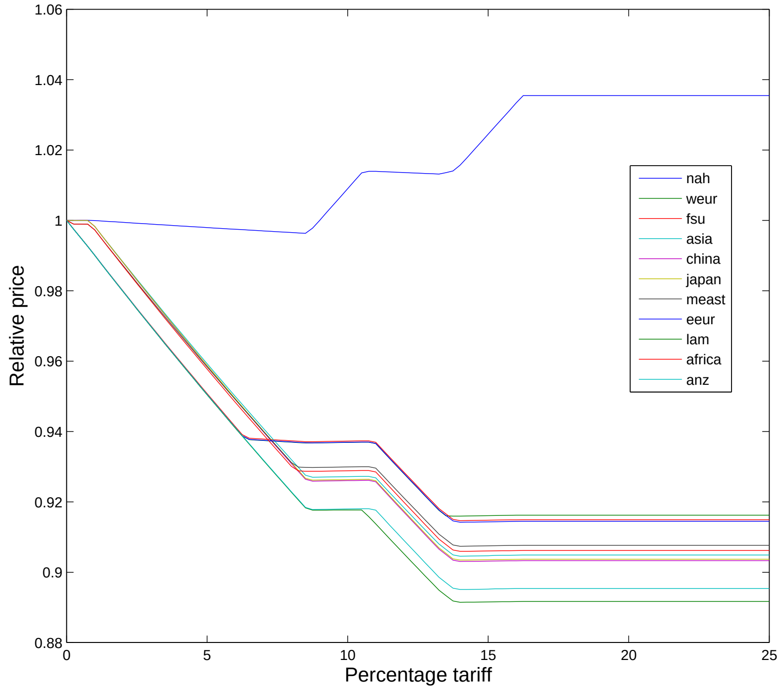

Figure 3: The price of agriculture in each region for an increasing tariff on agriculture in North America. The prices are relative to the price with zero tariffs.

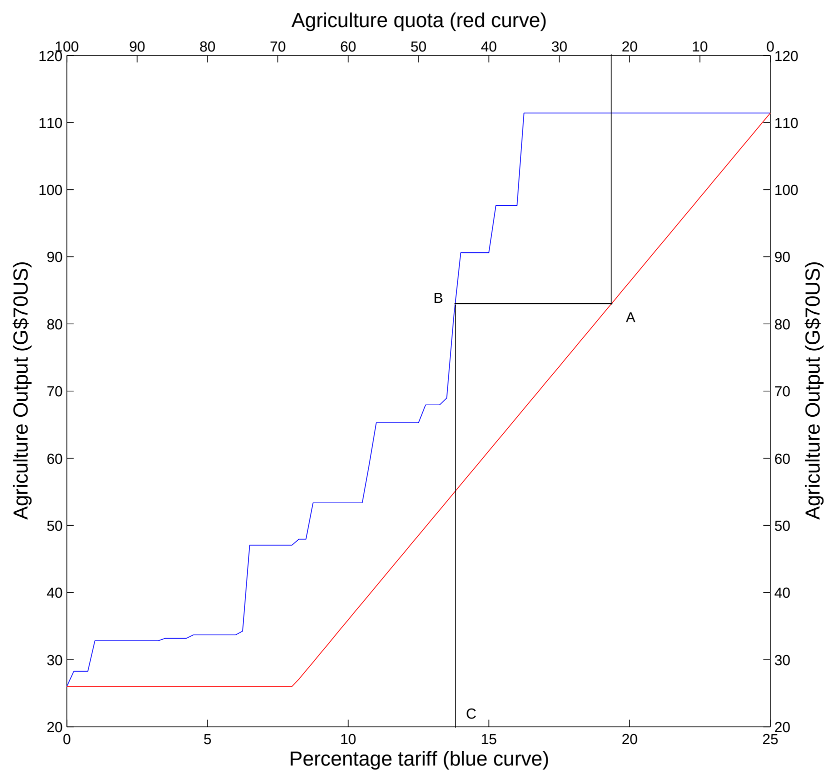

Figure 4: A comparison of the outputs with a tariff and a quota in North America. The red curve represents the quota and the blue curve represents the tariff. See the text for a description of the lines and labels.

tariff that gives the same output can be found be following the line to point B then point C. In the example, a tariff of ∼13% will give the same solution as a quota of ∼23G$US. The extreme end points are eas to check, a tariff of greater than ∼17% will give the same solution as a quota of zero.

Figure 4 also shows the mathematical differences in varying the objective function (step-wise linear) and a constraint (linear) (c.f. Sierksma, 2002). When the objective function has a linear increase, as for increasing tariffs, then the solution takes steps when a new-constraint becomes binding. If a binding constraint has a linear variation, as for the quota, then the solution will change linearly due to the tightening constraint. The opposite occurs in the dual variables; the objective in the primal are in the constraints in the dual and vica-versa. This also explains the different form of the curves in Figures 1 and 2 compared to Figure 3. These details are also clarified in the next section on quotas.

4.3 Quotas

4.3.1 Manufacture quota in Western Europe

Consider a linear decreasing quota on manufacturing in Western Europe from 100G$US70 to 0G$US70. No other regions have a quota applied. The results are shown in Figures 5-7. These results do not seek to represent the observed real-world quotas, but rather demonstrate the implementation of quotas in the model.

Figure 5 shows the changes in production as the quota decreases. Note that the scale has been normalized relative to the output with zero tariffs to allow for easier comparison; the manufacturing outputs vary by large amounts in each region. The quota becomes binding at approximately 55G$US70 and then forces production to shift to Western Europe and out of North America. Interestingly, the quota also has an indirect effect on Manufacturing output in China, Asia, and Japan. This is due to the changes in comparative advantage in each region under binding factor constraints. Figure 6 shows the indirect changes to agricultural output in each sector. As various regions decrease (increase) production of a good, then production of another good may increase (decrease). This was also the case for tariffs.

Figure 7 shows the price in each regions as a result of the quota. The quota forces the prices up in Western Europe since it is forced to produce a good that it does not have comparative advantage in producing. Consequently, there is a small drop in the price of manufacturing in other regions since the regions with comparative advantage supply more of the world demand of manufacturing. The price changes for manufacturing are smaller than for agriculture in North America, Figure 3. This is since the changes in the output due to the tariff on agriculture were up to 500%, while the changes in output due to the quota on manufacturing are much smaller; compare Figures 1 and 5. However, the quota does cause a change of up to 1% in the price of agriculture (results not shown).

5 Conclusion

The first part of this paper incorporated barriers to trade into the World Trade Model. Tariffs were added as a new component of value added in the objective function, this

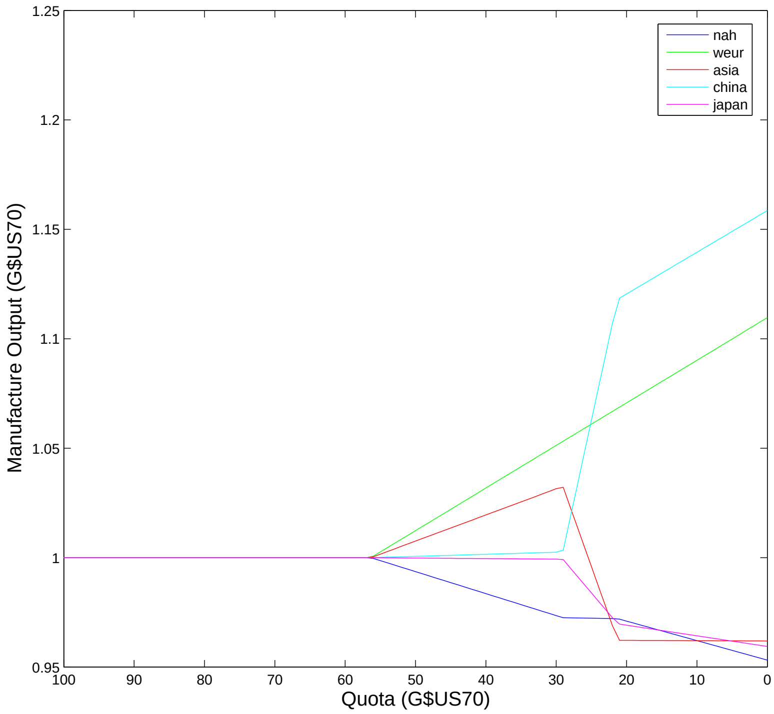

Figure 5: The output in the manufacture sector for an increasing quota on manufacturing in Western Europe.

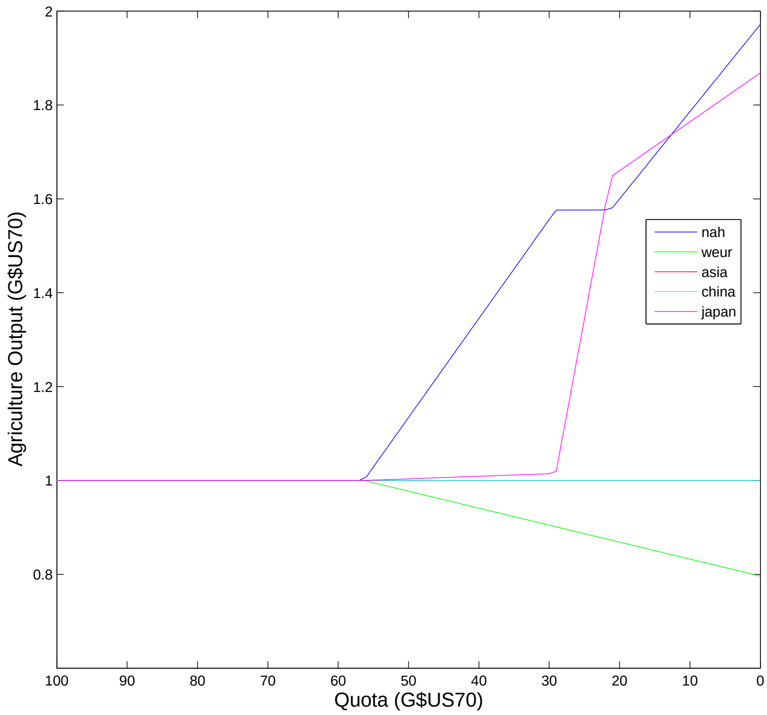

Figure 6: The output in the agriculture sector for an increasing quota on manufacturing in Western Europe.

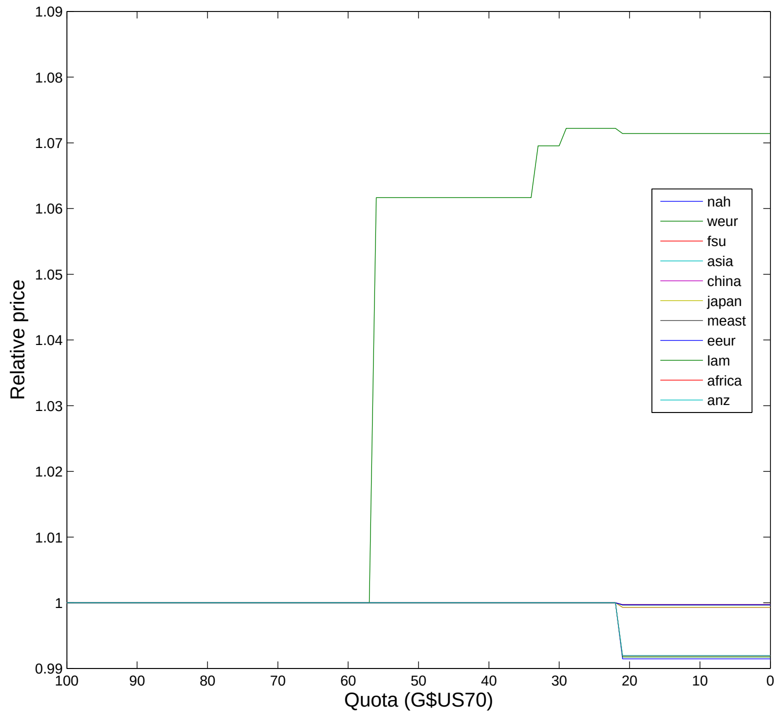

Figure 7: The relative price of manufactured goods in each region for an increasing quota on manufacturing in Western Europe. The prices are relative to the price with zero tariffs.

lead to an increased price in the dual formulation. Quotas represent a new constraint on the trade flows and this also leads to an increased price in the dual formulation. Other barriers to trade, such as export restrictions and export taxes, were also incorporated into the model through special application of tariffs and quotas. It was shown how it was possible to get an equivalent tariff for a given quota in the World Trade Model where the tariff is put equal to the rent earned for the quota.

We demonstrated the model with two illustrative examples. First, we considered the production outputs and prices for an increasing agricultural tariff in North America. Next we considered the production outputs and prices for an increasing quota on manufacturing in Western Europe. Both examples showed the importance of indirect effects on the solution and changes in prices due to shifting comparative advantage.

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Indices	m		number of regions
	n		number of goods
	s		number of transport sectors
	k		number of factors of production
	i, j		index for regions $i, j = 1...m$
Exogenous Parameters	A_i	$(n+s) \times (n+s)$	matrix of interindustry production coefficients in region i
	F_i	$k \times (n+s)$	matrix of factor inputs per unit of output in region i
	D	$(m) \times (m)$	matrix of interregional distances
	W	$(n+s) \times (n+s)$	matrix of weight of goods
	T_{ij}	$(n+s) \times (n+s)$	matrix of requirements for transportation from i to j
	y_i	$(n+s) \times 1$	vector of final demand of goods in region i
	π_i	$k \times 1$	vector of factor prices in region i
	f_i	$k \times 1$	vector of factor endowments in region i
	f_i^*	$k \times 1$	vector of factor use in absence of trade in region i
	p_i^*	$(n+s) \times 1$	vector of goods prices in absence of trade in region i
Endogenous Variables	x_i	$(n+s) \times 1$	vector of output in region i
	e_{ij}	$(n+s) \times 1$	vector of goods exported from region i to region j
	p_i	$(n+s) \times 1$	vector of goods prices in region i
	r_i	$k \times 1$	vector of factor scarcity rents in region i
	α_i	scalar	benefit-to-trade shadow price in region i

Table 1: Indices, parameters and variables for the WTM, from Strømman and Duchin (2005b).

Code	**Region**
nah	High income North America
weur	Western Europe
fsu	Former Soviet Union
asia	Asia
china	China
japan	Japan
meast	Middle East
eeur	Eastern Europe
lam	Latin America
africa	Africa
anz	Australia and New Zealand

Table 2: The regions used in the model.

Code	**Good**	**Type**	**Unit**
coal	Coal	Tradable	Mtce
oil	Oil	Tradable	Mtce
gas	Gas	Tradable	Mtce
elec	Electricity	Non-tradable	G$US70
min	Mining	Tradable	G$US70
ag	Agriculture	Tradable	G$US70
man	Manufacturing	Tradable	G$US70
serv	Services	Non-tradable	G$US70
crude	Crude oil transport	Tradable	Gtkm
bulk	Bulk transport	Tradable	Gtkm
cont	Container transport	Tradable	Gtkm
lng	LNG transport	Tradable	Gtkm

Table 3: The goods used in the model and their characteristics. tce represents "tonnes of coal equivalents", tkm is "tonne kilometers".

Code	**Factor**	**Unit**
land	Land	Mha
lab	Labor	Mworkers
cap	Capital	G$US70
coal	Coal	Mtce
oil	Oil	Mtce
gas	Gas	Mtce

Table 4: The factors of production used in the model.