Option Values and the Choice of Trade Agreements

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Abstract

This paper analyzes how uncertainty influences the formation and design of regional trade agreements (TAs). Two sources of uncertainty – in demand and costs – are considered. Using a multi-stage game we show that, as long as some decisions are made after uncertainty is resolved, all TAs have option values. But, because TAs differ in their flexibility and degrees of coordination these option values vary across TAs. Thus, under uncertainty, the usual cost/benefit analysis that underlies the formation and design of TAs is altered to reflect these option values. We also show that due to the flexibility and coordination differences among TAs, their option values are affected differently by uncertainty. Consequently, the formation and design of TAs is also affected by the nature and degree of uncertainty. We demonstrate that the effects of an increase in uncertainty on the choice of TAs depend on the relative responsiveness of the TAs' option values with respect to the change in uncertainty, which in turn depends on the convexity properties of the countries' welfare functions under the different TAs. In particular, a TA whose option value is more responsive to a change in uncertainty becomes relatively more attractive when uncertainty increases. This enables us to predict which TAs are likely to emerge in an uncertain world. Using a specific example, we then show the effects of a change in both demand and cost uncertainty on the choice of TAs. We also examine the timing of the resolution of uncertainty and its effect on the choice of TAs and show that it can significantly impact the type of trade agreement that countries wish to form.

Keywords: Trade Agreement, Free Trade Area, Customs Union, Uncertainty, Resolution of Uncertainty.

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1 Introduction

Since Viner (1950), the costs and benefits of different types of trade agreements (TAs) have been extensively discussed in the literature.[1] More recently, particularly following the pioneering work of Riezman (1985), the choice of TAs has been analyzed as an application of the general problem of coalition formation. Nevertheless, comparatively little attention has been paid to the question of how countries choose between different TA designs under uncertainty.[2] A notable exception is the literature on the role of TA membership as an insurance mechanism.[3]

In this paper, we argue that the introduction of uncertainty alters the cost-benefit calculus associated with TA formation in ways that go beyond the insurance considerations already considered in the literature. In particular, we show that if member countries have the opportunity to make at least some decisions after uncertainty is resolved, then *all* TAs have an option value. The intuition is straight forward: a TA's option value simply reflects the value of being able to make at least some decisions after uncertainty is resolved.[4]

While all TAs have an option value, these option values differ across TAs. This is because TAs are characterized by different rules and imply different behaviour. For example, apart from the World Trade Organization's (WTO) "most favoured nation" (MFN) rule,[5] each TA imposes a distinct set of trade policy restrictions on members. At one extreme, a country that stands alone (SA) can choose its external tariffs as it pleases. While a free trade area (FTA), such as NAFTA, permits members to choose their own external tariff rates, they must agree to: (i) free trade with their partner and (ii) a schedule of "rules-of-origin" that determine the duty-free status of goods originating in non-member nations but traded within the FTA. At the other extreme, a customs union (CU), such as the European Union, requires members to commit to: (i) intra-union free trade, (ii) jointly determine a 'common external tariff' (CET) rate to levy on non-members and (iii) share the resulting CET revenue according to an agreed formula. In the following we refer to the three possible cases: SA, FTA and CU as TAs.

To appreciate why differences among TAs give rise to different option values, note that a country's ability to respond to changes in the trading environment, under a given TA, depends on two factors: degrees of freedom in the choice of tariffs and the degree of coordination/cooperation in decision making. The reason why more degrees of freedom (less restrictions) in the choice of tariffs increase responsiveness is obvious (this is what is

[1] For a comprehensive review of the TA literature see Freund and Ornelas (2010).

[2] There is, of course, a venerable literature on unilateral trade policy choice under uncertainty. See, for example, the work by Dasgupta and Stiglitz (1977) and Young (1979), among others, contrasting tariffs and quotas under uncertainty. More recently, Grant and Quiggin (1997) have looked at strategic trade policy under uncertainty.

[3] Under uncertainty, a trade bloc may have an insurance value for members by binding them more closely to a free trade future with each other. Ethier (2002) refers to the insurance motive for contingency measures (i.e. unilateralism) within a multilateral framework. Perroni and Whalley (2000) argue that small countries may seek to join regional trade agreements as insurance against future protection. Wu (2005) distinguishes between the self-insurance and self-protection motives for trade bloc membership.

[4] This is simply an implication of the Blackwell Theorem (Blackwell, 1953).

[5] The MFN rule require countries to levy identical tariffs on trading partners.

known as the LeChatelier principle; see Samuelson (1947)). The reason why, in general, greater coordination also increases responsiveness is that it implies that more interdependent factors/variables/externalities are taken into account in joint decision making.[6]

A country's overall ability to respond to changes in the trading environment - which we refer to as its (degree of) flexibility - is the product of these two factors and will depend on the type of TA of which it is a member. For example, a FTA has more degrees of freedom in choosing tariffs than a CU, but a CU involves greater coordination than a FTA. Consequently, TAs differ in terms of their overall flexibility, which in turn implies that they have different option values.

But, the differences among TAs have an additional, related, consequence. They also imply that a *change* in uncertainty affects the TAs' option values differently, because TAs have different degrees of flexibility. Thus, the *relative* attractiveness of the TAs will be affected by a change in uncertainty. It is, therefore clear that the nature, degree and effect of uncertainty on option values become an important part of the cost/benefit analysis of TA choice.

In this paper, we examine the relationship between uncertainty and TA formation in the context of a partial equilibrium, three-country world characterized by imperfect competition between firms. A three-stage game is considered in which countries choose a TA in stage one,[7] optimal tariffs are chosen in stage two and firms choose their profit maximizing outputs in stage three. In stage one, countries can join a FTA, a CU or choose to stand alone. Our model incorporates uncertainty in both demand and supply. In order to remove pure insurance considerations (which have, in part, already been addressed in the literature), we assume that all countries are risk neutral.

First, we show that, provided that at least some decisions are made after uncertainty is resolved, all TAs have option values. These option values are simply the expected value of (perfect) information. They reflect the fact that a country can do better if it makes (more of) its decisions after, rather than before, uncertainty is resolved. This option value benefit is, therefore, a new factor in the standard costs-benefits analysis of TAs.

We demonstrate that, with risk neutral countries, the effect of uncertainty on option values is the same as its effect on the countries' (Nash equilibrium) expected welfare. Consideration of the option values, therefore, allows us to analyze the TA choice problem. Moreover, we show that if member countries' welfare functions are convex in the random variables (as is often the case when some decision are made after the resolution of uncertainty[8]), then their expected (Nash equilibrium) welfare, as well as their option values, for all TAs, increase with demand, or cost uncertainty. The effect of an increase in uncertainty on the choice of TAs, therefore, depends on the

[6] For example, within a standard Cournot model, it is straightforward to show that responsiveness (say, to a change in demand conditions) is greater for cooperating than non-cooperating duopolists.

[7] Assuming no renegotiations.

[8] Which, in turn, follows from common properties of maximum functions (specifically, if the objective function is convex in the exogenous variable, so is the maximum function). See footnote 20 below.

relative increase in option values for different TAs.

Next, we explain the effect of an increase in uncertainty, captured by a mean-preserving-spread (MPS), on the relative attractiveness of TAs. We provide both sufficient and necessary and sufficient conditions for relating the effects of a MPS on the relative attractiveness of TAs to the ranking of convexity (in random variables) of Nash equilibrium welfare functions. Specifically, we show that a MPS in a particular random variable makes a given TA relatively more attractive, compared to another TA, if the former TA's Nash equilibrium welfare function is *everywhere* more convex with respect to this random variable, compared to the latter TA's Nash equilibrium welfare function. Second, we show that a MPS in a particular random variable makes a given TA relatively more attractive, compared to another TA, if and only if the former TA's Nash equilibrium welfare function is "*on average*" more convex with respect to this random variable, compared to the latter TA's Nash equilibrium welfare function. The two versions of this result enable us to determine the effects of an increase in uncertainty on the choice of TAs, by referring to convexity properties.

The results regarding the role of convexity are important in that they tell us what determines the effects of an increase in uncertainty on the relative attractiveness of TAs. But, it would be even more interesting if could explain what determines relative convexity. Unfortunately, as is recognized the game theory literature,[9] the value of information and convexity (and hence also changes in the value of information), are generally difficult to derive qualitatively in a strategic game. This simply reflects the fact that what may be possible to derive easily for a single decision maker (in this case, the value of information and convexity), may not be possible in a Nash equilibrium (for strategically interacting players). Indeed, in our framework these difficulties are even greater. First, not only do we have strategically interacting countries, we also have a multi-stage game with both cooperative and non-cooperative elements. Second, we need to derive both option values and *changes* in option values. Nevertheless, as our results and intuition suggest, the degrees of convexity of Nash equilibrium welfare functions (which determines the degree of responsiveness) simply reflects the TAs' overall flexibility. In other words, a more flexible TA will give rise to greater convexity, which implies greater responsiveness to changes in uncertainty. But, as we noted above, greater flexibility itself is a product of degrees of freedom in choosing tariffs and degree of coordination. Hence, these are also the two factors which ultimately determine the degree of convexity.

To demonstrate the "option value effect" in TA choice, we provide an example with commonly used linear demand and cost functions. This example enables us to obtain an explicit solution for the Nash equilibrium of the multi-stage game. Moreover, it yields Nash equilibrium welfare functions which are indeed convex and can also be used to rank degrees of convexity, thus allowing us to make predictions about the effects of an increase

[9] The earliest discussion is in Hirshleifer, (1971). See also Kamien, Tauman and Zamir (1990), Bassam, Gossner and Zamir, (2003) and Peski (2008).

in uncertainty on the choice of TAs.

Using this example, we show that (i) an increase in demand uncertainty in a TA member country will increase the attractiveness of a FTA relative to a CU and the attractiveness of a CU relative to SA (ii) an increase in demand uncertainty in a country that is not a TA member has no effect on the relative rankings of the three TAs. (iii) An increase in cost uncertainty in a TA member country will decrease the attractiveness of a FTA relative to SA and the attractiveness of SA relative to a CU (iv) an increase in cost uncertainty in a country that is not a TA member will increase the attractiveness of a CU relative to a FTA and the attractiveness of a FTA relative to SA.

We also briefly examine the role of the timing of the resolution of uncertainty by examining an alternative scenario in which uncertainty is resolved "later" (namely, where tariffs are chosen before, instead of after the resolution of uncertainty). We show that, in this case, a change in uncertainty does not affect the choice of TAs, thus it does not play an interesting role.

Finally, it should be noted that, reflecting the risks associated with trade policy commitment under uncertainty, the WTO provides a role for 'contingency measures' such as safeguards and anti-dumping measures. Such measures act as a 'safety valve' permitting TA members to temporarily, and in a WTO-compliant fashion, renege on their trade liberalization commitments in order to ameliorate any associated adjustment costs.[10] Note that contingency measures are a response to a particular type of uncertainty; that which arises from a temporary change in the trading environment. In contrast, this paper examines how countries make (irreversible) trade bloc membership decisions given that there is a potential for the trading environment to alter permanently in the future. Moreover, since all TAs must comply with WTO rules, contingency measures tend to be a standard feature of all types of TAs. As such they are unlikely to explain why countries prefer one type of TA over another - a FTA over a CU, for example.

2 The General Framework

Consider a world of three countries in which TAs can form. Assume that one country, Country 3 here, is "passive" in the sense that it does not sign TAs. Countries 1 and 2, on the other hand, are "active"; they may negotiate a bilateral TA if they wish. It is further assumed that countries 1 and 2 can choose between two alternative types of bilateral trade blocs - a FTA or a CU. Alternatively, countries 1 and 2 may prefer to stand alone (SA). Define the set of three possible coalition structures as $Y = (sa, fta, cu)$.[11] In what follows, all three elements in

[10] See WTO (2009) for a comprehensive survey of this literature. The use of contingency measures can forestall more extreme protectionist tendencies (Bagwell and Staiger, 1990), help governments garner current domestic support for trade liberalization when future support is not guaranteed (Bagwell and Staiger, 2005), 'shelter' firms in member countries from world price fluctuations (Freund and Ozden, 2008) and solidify cooperation between members who wish to avoid being targeted by such measures (Martin and Vergote, 2008). While the inclusion of contingency measures tends to reduce the (terms-of-trade) benefits arising from cooperation, it allows countries to address the contractual incompleteness of trade agreements (Horn et al., 2010).

[11] The assumption that Country 3 is passive means that we do not have to (cannot) consider the case of global free trade. This simplifies the analysis significantly as, otherwise, we would have to consider all possible coalition structures among the three countries,

Y, including the sa case, are referred to as "types" of TAs. Consistent with WTO rules, this paper assumes that all TA types satisfy the MFN principle.

For simplicity, we assume that there is one firm in each country and they all produce a homogeneous product.[12] Country $i's$ firm is referred to as firm i.

The three countries engage in a multi-stage trade policy game. In stage one, countries 1 and 2 choose a TA, $y \in Y$ and associated lump-sum transfers, K_i^y, $i = 1, 2$. The lump-sum payments may (but do not need to) be state contingent.[13] We assume that the cost of TA renegotiation[14] is prohibitive[15] (for example, due to non-trivial reputation costs).[16] In stage two, given the TA that has formed, all three countries choose their tariffs. These tariffs are summarized by the $3X3$ matrix T, whose ij^{th}element, t_{ij}, denotes the tariff that Country i pays Country j, and where $t_{ii} = 0$. For convenience, we define the vector of tariffs paid by country i (the i^{th} row in the matrix T) as $t_{i\cdot} = (t_{i1}, t_{i2}, t_{i3})$. Similarly, we define the vector of tariffs paid to country j (the j^{th} column in the matrix T) as $t_{\cdot j} = (t_{1j}, t_{2j}, t_{3j})$. Finally, we define the vector of all the tariffs (all the elements in the T matrix) by the $(1X9)$ vector t.

In stage three, given the previously chosen TAs and tariffs, the three firms choose the total amount of output that they produce and the quantities to be sold in each market, in a Cournot-Nash game. Country $i's$ firm is referred to as firm i. These outputs are summarized by the $3X3$ matrix Q, whose ij^{th}element, q_{ij}, denotes the quantity that Country i sells in Country j. We denote the vector of quantities sold by Country i (the i^{th} row in the matrix Q) as $q_{i\cdot} = (q_{i1}, q_{i2}, q_{i3})$. Similarly, we define the vector of quantities sold to Country j (the j^{th} column in the matrix Q) as $q_{\cdot j} = (q_{1j}, q_{2j}, q_{3j})$. It is also useful to define the total amount of output sold in Country i as $Q_i \equiv \sum_{j=1}^{3} q_{ji}$ and the total amount of output produced by Country i as $Q^i \equiv \sum_{j=1}^{3} q_{ij}$, respectively. Finally, we define the vector of all the quantities (all the elements in the Q matrix) by the $(1X9)$ vector q.

Country $i's$ demand function is given by:

$$p_i = D_i(Q_i, a_i), \; i = 1..3, \tag{1}$$

not just those involving countries 1 and 2. It turns out that in this model, without uncertainty, global free trade dominates all other types of trade agreements. On the other hand, once uncertainty is introduced, the primacy of global free trade can no longer be guaranteed. Detailed analysis of the preference for global free trade under uncertainty is left for future research.

[12] Assuming multiple firms simply changes the number of players in the quantity determination game, which will give rise to a different Nash equilibrium in quantities. But, this will yields little additional insight for our purposes, while making the analysis more cumbersome (with extra parameters for the number of firms). It will not affect any of the main points of the paper. Namely, TAs would still have option values that are affected by flexibility and the nature of uncertainty and this in turn can explain the effects of uncertainty on the choice of TAs.

[13] In general, it seems reasonable that transfer payments are negotiated at the same time as TAs. If actual transfer payments are made after the resolution of uncertainty we need to consider several alternative timing scenarios. Moreover, note that in such a case, we have to take into account renegotiations as well as situations in which a country may not be able to meet its payment obligations. These issues are worthy of separate consideration and will not be pursued here.

[14] The possibility of trade bloc renegotiation is an important issue deserving of separate analysis.

[15] But, our main results regarding the role of option values (see footnote 12 above) will still hold as long as renegotiation costs are not negligible.

[16] Schwartz and Sykes (2002) argue that the costs of reneging on trade agreements are twofold; the reneging country suffers reputation and credibility costs when dealing with the injured country in the future and also incurs costs when dealing with all other nations aware of the breach. Maggi (1999) suggests that the dissemination of information is a primary role of the WTO, informing third parties of trade agreement breaches and thus strengthening the enforcement mechanism of reputation costs.

where a_i is a demand shifting random parameter and $D_i(Q_i, a_i)$ is decreasing in Q_i and increasing in a_i. The technology of the firms in the three countries is captured by their cost functions:

$$C_i = H_i(Q^i, c_i),\ i = 1..3, \tag{2}$$

where c_i is a cost shifting random parameter and $H_i(Q^i, c_i)$ is increasing and (weakly) convex in Q_i.

Note that non-linearity in random variables (of either demand, or cost functions) introduces risk aversion (or affinity) into the objective function (even though the countries are risk neutral). Since we want to remove pure insurance considerations (which is why we assume that all countries are risk neutral in the first place), in the **following we** assume that both demand and cost functions are linear in random variables.

2.1 The Source of Uncertainty

We assume that countries face demand and cost uncertainty. Specifically, we assume that the demand parameter vector, $a = (a_1, a_2, a_3)$, is a vector of random variables, with means $E(a_j) = \mu_{ja}$ and variances $Var(a_j) = \sigma^2_{ja}$. Similarly, we assume that the cost parameter vector, $c = (c_1, c_2, c_3)$, is a vector of random variables with means $E(c_i) = \mu_{ic}$ and variances $Var(c_i) = \sigma^2_{ic}$. For notational convenience, it is also useful to the define the $1X6$ vector of all random variables as $z = (a, c)$. Thus, $z_i = a_i,$ for $i = 1...3$ and $z_i = c_i,$ for $i = 4...6$. We define the variance-covariance matrix of z as Σ, where the ij^{th} element of Σ is given by $\sigma_{ij},\ i, j = 1...6$.

2.2 The Resolution of Uncertainty

In general, uncertainty may be resolved at any one of four different points of the multi-stage trade policy game. At one extreme, uncertainty may be resolved prior to the first stage. That is, TAs, tariffs and firm outputs are all determined under complete certainty. Alternatively, uncertainty may be resolved "early"; that is, between stages one and two. This situation, in which TA choice is made in an environment of uncertainty, while tariffs and firm outputs are determined under certainty is, henceforth, referred to as the Early Resolution (ER) case. Another possibility is that uncertainty is resolved "late"; that is, between stages two and three. This situation, in which TA and tariff choices are made under uncertainty, while firm output choice occurs under certainty is, henceforth, referred to as the Late Resolution (LR) case. A final possibility is that uncertainty is only resolved after all decisions have been made; that is, after stage three.[17]

Clearly, neither extreme case is interesting. Moreover, as will be shown below, in the LR case an increase in uncertainty does not affect the choice of tariffs and, consequently, it has no effect on the choice of TAs. This makes the LR case also uninteresting. In this paper we, therefore, focus on the ER case.[18]

[17] This last situation is not particularly interesting since, with risk neutrality and demand/cost functions that are linear in random variables, the countries' welfare functions also become linear in random variables, so that only the means (and not higher moments) are important; hence uncertainty plays a limited role.

[18] It may also be interesting to consider a case in which the timing of the tariff decision itself depends on the TA. For example, greater "stickiness" of tariffs with a CU may suggest that this is a LR case. On the other hand, the fact that external tariffs are

Finally, it is assumed that once uncertainty is resolved, regardless of when that may be, the realizations of all random variables become common knowledge to all players.

3 Stage 3: Output Choice

In stage 3, the three firms choose their outputs simultaneously in a Cournot-Nash game given the chosen tariffs and TAs. Given the demand functions defined in equations (1) - (2) and the tariff rates chosen by each country, the profit firm i makes from selling in all three countries is given by:

$$\pi_i = \sum_{j=1}^{3}\{[D_j(Q_j, a_j) - t_{ij}]q_{ij}\} - H_i(Q^i, c_i) \equiv \pi_i(q, t_{i\cdot}; a, c_i),\ i = 1..3. \tag{3}$$

Country $i's$ (maximum) profit function is defined as[19]:

$$\overline{\pi}_i[t_{i\cdot}, q^{-i}; a, c] \equiv \max_{q_{i\cdot}} \pi_i(q, t_{i\cdot}; a, c_i),\ i = 1..3 \tag{4}$$

where q^{-i} represents the vectors of quantities sold by the two other countries (excluding i).

The Nash equilibrium quantities are then obtained by simultaneously solving the problems in (4) for the three countries. Let these Nash Equilibrium quantities be denoted as $q^*_{ij} = q^*_{ij}(t; a, c),\ i, j = 1..3$. Thus, we can write Country $i's$ Nash Equilibrium vector of quantities as,

$$q^*_{i\cdot} = q^*_{i\cdot}(t; a, c),\ i = 1..3, \tag{5}$$

and the Nash Equilibrium quantities in all three countries as the vector, $q^* = q^*(t; a, c)$. Using equations (4) and (5), the corresponding Nash equilibrium profits in Country i, denoted as $\pi^*_i[t; a, c]$, can be written as:

$$\pi^*_i[t; a, c] \equiv \pi_i[q^*(t; a, c), t_{i\cdot}; a, c_i],\ i = 1..3. \tag{6}$$

Let us now consider the properties of the profit functions $\overline{\pi}_i[t_{i\cdot}, q^{-i}; a, c]$ and the corresponding Nash equilibrium profits $\pi^*_i[t; a, c]$. First, note that in a non-game theoretic setting (with a single decision maker), we simply consider the properties of the profit functions $\overline{\pi}_i[t_{i\cdot}, q^{-i}; a, c]$. In a game theoretic setting, however, with interacting decision makers, we need to examine the properties of the Nash equilibrium profits given by $\pi^*_i[t; a, c]$. Unfortunately, but not surprisingly, the properties of the $\pi^*_i[t; a, c]$ functions are more complicated than those of the $\overline{\pi}_i[t_{i\cdot}, q^{-i}; a, c]$ functions. Consequently, results that can be easily obtained for single decision makers cannot, necessarily, be obtained in a game-theoretic setting. To demonstrate this, consider the following two examples.

Example 1: In a non-game theoretic setting, it easy to prove that profit functions are convex in the random variables. To see this, note that since demand and cost functions are linear in random variables, so are

easier to change with a FTA may suggest that this may be a ER case. We do not pursue this further, but note that, essentially, if the cost of adjusting tariffs is very low with a FTA, then tariffs will always be re-adjusted, so that effectively we will be in the LR case.

[19] Note that with the "joint" cost functions in equation (2), even if markets are segmented, each country has to maximize its total profits, rather than its profits in each market separately.

the $\pi_i(q, t_{i\cdot}; a, c_i)$ functions. As is well known (and can be easily proven), this implies that the $\overline{\pi}_i[t_{i\cdot}, q^{-i}; a, c]$ functions are convex in the random variables.[20] In a game theoretic setting, however, Nash Equilibrium profits functions are not necessarily convex in the random variables (parameters). Thus, as is recognized in the game theory literature,[21] within the context of strategic game, it is generally difficult to derive the value of information as well as the effects of uncertainty on this value.

Example 2: With a single decision maker, it usually easy to obtain comparative statics results (say, the effects of shifts in demand/cost parameters, or a change in some constraint), This becomes much more complicated in a strategic game because we need to compare different Nash equilibria (rather than the effect on a single objective function).

4 Stage 2: Tariff Choice

In stage 2, the countries choose their tariffs given the TA in stage 1 and the known state of the world. We define the net welfare of Country i (welfare minus lump sum transfers) as the sum of consumer surplus, producer surplus and tariff revenues. Using the Nash equilibrium quantities derived above, we can explicitly write Country $i's$ (net) welfare in stage 2 as:

$$w_i(t; a, c) \equiv \{\int_0^{Q_i^*} D_i(Q_i, a_i)dQ - D_i(Q_i^*, a_i)Q_i^*\} + \pi_i^*[t; a, c] + q_{\cdot i}^*(t; a, c)'t_{\cdot i} \tag{7}$$

where $Q_i^* = \sum_{j=1}^{3} q_{ji}^*$ and $q_{\cdot i}^*(t; a, c)'t_{\cdot i} = \sum_{j=1, j\neq i}^{3} q_{ji}^*(t; a, c)t_{ji}$ is total tariff revenue received by Country i.[22]

4.1 Tariff Choice: Stand Alone and Free Trade Area

In order to be able to examine the choice of tariffs, we must first consider the tariff restrictions implied by the different TAs. Country 3 does not sign TAs (it always stands alone), so its tariff restrictions are independent of the TA chosen by countries 1 and 2; they are simply given by the MFN rules. Thus, for any $y \in Y$ chosen by countries 1 and 2, Country 3's feasible tariffs set, defined as T_3, is given by:

$$T_3 \equiv \{t_{13}, t_{23}, t_{33} : t_{13} = t_{23},\ t_{33} = 0\}. \tag{8}$$

If countries 1 and 2 stand alone (by definition if one does, so does the other) their tariff restrictions are also

[20] In fact, the more general result is as follows. Suppose that for each $x \in A$ the maximum is obtained for some $y^*(x) \in B$, where B is the feasible set and A is a convex set; $A \rightarrow R$, $A \subset R^n$, $B \subset R^k$. Then, if $F(y, x)$ is a convex function of x for all fixed y, then $J(x) \equiv \max_y\{F(y, x),\ y \in B\}$, is convex in x. Moreover, if $F(y, x)$ is a concave function of (x, y) on the convex set $A\ X\ B$, then $J(x)$, is concave in x. In addition, if $F(y, x)$ is a continuous function of y, x, then $J(x)$ is a continuous function of x.

[21] See footnote 9 above.

[22] Country $i's$ welfare in stage 2 can, alternatively, be given by a more general welfare function. For example, a weighted sum of its three components in equation (7). As will be shown below, this will not affect the role of the TAs' option values substantially.

given by the MFN rules. Thus, the feasible tariffs set for Country i, defined as T_i^{sa}, is given by:

$$T_1^{sa} \equiv \{t_{11}, t_{21}, t_{31} : t_{21} = t_{31},\ t_{11} = 0\} \tag{9}$$

$$T_2^{sa} \equiv \{t_{12}, t_{22}, t_{32} : t_{12} = t_{32},\ t_{22} = 0\} \tag{10}$$

Note that a sa country always chooses only one tariff.

If all three countries stand alone, the feasible set of all tariffs, defined as T^{sa}, is given by,

$$T^{sa} \equiv \{t : t_{21} = t_{31},\ t_{12} = t_{32},\ t_{13} = t_{23},\ t_{11} = t_{22} = t_{33} = 0\}. \tag{11}$$

If countries 1 and 2 form a FTA in the first stage, then $t_{12} = t_{21} = 0$. Moreover, the MFN rule requires that $t_{13} = t_{23}$ (and, of course, $t_{ii} = 0$). Given these restrictions, we can define the feasible tariffs sets facing countries 1 and 2, when they form a FTA, as $T_i^{fta},\ i = 1, 2$, namely,[23]

$$T_1^{fta} \equiv \{t_{11}, t_{21}, t_{31} : t_{21} = 0,\ t_{11} = 0\} \tag{12}$$

$$T_2^{fta} \equiv \{t_{12}, t_{22}, t_{32} : t_{12} = 0,\ t_{22} = 0\}. \tag{13}$$

Given the tariff restrictions facing all countries, the feasible set of all tariffs is now given by,

$$T^{fta} \equiv \{t : t_{12} = t_{21} = 0,\ t_{13} = t_{23},\ t_{11} = t_{22} = t_{33} = 0\}.$$

Notice that, as in the sa case above, with fta each country chooses only one tariff. Therefore, it is unclear whether, compared to sa, a FTA member has fewer (trade policy) degrees of freedom with which to respond to changes in the trading environment. This, however, is simply due to the MFN rule. Without the MFN rule, a country will clearly have greater flexibility to respond to changes in the trading environment under sa than fta.

Each country maximizes its welfare given the combined set of tariff restrictions that follow from the agreement $y \in Y$. The three countries' net welfare maximization problems are, therefore, given by:

$$\max_{t_{\cdot i}} \{w_i(t; a, c) : t_{\cdot 1} \in T^y\},\ i = 1..3,\ y = sa, fta, \tag{14}$$

Alternatively, we can satisfy the restrictions in T^y, $y = sa, fta$, by substituting them directly into each country's welfare function. First, define the single tariff that is chosen by each of the three countries when countries 1 and 2 choose an agreement $y = sa, fta$ in the first stage as:

$$t_1^{sa} \equiv t_{21} = t_{31},\ t_2^{sa} \equiv t_{12} = t_{32},\ t_3^{sa} \equiv t_{13} = t_{23} \tag{15}$$

$$t_1^{fta} \equiv t_{31},\ t_2^{fta} \equiv t_{32},\ t_3^{fta} \equiv t_{13} = t_{23}.$$

[23] Implicit in our definition of a FTA is the assumption that the rules of origin required to support the different external tariff rates levied by countries 1 and 2 on the excluded Country 3 are completely effectively enforced and that, consequently, there is no trade deflection between the FTA members.

Using these definitions and substituting the restrictions directly into the countries' welfare functions, we get:

$$w_i^y \equiv w_i^y(t_1^y, t_2^y, t_3^y; a, c) \equiv \{w_i(t_1, t_2, t_3; a, c) : t \in T^y,\ \textit{definitions}\ (15)\},\ i = 1..3.\}. \tag{16}$$

In other words, the w_i^y functions are the original w_i functions, but with all the constraints (and definitions (15)) imposed; they are functions of three tariffs, rather than all the tariffs. If we define the vector of tariffs as $t^y = (t_1^y, t_2^y, t_3^y)$, $y = sa, fta$, we can write the net welfare functions as, $w_i^y(t^y; a, c)$.

The three countries' net welfare maximization problems can now be written as:

$$\max_{t_i^y}\{w_i^y(t^y; a, c),\ i = 1..3,\ y = sa, fta\}.$$

Let the Nash equilibrium tariff in Country i be denoted as $t_i^{*y}(a, c),\ i = 1..3,\ y = sa, fta$. The corresponding Nash equilibrium net welfare in each country is, therefore, given by:

$$w_i^{*y}(a, c) \equiv w_i(t^{*y}(a, c); a, c),\ i = 1..3,\ y = sa, fta, \tag{17}$$

where $t^{*y}(a, c) = [t_1^{*y}(a, c), t_2^{*y}(a, c), t_3^{*y}(a, c)]$ is the vector of equilibrium tariffs, for $y = sa, fta$.

Let us consider the convexity properties of the $w_i^{*y}(a, c)$ functions. First, from the result in footnote 20 above, it follows that if $w_i(t; a, c)$ is convex in the random variables then so is the maximum function: $\max_{t_i^y}\{w_i^y(t^y; a, c)\}$. But, is $w_i(t; a, c)$ convex in the random variables? From the definition in equation (7) it is clear that even convexity of the Nash equilibrium profit functions (which, in general, is not guarantied), does not imply convexity of $w_i(t; a, c)$. In addition, we would need the convexity of supply functions and consumer surplus; neither of which is guaranteed. Moreover, from the discussion of the properties of Nash equilibrium maximum functions in Section 3, it follows that, within a multi-player, game-theoretic setting, even if the maximum functions ($\max_{t_i^y}\{w_i^y(t^y; a, c)\},\ i = 1...3$) are all convex, it does not necessarily mean that the Nash equilibrium welfare functions, $w_i^{*y}(a, c)$, are also convex. As will be discussed further below, this has important implications for our analysis of TA option values and the choice of TAs.[24]

4.2 Tariff Choice: Customs Union

If countries 1 and 2 choose a *cu* in the first stage, in addition to free trade between them ($t_{12} = t_{21} = 0$), they also levy a common tariff on Country 3 ($t_{31} = t_{32}$). Letting T_{12}^{cu} be the feasible tariffs set for countries 1 and 2 when they form a *cu*, then we have:

$$T_{12}^{cu} \equiv \{(t_1, t_2) : t_{12} = t_{21} = 0,\ t_{31} = t_{32},\ t_{11} = t_{22} = 0\}. \tag{18}$$

[24] Clearly, if we replace Country $i's$ welfare functions by a weighted sum of the three components in equation (7), we would still face the same convexity issues as in the case of a simple sum. Thus, this will not affect the role of the TAs' option values substantially.

Since Country 3 does not sign a TA, its feasible set of tariffs T_3 is, once again, defined by equation (8). With a *cu*, therefore, the *cu* members between them jointly choose only one tariff, while Country 3 chooses only one tariff of its own.

Given the tariff restrictions facing Country 3 and the *cu* countries, the feasible set of all tariffs is given by,

$$T^{cu} \equiv \{(t_1, t_2, t_3) : t_{12} = t_{21} = 0,\ t_{31} = t_{32},\ t_{11} = t_{22} = t_{33} = 0,\ t_{13} = t_{23}\}. \tag{19}$$

We can satisfy the restrictions in (19) by substituting them directly into the countries' objective functions. To do this, define the tariffs to be chosen by the *cu* and country 3 as:

$$t^{cu} \equiv t_{31} = t_{32},\ t_3^{cu} \equiv t_{13} = t_{23} \tag{20}$$

Then, using these definitions and substituting the restrictions directly into the objective functions, we get in the *cu* case:

$$w_i^{cu} \equiv w_i^{cu}(t^{cu}, t_3^{cu}; a, c) \equiv \{w_i(t_1, t_2, t_3; \gamma) :\ (t_1, t_2, t_3) \in T^{cu},\quad \textit{definitions}\ (20)\} \tag{21}$$

Note that, now, w_i^{cu} is a function of two tariffs.

We assume that with a *cu* countries 1 and 2 jointly choose their optimal tariffs by maximizing (a social welfare function which is simply) the sum of their welfare:[25]

$$w^{cu}(t^{cu}, t_3^{cu}; a, c) \equiv w_1^{cu}(t^{cu}, t_3^{cu}; a, c) + w_2^{cu}(t^{cu}, t_3^{cu}; a, c) \tag{22}$$

Country 3, on the other hand, maximizes its welfare function as before. Thus, when countries 1 and 2 choose a *cu*, the maximization problems can be written as:

$$\max_{t^{cu}}\{w^{cu}(t^{cu}, t_3^{cu}; a, c)\},\ \text{and}\ \max_{t_3^{cu}}\{w_3^{cu}(t^{cu}, t_3^{cu}; a, c)\} \tag{23}$$

We assume that objective functions w^{cu} and w_3^{cu}, are strictly concave in t^{cu}, t_3^{cu}, respectively. Let the Nash equilibrium tariffs in the *cu* case be denoted as $t^{*cu}(a,c),\ \ t_3^{*cu}(a,c)$. The corresponding Nash equilibrium welfare in each country is then given by:

$$w_i^{*cu}(a,c) \equiv w_i^{cu}[t^{*cu}(a,c), t_3^{*cu}(a,c); a, c],\ i = 1..3, \tag{24}$$

As already noted in the context of the profit functions and sa/fta welfare functions, the properties of the $w_i^{*cu}(a,c)$ functions (particularly convexity) is also unclear; an issue which we will discuss in detail below.

Before we move on to stage 1, it is important to note that the differences between the Nash equilibrium tariffs, and hence Nash equilibrium welfare, under the three agreements are due to two factors: (i) differences in the

[25] Since $K_1^{cu} + K_2^{cu} = 0$, it follows that the sum of the two countries' welfare is the same as the sum of their net welfare. Maximizing a weighted sum of welfare yields similar results.

TAs degree of flexibility in the choice of tariffs (captured by the feasible tariff sets, T^y, $y = sa, fta, cu$ above) and (ii) differences in the degree of coordination in the tariff game. Consider the first factor. Given the MFN rules, we know that whereas cu is the least flexible, the relative flexibility of sa and fta is not clear (they both have the same number of tariffs to be chosen by each country). As for the second factor, whereas in the sa and fta cases each country maximizes it own welfare function, in the cu case a joint welfare function is maximized (by countries 1 and 2). The comparison between the cu and the other two TAs is, therefore, complicated because we need to consider the contributions of these two sets of differences.

4.3 Stage 1: The Choice of Trade Agreement

In stage 1, before the state of the world is known, countries 1 and 2 choose a TA. Given the countries' risk neutrality, they simply consider their expected welfare.[26]

In principle, we could use a general solution concept for the choice of an agreement; Nash Bargaining or the core, for example.[27] Since the specific solution concept is not the focus of the paper, we proceed (for consistency) by using the same social welfare function that was used above; namely, the sum of the two countries' expected welfare.

For any $y \in Y \equiv \{sa, fta, cu)$, let the total expected welfare of countries 1 and 2 be given by:

$$\begin{aligned} E[w^{*y}(a,c)] &\equiv \{E[w_1^{*y}(a,c) + K_1^y(a,c)]\} + \{E[w_2^{*y}(a,c) + K_2^y(a,c)]\} \\ &= E[w_1^{*y}(a,c)] + E[w_2^{*y}(a,c)], \end{aligned}$$

where $K_1^y(a,c)$ and $K_2^y(a,c)$ may be state contingent or fixed transfers, such that $K_1^y(a,c) + K_2^y(a,c) = 0$ for all (a,c), with $K_i^{sa}(a,c) = 0$[28] and m denotes (all) the moments of the distributions of the random variables a, c. Countries 1 and 2 select the TA that yields the highest total expected welfare, $E[w^{*y}(a,c)]$. Specifically, let y^* be the chosen (equilibrium) agreement, Then,

Proposition 1 *The agreement y^* is chosen if and only if for all $y \in Y$: $E[w^{*y}(a,c)] > E[w^y(a,c)]$ for all $y \neq y^*$*

Proof. (i) If $E[w^{*y}(a,c)] > E[w^y(a,c)]$ for all $y \neq y^*$, there must be corresponding transfers, given by $K_i^{y^*}$, where $K_1^{y^*} + K_2^{y^*} = 0$, such that $E[w_i^{*y^*}(a,c) + K_i^{y^*}] > E[w_i^{*y}(a,c)]$,[29] thus y^* is preferred to any another agreement. (ii) If y^* is chosen, it must be better than any other agreement for both countries. In other words, we must have: $E[w_i^{*y^*}(a,c) + K_i^{y^*}] > E[w_i^{*y}(a,c)]$, $i = 1,2$, for all $y \neq y^*$, where $K_1^{y^*} + K_2^{y^*} = 0$.

[26] But, remember that risk neutrality, here, does not imply that only first moments matter.

[27] In our context, both Nash Bargaining and the core are problematic. Specifically, the nature of the Nash bargaining "social welfare function" (non-linear and multiplicative) combined with the existence of uncertainty and a multi-stage, multi-party game, makes the solution intractable. The use of the core, on the other hand, does not always yield a unique equilibrium.

[28] Since without an agreement there would not (need not) be any transfers.

[29] But, on the other hand, there are no transfers, K_i^y, where $K_1^y + K_2^y = 0$, such that $E[w_i^{*y}(a,c) + K_i^y] > E[w_i^{*y^*}(a,c)]$.

Hence, $E[w^{*y}(a,c)] = E[w_1^{*y^*}(a,c) + K_1^{y^*}] + E[w_2^{*y^*}(a,c) + K_2^{y^*}] = E[w_1^{*y^*}(a,c)] + E[w_2^{*y^*}(a,c)] > E[w_1^{*y}(a,c)]$ $+E[w_2^{*y}(a,c)] = E[w^y(a,c)]$, for all $y \neq y^*$.[30] ■

5 Preferred Trade Agreements Under Uncertainty

In this section we examine the effects of uncertainty on the choice of TAs in the early resolution of uncertainty case. We also briefly comment on the effects in the late resolution case.

5.1 The Effect of Uncertainty on the Choice of TAs

Our main objective is to examine the effect of an increase in uncertainty on the choice of TAs. The most natural and general way to do this is to consider the effects of a mean-preserving-spread (MPS in the following) on the choice of TAs. For example, assume that all the variables in the vector $z = (a,c)$ are certain, except for z_j. Now, let z_j be a MPS of s_j (in the sense of Rothschild and Stiglitz (1970)).[31] Since we assume that all variables except for z_j are certain, for convenience, we can (suppress all the other variables and) write the Nash equilibrium expected welfare of Country, $i = 1,2,$ given the TA $y,$ simply as $E[w_i^{*y}(z_j)]$. The effect of a MPS is then given in the following Lemma.

Lemma 1: If z_j is a MPS of s_j and $w^{*y}(z_j)$, $i = 1,2$ is convex then: $E[w^{*y}(z_j)] > E[w^{*y}(s_j)]$.

Proof. This follows from Rothschild and Stiglitz (1970).[32] ■

In other words, a MPS increases the Nash equilibrium total expected welfare of countries 1 and 2.

Let us now show that this result can be reinterpreted as saying that the option value of a TA increases with a MPS. First, define the option value of TA y, for countries 1 and 2, as the difference between total Nash equilibrium expected welfare when their decisions (regarding outputs and tariffs) are made with and without information (the difference between the "expectation of the Max" and the "Max of the expectation"). In other words, the option value simply captures the value of information. First, note that the Nash equilibrium expected value of (maximum) welfare, for country $i = 1,2$, when decisions (regarding outputs and tariffs) are made with information - the "expectation of the Max" - is simply given by $E[w_i^{*y}(a,c)]$. The total Nash equilibrium expected welfare for countries 1 and 2 is, therefore, $E[w^{*y}(a,c)] = E[w_1^{*y}(a,c)] + E[w_2^{*y}(a,c)]$. Second, what about the case when decisions are made without information (the "Max of the expectation")? This is given in the following Lemma:

[30] It is useful to note that while the choice of agreement is always unique, the transfers are not uniquely determined. Since our objective is to identify the optimal trade agreement this is not a major problem here.

[31] That is, let the random variables z_j and s_j be distributed according to the density functions g_{z_j} and g_{s_j} with supports in $[\underline{n}, \overline{n}]$ (which may differ) and with cumulative distributions, $G_i(r) = \int_{\underline{n}}^{r} g_i(x)dx$, $i = z_j, s_j$. Define $\Phi_i(v) \equiv \int_{\underline{n}}^{v} G_i(\tau)\, d\tau$, $i = z_j, s_j$. Then, z_j is a MPS of s_j if (i) $\Phi_{z_j}(v) \leq \Phi_{s_j}(v)$, for all $v \in [\underline{n}, \overline{n}]$, (ii) $\Phi_{z_j}(\overline{n}) = \Phi_{s_j}(\overline{n})$ (for means to remain fixed).

[32] Rothschild and Stiglitz (1970) actually consider concave functions, but our Lemma is implied by their result. See Riley (2012) for both concave and convex functions.

Lemma 2: The total Nash equilibrium expected welfare, for countries 1 and 2, when decisions are made without information is given by $w^{*y}[E(a), E(c)]$.

Proof. See Appendix 7.1. ■

Lemma 2 shows that total Nash equilibrium expected welfare when decisions are made without information, depends on first moments only; thus it is unaffected by a MPS.

Given Lemma 2, the option value of TA y, for countries 1 and 2, denoted as ov^y, can be written as:

$$\begin{aligned} ov^y &= E[w^{*y}(a,c)] - w^{*y}[E(a), E(c)] \\ &= \sum_{i=1}^{2} \{E[w_i^{*y}(a,c)] - w_i^{*y}[E(a), E(c)]\} \end{aligned} \tag{25}$$

Equation (25) implies that a MPS affects the option value of a TA (for countries 1 and 2) only through its effect on $E[w^{*y}(a,c)]$. Thus, it is possible to compare the effects of a MPS on option values by comparing its effects on $E[w^{*y}(a,c)]$. Using this result, the effect of a MPS on TA option values is given by the following proposition:

Proposition 2 If $w^{*y}(z_j), i = 1, 2$, is convex, a MPS increases the option value of TA y for countries 1 and 2.

Proof. This follows immediately from Lemmas 1 and 2 and equation (25). ■

Proposition 2 implies that if $w^{*y}(z_j)$ is convex for all y, then a MPS increases the option values of all TAs. But, unfortunately, this does not explain how a MPS affects the choice of TAs. Clearly, what matters is the relative increase in option values. Specifically, comparing TAs y and $k \neq y$, a MPS will make TA y relatively more attractive if its option value increases relative to the option value of TA k. This implies that we have to compare the relative responsiveness of the TAs' option values to a MPS. The determinant of the relative (responsiveness and hence) attractiveness is given in the following proposition.

Proposition 3: For all $y, k = sa, fta, cu,\ k \neq y$, a MPS in z_j will increase the attractiveness (to countries 1 and 2) of TA y relative to TA k : (i) *if* $w^{*y}(z_j)$ is more convex in z_j than $w^{*k}(z_j)$, for all z_j, (ii) *if and only if* $w^{*y}(z_j)$ is, "on average" (as defined in Appendix 7.2), more convex in z_j than $w^{*k}(z_j)$.

Proof. See Appendix 7.2. ■

First, note that Proposition 3(i) states that greater convexity for all z_j is a sufficient condition. Proposition 3(ii), on the other hand, provides the necessary and sufficient condition. This necessary and sufficient condition does not require that $w^{*y}(z_j)$ should be more convex for *all* z_j; it is enough if "on average" (precisely defined in Appendix 7.2) it is more convex in z_j than $w^{*k}(z_j)$. Note, however, that if the functions $w^{*y}(z_j),\ y = sa, fta, ca$ are quadratic, then convexity rankings are global (for all z_j), so that greater convexity becomes a necessary and sufficient condition.

Second, consider the implications of Proposition 3 for option values. From Proposition 3 (and Proposition 2) it follows that, for all $y, k = sa, fta, cu,\ k \neq y$, a MPS in z_j will increase ov^y relative to ov^k : (i) if $w^{*y}(z_j)$ is more convex in z_j than $w^{*k}(z_j)$ for all z_j (ii) *if and only if* $w^{*y}(z_j)$ is, "on average", more convex in z_j than $w^{*k}(z_j)$.

Although the results in Proposition 3 are important in that they tell us what determines the effects of an increase in uncertainty on the relative attractiveness of TAs, it would be even more interesting if we could explain what determines relative convexity. Unfortunately, as we have already pointed out, convexity is generally difficult to derive in a strategic game. Nevertheless, intuitively, it would seem that the degrees of convexity of Nash equilibrium welfare functions, which determines the degree of responsiveness to a MPS, reflects the TAs' overall flexibility. Namely, a more flexible TA will give rise to greater convexity which, in turn, implies greater responsiveness to changes in uncertainty. But, since the overall degree of flexibility itself is a product of degrees of freedom in choosing tariffs and degree of coordination, the degree of convexity is ultimately determined by these two factors.

Clearly, without specific information about the structure of the model, comparing and explaining degrees of convexity (hence responsiveness) is, in general, not simple. Thus, to be able to carry out these comparisons, it would be useful if we could make use of a standard result that relates the ranking of expected values of functions to the ranking of variances.

We know that if $w^{*y}(\cdot)$ is convex and s_j is a MPS of z_j, then $Var(s_j) > Var(z_j)$ implies $E[w^{*y}(s_j)] > E[w^{*y}(z_j)]$ if and only if $w^{*y}(\cdot)$ is a quadratic function.[33] This result suggests that the quadratic case, here, is very attractive. In fact, as we will show below, the quadratic case has an additional useful property. Specifically, with a quadratic function it is very easy to compare degrees of convexity. This means that we can easily rank relative responsiveness to an increase in uncertainty, which is exactly what we need to do to be able to determine the change in the TA's relative attractiveness. Moreover, as is clear from Proposition 3 (ii), with quadratic functions, the convexity ranking (which is now global) is necessary and sufficient in order to be able to rank the effects of a MPS on the relative attractiveness of TAs.

It should be noted, however, that in the theory of choice under uncertainty, quadratic utility functions have unappealing properties.[34] So, why should it be a reasonable case to consider here? The answer is simple: because the usual objections are irrelevant here for two reasons. First, we assume risk neutrality (so having increasing absolute risk aversion is irrelevant). Second, and more importantly, we will show below that, under certain conditions (namely, with commonly used demand and cost functions), a quadratic expected welfare function does, in fact, emerge as the Nash equilibrium of the multi-stage game; a rather convenient result. In other words,

[33] See Rothschild and Stiglitz (1970).
[34] Non-global monotonicity and increasing absolute risk aversion.

we do not have to *assume* that we have a quadratic case; under certain conditions regarding demand and cost functions this case will *emerge* as the Nash equilibrium case. We will demonstrate that given such a quadratic Nash equilibrium expected welfare function, it is easy to compare the responsiveness of TAs to an increase in uncertainty. Thus, we will be able to determine the effects of uncertainty on the choice of TAs.

5.2 A Linear Example

Since, in general, convexity of Nash equilibrium welfare functions cannot be guaranteed in a game-theoretic framework, in this section we provide an example in which convexity is indeed satisfied. We do this by applying, commonly used, linear demand and cost functions. Using these functions, we obtain an explicit solution for the Nash equilibrium of the multi-stage game. In particular, we obtain Nash equilibrium welfare functions which are convex and can also be used to rank degrees of convexity. Thus, we can explain the effects of an increase in uncertainty on the choice of TAs.

We assume that Country $j's$ demand and cost functions, respectively, are given by:[35]

$$p_j = a_j - Q_j, \ j = 1..3, \tag{26}$$

$$C_i = c_i q, \ i = 1..3. \tag{27}$$

where a_j and c_i are the (random) demand and cost parameters as defined in Section 2.1.

Given these linear demand and cost functions, it can be shown that the solutions of the (different stages of the) game have the following properties:[36]

1. $\pi_i^*[t; a_j, c], \ i = 1..3$, is decreasing in c_i and t_{ij}, increasing in c_h, and t_{hj} for all $h \neq i$ (and all j) and convex in a, c.

2. For all TAs, the corresponding welfare functions, $w_i^y(\cdot)$, are strictly concave in their "own" tariff and additively separable in all tariffs. Hence, tariffs are strategically neutral, so we can solve for them separately.[37]

3. For all TAs, the corresponding welfare functions, $w_i^y(\cdot)$ are quadratic functions in (a, c, t^y) (without any linear terms), which implies that $E\{w_i^y(t^y; a, c)\}$ is quadratic in t^y and the first moments (m_1), but linear in the second moments (m_2).

4. For all TAs, the Nash equilibrium welfare functions, $w_i^{*y}(a, c), \ i = 1..3, \ y = sa, fta, cu$, are quadratic and convex in all the random variables. This convexity implies that $E[w_i^{*y}(a, c)]$ is increasing in all demand and cost variances.

[35] Where each market can be treated distinctly.

[36] For proofs see Appendix 7.3.

[37] Since market segmentation and additivity of welfare functions apply to all TAs, separability and hence strategic neutrality occur in all three agreements.

3. Since $w^{*y}(a,c) = w_1^{*y}(a,c) + w_2^{*y}(a,c)$, total Nash equilibrium expected welfare also has the same properties.

The properties above have the following implications. An increase in uncertainty (as captured here by an increase in demand or cost variance, holding means fixed) increases Nash equilibrium expected welfare and hence also option values, for all TAs.[38] Therefore, when uncertainty increases, the attractiveness of a TA increases, if its option value increases relative to another TA's option value. But, since the $w_i^{*y}(a,c)$ functions are quadratic and convex in all the random variables, the responsiveness of TAs to a change in uncertainty is simply captured by the parameters corresponding to the different variances. This enables us to compare responses to changes in uncertainty across TAs.

5.3 The Effects of Uncertainty in the Linear Case

In this section we examine the effects of a change in uncertainty on the choice of TAs, given our linear demand and cost functions. The results are summarized in the following propositions.

Proposition 4: An increase in uncertainty in variable $z_j,\ j = 1...6$ (as captured by an increase in $var(z_j)$) will increase the attractiveness (to countries 1 and 2) of TA y relative to TA k if and only if $w^{*y}(z),\ y = sa, fta, cu$, is more convex in z_j than $w^{*k}(z),\ k = sa, fta, cu,\ k \neq y$.[39]

Proof. The $E[w^{*y}(z)]$ functions are linear and increasing in all variances, since $w^{*y}(z)$ is quadratic and convex in the random variables, respectively, for all $y = sa, fta, cu$. Thus, $\partial E[w^{*y}(z)]/\partial var(z_j) = \partial^2 w^{*y}(z)/\partial z_j^2$ $= \lambda_j^y > 0$, where λ_j^y is a positive constant parameter (corresponding to the term z_j^2 in the $w^{*y}(z)$ function, as given in Appendix 7.3.4). This implies that comparing two TAs y and k we have: $\partial E[w^{*y}(z)]/\partial var(z_j)$ $-\partial E[w^{*y}(z)]/\partial var(z_j) = \lambda_j^y - \lambda_j^k$. But, $\lambda_j^y - \lambda_j^k > 0$ if and only if $w^{*y}(z)$ is more convex in z_j than $w^{*k}(z),\ y,k = sa, fta, cu,\ k \neq y$. ■

So what is the actual effect of an increase in demand and cost uncertainty on the choice of TAs? This is given in the next proposition.

Proposition 5: (i) An increase in demand uncertainty in either Country 1, or Country 2 (as captured by an increase in $var(a_j),\ j = 1,2$), will increase the attractiveness of fta relative to cu and the attractiveness of cu relative to sa. (ii) An increase in demand uncertainty in Country 3 (an increase in $var(a_3)$) has no effect on the relative rankings of the three TAs. (iii) An increase in cost uncertainty in either Country 1, or Country 2 (an increase in $var(c_j),\ j = 1,2$) will decrease the attractiveness of fta relative to sa and

[38] That is, $E[w_i^{*y}(a,c)]$, $i = 1,2$ and $E[w^{*y}(a,c)] - w^{*y}[E(a), E(c)]$ increase for all y.

[39] This is, of course, a special case of Proposition 3 above. First, here an increase in uncertainty is captured by an increase in variance, rather than the more general MPS. Second, here convexity is captured by a parameter (of the quadratic function). Third, here greater convexity is a necessary and sufficient condition (because the convexity ranking is global; namely, for all z_j), whereas in Proposition 3 it was sufficient, but not necessary (the necessary and sufficient condition there requires that we have greater convexity "on average").

the attractiveness of sa relative to cu. (iv) An increase in cost uncertainty in Country 3 (an increase in $var(c_3)$) will increase the attractiveness of cu relative to fta and the attractiveness of fta relative to sa.

Proof. Given Proposition 4 and the parameter values in Appendix 7.3.4: (i) for the variances of a_1 and a_2 we have: $\lambda_j^{fta} > \lambda_j^{cu} > \lambda_j^{sa} > 0$ for $j = 1..2$, (ii) for the variance of a_3 we have: $\lambda_3^{fta} = \lambda_3^{cu} = \lambda_3^{sa} > 0$, (iii) for the variances of c_1 and c_2 we have:$\lambda_j^{cu} > \lambda_j^{sa} > \lambda_j^{fta} > 0$, for $j = 4, 5$,(iv) for the variance of c_3 we have: $\lambda_3^{cu} > \lambda_3^{fta} > \lambda_3^{sa} > 0$.[40],[41] ■

Proposition 5 shows, that in the linear case, it is indeed possible to provide a more precise prediction of the effects of demand and cost uncertainty on the choice of TAs. Specifically, we are now able to obtain the precise convexity ranking of TAs with respect to all random variables and this enables us to determine the effects of uncertainty on the choice of TAs. The explanation for the actual ranking of convexity was already provided in the previous section; it is ultimately a product of degrees of freedom in choosing tariffs and degree of coordination.

It is interesting to note that a change in demand variances has a different effect on the TAs' relative attractiveness, than a change in cost variances. This, of course, reflects the fact that convexity rankings of demand and cost random variables are different. But why are these convexity rankings different? The intuitive answer to this question is that, in general, cost effects are more complex than demand effects. This is the case because all cost, but not all demand, random variables appear in the solutions for quantities and tariffs (see Appendix 7.3.2).[42] It is, therefore, not surprising that the trade-off between tariff-flexibility and coordination will be different for demand and cost uncertainty. Specifically, intuition suggests that an increase in cost uncertainty increases the relative importance of coordination. Thus, as cost uncertainty increases, CU becomes relatively more attractive (than FTA) because it involves greater coordination vis-à-vis cost externalities.

The results of Proposition 5 with respect to demand uncertainty are demonstrated in Figure 1 below. First, let us consider what happens when *demand* (but, for now, no cost) uncertainty is gradually introduced into the model. Figure 1 shows the cu/fta indifference loci for different $(\sigma_{1a}^2, \sigma_{2a}^2)$ pairs.[43] For any $(\sigma_{1a}^2, \sigma_{2a}^2)$ pair, cu is preferred in the area "between" the two "arms" of the indifference locus, whereas fta is preferred outside of this area (sa is everywhere the least preferred). Note that the no-uncertainty case is captured by the (two arms of the) linear indifference locus corresponding to the pair: $\sigma_{1a}^2 = \sigma_{2a}^2 = 0$. In this case, when member countries have sufficiently similar demands (everything else being identical), they prefer cu to any other type of TA. When member demands are sufficiently dissimilar, however, fta is preferred. The intuition underlying the results in

[40] The effects of changes in covariances can be easily obtained by comparing the coefficients that correspond to the "cross terms" $z_i z_j$, $i \neq j$ in the expressions for $w^{*y}(a, c)$ in Appendix 7.3.4: the attractiveness of a TA with a higher coefficient increases relative to a TA with a lower coefficient. For example, an increase in the covariance between demands in countries 1 and 2 increases the attractiveness of cu relative to both fta and sa, but does not change the attractiveness of fta relative to sa.

[41] It should be noted, however, that when there is no cost uncertainty sa is always least preferred, regardless of demand uncertainty and, in addition, it is never most preferred, for any type of uncertainty.

[42] Not all random variables appear because of the assumption of segmented markets.

[43] Remember that an increase in $var(a_3)$ has no effect on the relative rankings of the three TA.

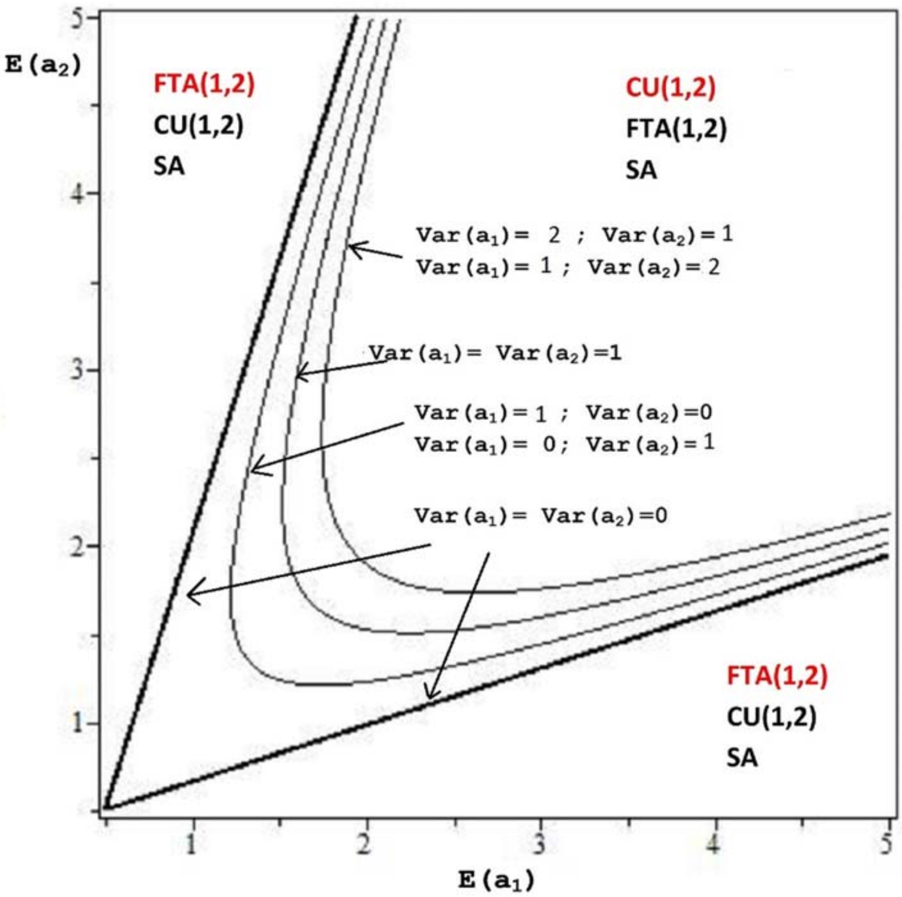

Figure 1: The impact of demand uncertainty on TA choice, taking: $\sigma^2_{3a} = \sigma^2_{ic} = 0$, $\mu_{ic} = \frac{1}{2}$ $\forall i$; $\sigma_{ija} = \sigma_{ijc} = 0$ $\forall i, j$; $\mu_{3a} = 1$.

Figure 1 is as follows. When member countries are sufficiently similar, on one hand, policy coordination in a CU is desirable since it allows members to extract additional rent from the excluded country compared to a FTA (or standing alone). On the other hand, being similar, the cost of choosing similar tariffs is not high anyway.[44] As either demand variance increases, the indifference locus moves up (along the main diagonal), becoming curved. As Figure 1 shows, when either variance increases, countries 1 and 2 are more likely to prefer fta to cu (i.e. the former is preferred for a wider range of mean demand parameters).

The results of Proposition 5 with respect to cost uncertainty are demonstrated in Figure 2 below.[45] Figure 2 shows the cu/fta indifference loci for different $(\sigma^2_{1c}, \sigma^2_{2c})$ pairs as the two arms of the curves going from the southwest to the northeast. For any $(\sigma^2_{1c}, \sigma^2_{2c})$ pair, cu is preferred to fta in the area "between" the two "arms" of the cu/fta indifference locus, whereas fta is preferred to cu outside of this area. The fta/sa indifference loci are given by the "circular curves" in the lower left corner. For any $(\sigma^2_{1c}, \sigma^2_{2c})$ pair, fta is preferred above the the indifference locus and sa is preferred below it. The cu/sa indifference loci are not shown because cu is

[44] Note that in Figure 1, taking the cost means to be equal biases the result in favour of a CU.
[45] Note that also in Figure 2, taking the cost means to be equal biases the result in favour of a CU.

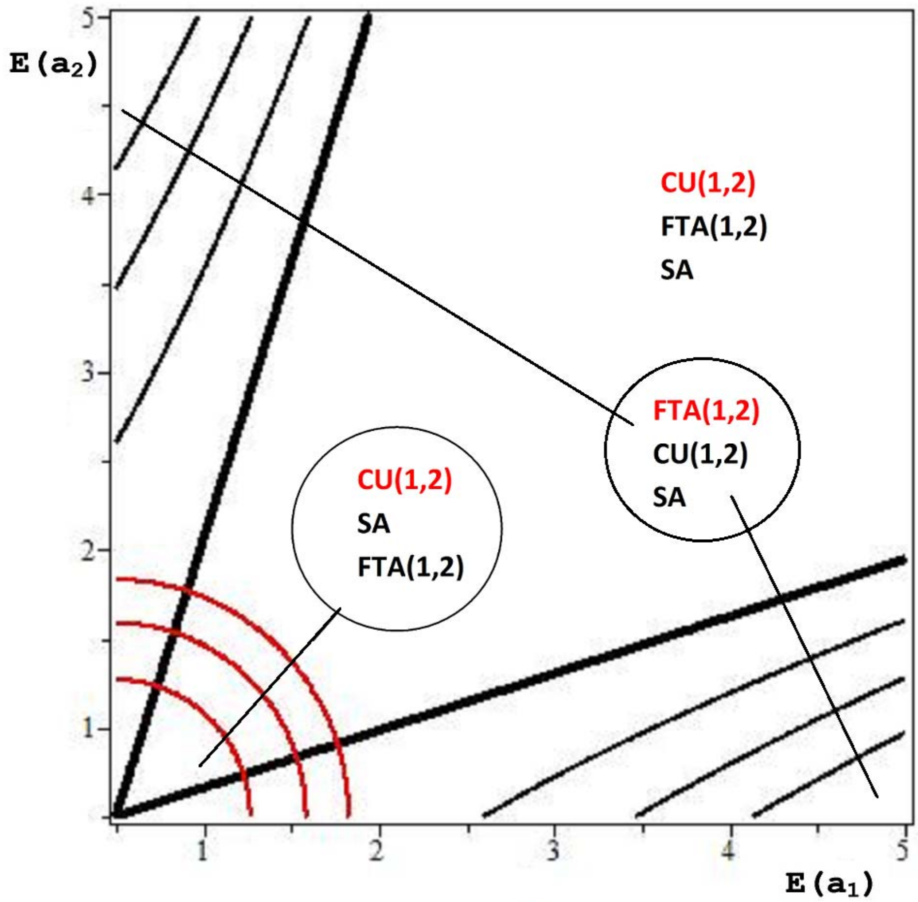

Figure 2: The impact of cost uncertainty on TA choice, taking: $\sigma^2_{ia} = \sigma^2_{3c} = 0$, $\mu_{ic} = \frac{1}{2}\ \forall i$; $\sigma_{ija} = \sigma_{ijc} = 0\ \forall i, j$; $\mu_{3a} = 1$. The cost varaince pairs for $\sigma^2_{1c}, \sigma^2_{2c}$ are $\{\ (0,0)\},\ \{(1,0),\text{ or }(0,1)\},\ \{(1,1)\}$ and $\{(1,2),\text{ or }(2,1)\}$.

everywhere preferred to sa. The no-uncertainty case is, again, captured by the two arms of the linear indifference locus (starting "near" the origin) corresponding to the pair: $\sigma^2_{1c} = \sigma^2_{2c} = 0$. Figure 2 shows that for any $(\sigma^2_{1c}, \sigma^2_{2c})$ pair, cu is preferred in the area "between" the two "arms" of the cu/fta indifference loci, whereas fta is preferred everywhere outside of this area *and* above the fta/sa indifference locus. Finally, although sa is always inferior to cu, it may sometime be preferred to fta.

The effects of an increase in cost uncertainty are also shown in Figure 2. When cost uncertainty, in any country, increases the two cu/fta indifference locus move away towards the two corners (northwest and southeast). Hence, countries 1 and 2 are more likely to prefer cu to fta. At the same time, the fta/sa indifference curve move farther away from the origin to the northeast. Thus, the attractiveness of fta relative to sa decreases with $var(c_i),\ i = 1, 2$.

5.4 The Effects of Uncertainty in the Linear LR Case

Before we conclude let us now briefly consider the effects of uncertainty on the choice of trade agreements in the LR case. The effects of uncertainty in the LR case are summarized in the following proposition:

Proposition 6 In a world in which uncertainty is resolved late a change in uncertainty does not affect the choice of TAs.

Proof. See Appendix 7.4. ■

In the LR case, a change in uncertainty does not affect the ranking of TAs and consequently, it plays no role in the choice of TAs. This explains why we focused on the ER case.

Finally, note that, in general, any option value associated with TA flexibility is, clearly, less prominent in the LR case than in the ER case since, in the former case, member countries do not have the opportunity to choose tariffs after uncertainty has been resolved.[46]

6 Conclusion

Before we conclude, two brief remarks are in order. First, it should be remembered that we use a partial, rather than a general equilibrium model. In a general equilibrium framework the countries' Nash equilibrium welfare functions may become more complicated because (in addition to the multi-stage game described here) their derivation also involves a set of (market clearing) conditions that determine prices.[47] Nevertheless, the option value determinants that we considered above will still be valid. Second, even within a competitive framework, where prices are taken as given (in stage 3), we would still have one strategic game (namely the choice of tariffs) and one joint-welfare maximizing stage (namely, the choice of a TA). Although the choice of quantities is now nonstrategic (hence, yielding "simple" convex profit functions), the choice of tariffs is within a strategic game, hence we would still need to obtain the properties of the Nash equilibrium welfare function. In conclusion, while in these alternative models the derivation of the TAs option values and their responsiveness may require additional/different consideration, the main idea of this paper would still hold. That is, TAs have option values which are affected by their flexibility, degree of coordination and the nature of uncertainty and these option values, in turn, affect the choice of TAs.

[46] It is also possible to consider the preferred *timing* of tariff decisions (early, or late), rather than the preferred agreements themselves. It can be shown that, in the presence of little (or no) uncertainty, since the option value of TA flexibility is very low, member countries are predisposed to prefer *cu* most and *sa* least, regardless of the timing of the resolution of uncertainty. As uncertainty rises, however, these preference change. For example, as demand uncertainty increases, TA members increasingly prefer *any* TA in which they can choose tariffs after the resolution of uncertainty. Moreover, when demand uncertainty is sufficiently high, countries even prefer standing alone to any TA in which tariffs are chosen before the resolution of uncertainty. These results simply reflect the fact that the option value associated with TA flexibility is greater if member countries can choose tariffs after uncertainty has been resolved.

[47] But, we would still obtain the welfare functions $w_i^{*y}(a, c)$ as some functions of the random variables, possibly with different properties.

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7 Appendix

7.1 Proof of Lemma 2

In stage 3, each country solves the problem: $\max_{q_{i\cdot}} E\left[\pi_i(q, t_{i\cdot}; a, c_i)\right]$. Since demand and cost functions are linear in random variables, so are the the profit functions,[48] $\pi_i(q, t_{i\cdot}; a, c_i)$, so that $E\left[\pi_i(q, t_{i\cdot}; a, c_i)\right] = \pi_i[q, t_{i\cdot}; E(a), E(c_i)]$. Thus, if each country maximizes its expected profit (its problem without information about the random variables), the Nash equilibrium quantities, total output in each market and profits must all be functions of first moments only. But, in stage 2, since demand is linear in random variables, consumer surplus (given the total market output which depends on first moment, but not the random variables) is also linear in random variables,

[48] For example, take the following demand and cost functions (which are linear in random variables): $p_j = D_j(Q_j) + a_j$, $C_i = H_i(Q^i)c_i$. Then, $E(\pi_i) = \sum_{j=1}^{3}\{[D_j(Q_j) + E(a_j) - t_{ij}]q_{ij}\} - H_i(Q^i)E(c_i) = \pi_i[q, t_{i\cdot}; E(a_j), E(c_i)]$.

so its expected value is also simply a function of first moments. Furthermore, given that all Nash equilibrium quantities depend on first moments, so must tariff revenues (for given tariffs). This, in turn, implies all the expected welfare functions depend on first moments only. Hence we can write $E\left[w_i^y(t^y;a,c)\right] = w_i^y\left[t^y;E(a),E(c)\right],$ where for convenience we now define, $t^y = (t_1^y, t_2^y, t_3^y)$, if $y = sa, fta$, and $t^y = t^{cu}, t_3^{cu}$, if $y = cu$. But then, it is clear that the Nash equilibrium tariffs and the corresponding Nash equilibrium welfare must also be functions of first moments only. In other words, for each country the Nash equilibrium welfare can be written as: $w_i^{*y}[E(a),E(c)]$. Thus, the total Nash equilibrium expected welfare, for **countries** 1 and 2, is $w_1^{*y}[E(a),E(c)] + w_2^{*y}[E(a),E(c)] = w^{*y}[E(a),E(c)]$.

7.2 Proof of Proposition 3

Let the distribution of z_j be denoted as: $g(z_j;\beta)$, $z_j \in [\underline{n},\overline{n}]$, where β is a parameter that represent a MPS. That is, as β increases the distribution becomes (second order) stochastically dominated, holding the mean fixed. Let the cumulative distribution of z_j be denoted as: $G(z_j;\beta) = \int_{\underline{n}}^{z_j} g(z_j,\beta)dz_j$. Now, if we define $F(z_j,\beta) \equiv \int_{\underline{n}}^{z_j} \frac{\partial G(z_j,\beta)}{\partial \beta}dz_j$, then for an increase in β to be a MPS we require that: (i) the area under G should increase with β, namely: $F(z_j,\beta) \geq 0$, for all z_j, (ii) the total area should remain fixed, namely: $F(\overline{n},\beta) = 0$.[49] Now, consider TA y. Its expected Nash equilibrium welfare is given by: $E[w^{*y}(z_j)] = \int_{\underline{n}}^{\overline{n}} w^{*y}(z_j)g(z_j,\beta)\,dz_j$. Using differentiation by parts twice, this can be written as: $E[w^{*y}(z_j)] = \varphi + \int_{\underline{n}}^{\overline{n}} \frac{\partial^2 w^{*y}(z_j)}{\partial z_j^2}[\int_{\underline{n}}^{z_j} G(z_j,\beta)\,dz_j]dz_j$, where φ is a constant. Thus, the effect of a MPS in z_j on $E[w^{*y}(z_j)]$ is given by: $\frac{\partial E[w^{*y}(z_j)]}{\partial \beta} = \int_{\underline{n}}^{\overline{n}} \frac{\partial^2 w^{*y}(z_j)}{\partial z_j^2}[\int_{\underline{n}}^{z_j} \frac{\partial G(z_j,\beta)}{\partial \beta}dz_j]dz_j = \int_{\underline{n}}^{\overline{n}} \frac{\partial^2 w^{*y}(z_j)}{\partial z_j^2}F(z_j,\beta)dz_j \equiv \Psi^y > 0$ (since $w^{*y}(z_j)$ is convex and $F(z_j,\beta) \geq 0$, for all z_j). Similarly, for TA k, the effect of a MPS in z_j on $E[w^{*k}(z_j)]$ is given by: $\frac{\partial E[w^{*k}(z_j)]}{\partial \beta} = \int_{\underline{n}}^{\overline{n}} \frac{\partial^2 w^{*k}(z_j)}{\partial z_j^2}F(z_j,\beta)dz_j \equiv \Psi^k > 0$. Note that Ψ^y and Ψ^k can be interpreted as the "weighted average" convexity measures of $w^{*y}(z_j)$ and $w^{*k}(z_j)$.[50] Thus, we have (i) a sufficient condition: if $\frac{\partial^2 w^{*y}(z_j)}{\partial z_j^2} > \frac{\partial^2 w^{*k}(z_j)}{\partial z_j^2}$ for all z_j than $\frac{\partial E[w^{*y}(z_j)]}{\partial \beta} > \frac{\partial E[w^{*k}(z_j)]}{\partial \beta}$, (ii) a necessary and sufficient condition: $\frac{\partial E[w^{*y}(z_j)]}{\partial \beta} > \frac{\partial E[w^{*k}(z_j)]}{\partial \beta}$ if and only if $\Psi^y > \Psi^k$. Clearly, condition (ii) does not require that $w^{*y}(z_j)$ should be more convex than $w^{*k}(z_j)$ for *all* z_j. It is enough that the "weighted average" measure of convexity in z_j is greater. Finally, conditions (i) and (ii) above are, respectively, the sufficient and the necessary and sufficient conditions that a MPS in z_j will make TA y relatively more attractive than TA k.

7.3 Explicit Solutions for the Linear Example

7.3.1 Nash equilibrium outputs and the corresponding profits are given by:

$q_{ij}^* = \frac{1}{4}[a_j + \sum\limits_{k \neq i}(c_k + t_{kj}) - 3(c_i + t_{ij})]$, $i = 1..3$, and $\pi_i^*[t;a,c] = \frac{1}{16}[a_j + \sum\limits_{h \neq i}(c_h + t_{hj}) - 3(c_i + t_{ij})]^2, i = 1..3.$

[49] See Rothschild and Stiglitz (1970), Mas-Colell et. al. (1995) for a discussion of these conditions.

[50] With weights $F(z_j,\beta)dz_j$.

7.3.2 Nash equilibrium tariffs are given by:

(i) $t_3^{*y}(a,c) = \frac{1}{10}(3a_3 - \sum_{i=1}^{3} c_i), y = fta, cu$, (ii) $t_i^{*sa}(a,c) = \frac{1}{10}(3a_i - \sum_{i=1}^{3} c_i),\ i = 1..3$, (iii) $t_i^{*fta}(a,c) = \frac{1}{7}a_i - \frac{1}{21}c_i + \frac{1}{3}c_j - \frac{3}{7}c_3,\ i,j = 1,2, i \neq j$ and (iv) $t^{*cu}(a,c) = \frac{5}{38}(a_1 + a_2) + \frac{1}{19}(c_1 + c_2) - \frac{7}{19}c_3$.

7.3.3 Country $1's$ welfare, $w_1^y(t^y; a,c)$, for each TA:

Let us define, $A_1(a,c) \equiv \frac{11}{32}{a_1}^2 + \frac{1}{16}\sum_{k\neq 1} {a_k}^2 + \frac{55}{32}{c_1}^2 - \frac{3}{8}\sum_{k\neq 1} c_1 a_k + \frac{1}{8}\sum_{h\neq 1}\sum_{k\neq 1} c_h a_k - \frac{17}{16}\sum_{k\neq 1} c_1 c_k + \frac{7}{32}\sum_{h\neq 1}\sum_{k\neq 1} c_h c_k - \frac{9}{16}a_1 c_1 - \frac{1}{16}\sum_{k\neq 1} c_k a_1$,

$B_1^{sa}(t^{sa}; a,c) \equiv \frac{3}{8}a_1 t_1^{sa} - \frac{1}{8}\sum_{j=1}^{3} c_j t_1^{sa} - \frac{5}{8}\left(t_1^{sa}\right)^2 + \frac{1}{4}\sum_{k\neq 1}\left(t_k^{sa}\right)^2 - \frac{1}{4}\sum_{k\neq 1} a_k t_k^{sa} + \frac{3}{4}\sum_{k\neq 1} c_1 t_k^{sa} - \frac{1}{4}\sum_{h\neq 1}\sum_{k\neq 1} c_h t_k^{sa}$

$B_1^{fta}(t^{fta}; a,c) \equiv \frac{3}{16}a_1 t_1^{fta} - \frac{1}{16}c_1 t_1^{fta} + \frac{7}{16}c_2 t_1^{fta} - \frac{9}{16}c_3 t_1^{fta} - \frac{21}{32}(t_1^{fta})^2 + \frac{1}{16}(t_2^{fta})^2 + \frac{1}{4}(t_3^{fta})^2 + \frac{1}{8}a_2 t_2^{fta} - \frac{1}{4}a_3 t_3^{fta} - \frac{3}{8}c_1 t_2^{fta} + \frac{3}{4}c_1 t_3^{fta} + \frac{1}{8}\sum_{h\neq i} c_h t_2^{fta} - \frac{1}{4}\sum_{h\neq 1} c_h t_3^{fta}$

$B_1^{cu}(t^{cu}; a,c) \equiv \frac{3}{16}a_1 t_{cu}^{cu} - \frac{7}{16}c_1 t_{cu}^{cu} + \frac{9}{16}c_2 t_{cu}^{cu} - \frac{7}{16}c_3 t_{cu}^{cu} - \frac{19}{32}\left(t_{cu}^{cu}\right)^2 + \frac{1}{4}\left(t_3^{cu}\right)^2 + \frac{1}{8}a_2 t_{cu}^{cu} - \frac{1}{4}a_3 t_3^{cu} + \frac{3}{4}c_1 t_3^{cu} - \frac{1}{4}\sum_{h\neq 1} c_h t_3^{cu}$

Then, the explicit expression for Country $1's$ welfare, as a function of tariffs and the random variables (equations (16) and (22)), is given by: $w_1^y(t^y; a,c) = A_1(a,c) + B_1^y(t^y; a,c)$, $y = sa, fta, cu$. Note that the $B_1^y(t^y; a,c)$ functions are concave in Country 1's tariff, spareable in all tariffs and linear in all the random variables. But, in addition, the $B_1^y(t^y; a,c)$ functions themselves also differ for different $y's$ (TAs), namely: for equal values of $t^y = t$, we have: $B_1^z(t; a,c) \neq B_1^y(t; a,c)$, if $z \neq y$. The solutions are similar for Country 2.

7.3.4 Country $1's$, Nash equilibrium welfare, $w_1^{*y}(a,c)$, for each TA:

$w_1^{*sa}(a,c) = \frac{2}{5}{a_1}^2 + \frac{1}{100}{a_2}^2 + \frac{1}{100}{a_3}^2 - \frac{3}{5}c_1 a_1 - \frac{7}{50}c_1 a_2 - \frac{7}{50}c_1 a_3 - \frac{1}{10}c_2 a_1 + \frac{3}{50}c_2 a_2 + \frac{3}{50}c_2 a_3 - \frac{1}{10}c_3 a_1 + \frac{3}{50}c_3 a_2 + \frac{3}{50}c_3 a_3 + \frac{79}{50}{c_1}^2 + \frac{7}{25}{c_2}^2 + \frac{7}{25}{c_3}^2 - \frac{57}{50}c_1 c_2 - \frac{57}{50}c_1 c_3 + \frac{14}{25}c_2 c_3$

$w_1^{*fta}(a,c) = \frac{5}{14}{a_1}^2 + \frac{4}{49}{a_2}^2 + \frac{1}{100}{a_3}^2 - \frac{4}{7}c_1 a_1 - \frac{8}{21}c_1 a_2 - \frac{7}{50}c_1 a_3 + \frac{20}{147}c_2 a_2 + \frac{3}{50}c_2 a_3 - \frac{1}{7}c_3 a_1 + \frac{4}{49}c_3 a_2 + \frac{3}{50}c_3 a_3 + \frac{9637}{6300}{c_1}^2 + \frac{13819}{44100}{c_2}^2 + \frac{1591}{4900}{c_3}^2 - \frac{3373}{3150}c_1 c_2 - \frac{941}{1050}c_1 c_3 + \frac{1823}{7350}c_2 c_3$

$w_1^{*cu}(a,c) = \frac{871}{2432}{a_1}^2 + \frac{167}{2432}{a_2}^2 + \frac{1}{100}{a_3}^2 + \frac{25}{1216}a_1 a_2 - \frac{47}{76}c_1 a_1 - \frac{33}{76}c_1 a_2 - \frac{7}{50}c_1 a_3 - \frac{1}{76}c_2 a_1 + \frac{15}{76}c_2 a_2 + \frac{3}{50}c_2 a_3 - \frac{5}{38}c_3 a_1 + \frac{3}{38}c_3 a_2 + \frac{3}{50}c_3 a_3 + \frac{3081}{1900}{c_1}^2 + \frac{521}{1900}{c_2}^2 + \frac{621}{1900}{c_3}^2 - \frac{1049}{950}c_1 c_2 - \frac{899}{950}c_1 c_3 + \frac{271}{950}c_2 c_3$.

The solutions are similar for Country 2 (with the proper change in indexing). The solution for $w^{*y}(a,c) = w_1^{*y}(a,c) + w_2^{*y}(a,c)$ is then obtained easily. To make comparisons of the coefficients of $w^{*y}(a,c)$ easier, we provide it with the coefficients converted into rational numbers, with three decimal points precision (when needed):

$w^{*sa}(a,c) = -0.08c_1a_3 - 0.04c_3a_2 - .54c_1a_1 - 2.28c_1c_2 - .24c_1a_2 - .24c_2a_1 - .54c_2a_2 - 0.04c_3a_1 - 0.08c_2a_3 - .58c_2c_3 + .12c_3a_3 - .58c_3c_1 + .41a_1^2 + 1.86c_1^2 + 1.86c_2^2 + .41a_2^2 + 0.02a_3^2 + .56c_3^2$

$w^{*fta}(a,c) = -0.08c_1a_3 - 0.061c_3a_2 - .434c_1a_1 - 2.14c_1c_2 - .381c_1a_2 - .381c_2a_1 - .435c_2a_2 - 0.061c_3a_1 - 0.08c_2a_3 - .648c_2c_3 + .12c_3a_3 - .648c_3c_1 + 1.84c_1^2 + 1.84c_2^2 + 0.02a_3^2 + .649c_3^2 + .439a_2^2 + .439a_1^2$

$w^{*cu}(a,c) = -0.053c_3a_1 - .421c_1a_1 - .421c_2a_1 - .661c_3c_1 - .661c_2c_3 - 2.21c_1c_2 - 0.053c_3a_2 - .421c_2a_2 - .421c_1a_2 + .12c_3a_3 - 0.08c_1a_3 - 0.08c_2a_3 + .427a_1^2 + .654c_3^2 + 1.90c_1^2 + 1.90c_2^2 + .427a_2^2 + 0.02a_3^2 + 0.041a_1a_2$

7.4 Proof of Proposition 6

From Property 3 in Section 5.2, with our linear demand and cost functions, each country's welfare function, $w_i^y(t^y;z)$ is a quadratic function in (z,t^y); but without any linear terms. This implies that $E\{w_i^y(t^y;z)\}$ is (i) quadratic in t^y and m_1, but linear in the m_2, (ii) additively separable in tariffs and second moments (there are no terms involving the product of tariffs and second moments)[51]. Let us write $E\{w_i^y(t^y,z)\} \equiv M_i^y[t^y,m_1,m_2]$. But, being a quadratic, we can break $M_i^y[t^y,m_1,m_2]$ into two parts; one containing all the terms that involve tariffs and one that does not. Namely, we can write it as: $M_i^y[t^y,m_1,m_2] = A_i^y(m_1,m_2) + B_i^y(t^y,m_1)$, where $B_i^y(0,m_1) = 0$ and $B_i^y(t^y,m_1)$ does not involve m_2 because of the separability of tariffs and second moments. Now, notice that since $M_i^y[t^y,m_1,m_2]$ is additively separable in tariffs and second moments, it follows that Nash equilibrium tariffs are unaffected by the second moments (since the countries' first order conditions for tariffs do not involve m_2). We can, therefore, write the Nash equilibrium tariffs as $t^{*y} = t^y(m_1)$. The Nash equilibrium expected welfare is, therefore, given by: $M_i^{*y}[m_1,m_2] \equiv M_i^y[t^{*y}(m_1),m_1,m_2] = A_i^y(m_1,m_2) + B_i^y[t^{*y}(m_1),m_1]$. But, notice that when tariffs are zero, the third stage problems (output choices) are the same for all TAs. Hence, it is clear that when tariffs are zero, each country's welfare and, therefore, expected welfare and option values, are also the same for all TAs. In other words, we have $A_i^y(m_1,m_2) = A_i(m_1,m_2)$, for all y, so that, $M_i^{*y}[m_1,m_2] = A_i(m_1,m_2) + B_i^y[t^{*y}(m_1),m_1]$ for all y. Using this, we can now obtain the effect of a change in a second moment on the countries' Nash equilibrium welfare very easily. Denote the j^{th} element in the vector of second moments, m_2, as m_2^j. For example, let m_2^j be the variance of z_j (the demand or cost variance of any country). Then we have: $\partial M_i^{*y}[m_1,m_2]/\partial m_2^j = \partial A_i(m_1,m_2)/\partial m_2^j$, for all $y = sa, fta, cu$. In other words, the effect of a change in (any) variance on a country's expected welfare is the same for all TAs. This is, therefore, also true for the total expected welfare of countries 1 and 2. Thus, a change in uncertainty does not affect the relative ranking of TAs by counties 1 and 2.

[51] That is, all the cross partial derivatives of tariffs and second moments are zero. Note for non-separability of tariffs and second moments we would need $w_i^y(t^y;z)$ to contain terms such as $t^y z_i^2$, in other words, it would have to be cubic and not quadratic.