International Trade, Minimum Quality Standards and the Prisoners' Dilemma*

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Abstract

Unilateral minimum quality standards are endogenously determined as the outcome of a non-cooperative standard-setting game between the governments of two countries. Cross-country externalities from the implementation of minimum quality standards are shown to give rise to a Prisoners' Dilemma structure in the incentives of policy-makers leading to inefficient policy outcomes. The role of minimum quality standards as non-tariff barriers is examined and the scope for mutual gains from reciprocal adjustment in minimum standards analysed. The analysis delivers four results. First, there exist four unregulated Nash equilibria in minimum standards, two symmetric and two asymmetric, depending on the quality ranking of firms in each market. The analysis establishes that in all four cases, unilaterally selected minimum quality standards are inefficient as a result of cross-country externalities. Second, minimum quality standards are shown to operate as non-tariff barriers to trade. Third, the world welfare maximising symmetric standard can be reached through reciprocal adjustments in national minimum standards from either of the two symmetric Nash equilibria. Finally, the scope for mutually beneficial cooperation is shown to be significantly restricted when cross-country externalities are asymmetric.Asymmetric externalities make a cooperative agreement at the world optimum infeasible.

Keywords: standards, quality, international trade, standard coordination

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1 Introduction

This paper extends a well-established vertical product differentiation model to a two-country framework in which international duopolists compete in quality and price in each market. Unilateral minimum quality standards are endogenously determined as the outcome of a non-cooperative standard-setting game between the governments of the two countries. The international context highlights the effects of cross-country externalities from the implementation of minimum quality standards that can be both positive, both negative, or asymmetric, depending on the quality of traded goods. These externalities are shown to give rise to a Prisoners' Dilemma structure in the incentives of the two policy-makers that leads to inefficient policy outcomes. The role of minimum quality standards as non-tariff barriers is examined and the incentives and scope for international cooperation analysed.

The paper contributes to both the international trade and industrial organisation literature in a number of ways.

First, the paper extends the literature that examines the effects of minimum quality standards in markets where firms offer vertically differentiated products by analysing national incentives to regulate quality in an open-economy setting. The cross-country externalities generated when countries are linked through international trade are not present in the literature that studies quality standards in the context of a single economy.

Second, the paper endogenously determines national minimum quality standards through the strategic interaction between policy-makers. To the best of my knowledge, this is the first analysis that endogenises national decisions to regulate quality in an international context. The industrial organisation literature has widely analysed the effects of minimum standards in a single country, but has done so by introducing minimum standards as exogenous constraints. Only recently has the issue of endogenous determination of quality standards begun to be addressed. Ecchia and Lambertini (1997) endogenously determine the minimum quality standard in the context of one country where a social planner sets the standard to maximise national welfare. This paper extends to two policy-makers, each of which unilaterally selects their national minimum quality standard to maximise national welfare. The individually optimal standard are shown to be jointly suboptimal as a result of the cross-country externalities.

Third, the analysis contributes to the literature on international cooperation by examining whether bargaining from a non-cooperative Nash equilibrium in minimum quality standards can lead to an efficient outcome. The analysis follows the approach of the literature on cooperation in tariffs (e.g. Bagwell and Staiger, 1999, 2002; Staiger and Tabellini, 1987) but shows that endogenous country asymmetries arising from specialisation in goods of different quality levels introduce constraints to cooperation that do not arise in the literature on cooperation in tariffs.

The related literature on minimum quality standards originates in the industrial organisation literature, with the development of vertical quality differentiation models (e.g. Gabszewicz and Thisse, 1979; Shaked and Sutton, 1982).

In his renowned paper, Ronnen (1991) uses the Shaked and Sutton framework to demonstrate that mild minimum quality standards are welfare improving in a duopoly where firms compete in prices and incur fixed quality-development costs. Similar results are obtained by Crampes and Hollander (1995) assuming that quality improvements increase variable rather than fixed costs.

The literature has more recently turned to open economy versions of the vertically differentiated duopoly framework. Motta and Thisse (1993) analyses the effects of environmental quality standards in autarky and free trade, while Boom (1995) analyses the effects of differing national standards for firms who cannot tailor quality to different markets. She finds that exit from the market with the more stringent standard may occur if the difference in national minimum standards is beyond a certain threshold, but does not determine national standards endogenously through a standard-setting game.

The model in this paper differs from Boom (1995) and other works assuming up-front quality development costs (Ronnen 1991, Zhou *et al.*, 2000, Herguera *et al.*, 2002, among others), by assuming firms incur quality dependent variable costs (as in Motta, 1993, Crampes and Hollander, 1994, and Lutz, 2005). Hence the model applies more closely to industries where quality improvements stem from higher quality of materials or ingredients or other factors embedded in the production process (e.g. textiles) rather than from innovative characteristics or design that arise from up-front investment in research and development (e.g. pharmaceuticals). The advantage of this cost specification is it gives firms the flexibility to tailor quality levels to different markets and to thus respond endogenously and asymmetrically to different quality standards.

The rest of the paper proceeds as follows. Section 2 introduces the model and characterises the unregulated equilibria. Section 3 examines national incentives for standard-setting and solves for the non-cooperative Nash equilibria in minimum quality standards. The properties of these are examined and contrasted to world welfare-maximising international standards. International cooperation in setting quality standards is analysed in Section 4. Section 5 concludes.

2 The Model

This section describes the economic environment of the two-country model of vertical product differentiation and characterises the unregulated equilibria. This lays the groundwork for the rest of the paper that analyses the non-cooperative standard-setting game between policy-makers and examines the scope and effects of international cooperation in standard-setting. The underlying quality differentiation model is closest to Motta (1993), Crampes and Hollander (1995) and Ecchia and Lambertini (1997) for a single economy.

2.1 Economic Environment

Consider two segmented markets, A and B, with a single firm located in each (firms A and B). The firms compete in quality and prices in each market, producing a vertically differentiated good. The firms can supply goods of a single quality level in each market but are able to differentiate the quality of their exports from the quality of their domestic sales. Let q_{ij} be the quality level of the good produced in country i (by firm i) and consumed in country j, where $i, j \in \{A, B\}$. We assume no upper bound to quality level so $q_{ij} \in [0, \infty)$. There is no potential entry of additional firms, but the duopolists may choose not to supply goods to either or both markets. Finally, we assume no transport costs.

The firms interact in a two-stage game. In the first stage, firms non-cooperatively select quality levels q_{AA}, q_{AB} and q_{BB}, q_{BA}, respectively. Perfect and costless commitment to these quality levels is assumed. Firms compete in prices in the second stage, given first stage quality levels. Firms have access to the same production technology, which involves variable costs that are convex in quality and linear in quantity. No sunk costs of quality development are assumed[1]. Let $V(S_{ij,}q_{ij})$ denote variable costs of production as a function of quality, q_{ij}, and sales, S_{ij}, of firm i in market j, where these are as in (1):

$$V(S_{ij,}q_{ij}) = bq_{ij}^2 S_{ij}, \text{ where } b > 0 \tag{1}$$

Convexity in quality is both necessary and sufficient for the existence of an interior solution[2] for quality choice in stage 1, and can thus be accompanied by an unlimited range for quality level q_{ij}.

The demand side is assumed to consist of a continuum of consumers in each market with a varying taste parameter[3], θ. Consumers are uniformly distributed, with unit density, over the interval $\left[0, \overline{\theta}\right]$ and derive utility from the first unit of purchase only. The indirect utility function of a consumer with taste parameter θ, purchasing a unit of a good with quality q and price p is described by (2):

$$U = \theta q - p \tag{2}$$

Given firms' decisions $(q_{ij,}p_{ij})$, consumers in each market choose between (i) purchasing one unit of the good from firm A, (ii) purchasing one unit of the

[1] Note that the absence of fixed sunk costs of quality development implies the equilibrium choice of qualities and prices would not change if firms chose these simultaneously and non-cooperatively, rather than sequentially and non-cooperatively. The sequential structure is preserved for purposes of comparability with the related literature.

[2] There is no interior solution for firm quality levels if the variable cost function is non-convex. For example, if variable costs are linear in quality, e.g. $V(q) = cq$, the low quality firm's best response is a quality level $\frac{4}{7}$ that of the high quality firm, while the high quality firm adds to profit by raising quality without limit (e.g. Choi and Shin, 1992). A solution can only be pinned down by assuming quality has a finite upper limit, $\overline{q}$, where the high quality firm locates.

[3] Parameter θ may also be interpreted as the inverse of the marginal rate of substitution between income and quality such that a consumer with a higher θ has a lower marginal rate of substitution between income and quality and thus a higher income. With this interpretation the framework presented is analogous to models where consumers vary in their income level rather than preference over quality e.g Gabszewicz and Thisse (1979), Shaked and Sutton (1982).

good from firm B, or (iii) making no purchase. Consumers receive zero utility if they do not buy the good. Note that since the minimum value for θ is zero, there is always a measure of consumers who prefer not to buy the good when prices are positive, implying incomplete market coverage. Parameter $\overline{\theta}$ measures market size, which is symmetric in both countries.

Further suppose the governments of countries A and B have the opportunity to regulate quality in their market by unilaterally setting minimum quality standards in a stage 0, prior to the strategic interaction of firms. Governments choose standards to maximise national welfare, anticipating firms' optimal price and quality responses.

The solution concept employed to solve the multi-stage game is subgame perfect equilibrium (SPE), found by backward induction. First, the unique second-stage equilibrium in prices is analysed and firms' payoffs described in terms of first-stage qualities. Second, optimal first stage quality decisions of firms are examined. This allows the unregulated equilibria to be characterised. Then, the effects of minimum quality standards are examined, yielding the regulated optimal quality responses of firms. Finally, the incentives for standard setting are analysed and the non-cooperative Nash equilibria in minimum standards characterised. The issue of international cooperation in standard setting is analysed in the next section of the paper.

2.2 The Price-Setting Subgame

Firms A and B compete in prices in each market in the final stage of the game, given stage 1 quality levels. It is common practice in the industrial organisation literature with one market to arbitrarily assign one firm as high quality, solving for equilibrium prices and qualities assuming an exogenous quality ranking between firms. Rather than assigning a particular quality ordering between firms in each market, we suppose that in each market j, there is a 'high' quality supplier (H), with quality level q_{Hj}, and a 'low' quality supplier (L), with quality level q_{Lj}, where $q_{Hj} \geq q_{Lj}$. This allows for the possibility that firms choose identical quality levels in stage 1. The associated price levels of these goods are denoted by p_{Hj} and p_{Lj}, respectively. We proceed to characterise equilibrium prices and qualities for the H and L quality goods supplied in each market and then examine the multiple equilibria that correspond to different configurations of quality rankings of firms A and B in the two markets.

Hence, in the final stage of the game, firm quality levels are fixed in market j, such that $q_{Hj} \geq q_{Lj}$. Let x_{Hj} and x_{Lj} denote quality-deflated prices for the H and L goods, respectively, and let r_j denote the quality ratio, such that:

$$x_{Hj} \equiv \frac{p_{Hj}}{q_{Hj}} \text{ and } x_{Lj} \equiv \frac{p_{Lj}}{q_{Lj}} \tag{3}$$

$$r_j \equiv \frac{q_{Hj}}{q_{Lj}} \tag{4}$$

Consider the structure of demand for the two goods. Let z_j denote the preference parameter of the marginal consumer in market j who is indifferent between purchasing one unit of the good of quality q_{Hj} at price p_{Hj} and one unit of the good of quality q_{Lj} at price p_{Lj}. The marginal consumer z_j follows directly from (2) and is given by:

$$z_j = \frac{p_{Hj} - p_{Lj}}{q_{Hj} - q_{Lj}} = \frac{r_j x_{Hj} - x_{Lj}}{r_j - 1} \tag{5}$$

Moreover, let k_j denote the preference level of the consumer who is indifferent between buying the differentiated good and not making a purchase. Consumption of one unit of the good of quality q_{Lj} at price p_{Lj} yields zero utility for this consumer, so from (2) it follows that $k_j \equiv x_{Lj} = \frac{p_{Lj}}{q_{Lj}}$. Hence, consumers with preference parameter $z_j \leq \theta \leq \overline{\theta}$ purchase good H and consumers for whom $x_{Lj} \leq \theta < z_j$ purchase good L. Consumers with $0 \leq \theta < x_{Lj}$ make no purchase.

The quantity demand for H and L goods in market j, and thus firm sales, are denoted by S_{Hj} and S_{Lj}, respectively, and given by:

$$S_{Hj} = \overline{\theta} - z_j = \overline{\theta} - \frac{p_{Hj} - p_{Lj}}{q_{Hj} - q_{Lj}} \tag{6}$$

$$S_{Lj} = z_j - x_{Lj} = \frac{p_{Hj} - p_{Lj}}{q_{Hj} - q_{Lj}} - \frac{p_{Lj}}{q_{Lj}} \tag{7}$$

The corresponding profits, Π_{Hj} and Π_{Lj}, from H and L sales in market j, are thus:

$$\Pi_{Hj} = \left(p_{Hj} - bq_{Hj}^2\right)\left(\overline{\theta} - z_j\right) \tag{8}$$

$$\Pi_{Lj} = \left(p_{Lj} - bq_{Lj}^2\right)\left(z_j - x_{Lj}\right) \tag{9}$$

Substituting for z_j and rearranging yields:

$$\Pi_{Hj} = \frac{1}{r_j - 1} q_{Hj}\left(x_{Hj} - bq_{Hj}\right)\left(\overline{\theta}\left(r_j - 1\right) - r_j x_{Hj} + x_{Lj}\right) \tag{10}$$

$$\Pi_{Lj} = \frac{r_j}{r_j - 1} q_{Hj}\left(x_{Lj} - bq_{Lj}\right)\left(x_{Hj} - x_{Lj}\right) \tag{11}$$

Maximising Π_{Hj} with respect to x_{Hj}, given x_{Lj} and r_j, yields the quality-deflated price reaction function (R_H) of firm H in j:

$$x_{Hj}\left(x_{Lj}\right) = \frac{1}{2r_j}\left[\overline{\theta}\left(r_j - 1\right) + br_j q_{Hj} + x_{Lj}\right] \tag{12}$$

Maximising Π_{Lj} with respect to x_{Lj}, given x_{Hj} and r_j, yields the reaction function (R_L) of firm L in j:

$$x_{Lj}\left(x_{Hj}\right) = \frac{1}{2}\left(bq_{Lj} + x_{Hj}\right) \tag{13}$$

The slopes of the price reaction functions, $\frac{dx_{Hj}}{dx_{Lj}}_{|R_H} = \frac{1}{2r_j}$ and $\frac{dx_{Hj}}{dx_{Lj}}_{|R_L} = 2$, respectively, confirm prices are strategic complements. Moreover, if $q_{Hj} > q_{Lj}$ in stage 1, then $r_j > 1$ and $x_{Hj} > x_{Lj}$, while if $q_{Hj} = q_{Lj}$ in stage 1, then $r_j = 1$ and (12) and (13) imply that $x_{Hj} = x_{Lj}$.

Solving (12) and (13) simultaneously yields the unique Nash equilibrium in quality-deflated prices, in terms of parameters b, $\overline{\theta}$, and firm quality levels:

$$x_{Hj} = \frac{1}{4q_{Hj} - q_{Lj}} \left(2q_{Hj}\overline{\theta} - 2q_{Lj}\overline{\theta} + 2bq_{Hj}^2 + bq_{Lj}^2\right) \tag{14}$$

$$x_{Lj} = \frac{1}{4q_{Hj} - q_{Lj}} \left(q_{Hj}\overline{\theta} - q_{Lj}\overline{\theta} + bq_{Hj}^2 + 2bq_{Hj}q_{Lj}\right) \tag{15}$$

Substituting (14) and (15) into (5) yields the equilibrium marginal consumer z_j:

$$z_j = \frac{1}{4q_{Hj} - q_{Lj}} \left(2q_{Hj}\overline{\theta} - q_{Lj}\overline{\theta} + 2bq_{Hj}^2 + bq_{Hj}q_{Lj}\right) \tag{16}$$

Equilibrium prices follow directly from (14) and (15):

$$p_{Hj} = \frac{q_{Hj}}{4q_{Hj} - q_{Lj}} \left(2\overline{\theta}\left(q_{Hj} - q_{Lj}\right) + 2bq_{Hj}^2 + bq_{Lj}^2\right) \tag{17}$$

$$p_{Lj} = \frac{q_{Lj}}{4q_{Hj} - q_{Lj}} \left(\overline{\theta}\left(q_{Hj} - q_{Lj}\right) + bq_{Hj}^2 + 2bq_{Hj}q_{Lj}\right) \tag{18}$$

Inspection of (17) and (18) reveals the quality gap, $(q_{Hj} - q_{Lj})$, to be a key determinant of prices. If firms choose identical quality levels $q_{Hj} = q_{Lj} = q_j$, then the quality gap is zero and prices collapse to marginal cost, $p_{Hj} = p_{Lj} = bq_j^2$. The Bertrand outcome for homogeneous goods where price is equal to marginal cost and firm profits are zero results. This drives the quality differentiation result of the literature, confirmed in the next section.

2.3 Nash Equilibrium in Firm Qualities

Anticipating the price implications of their quality decisions, firms set quality levels non-cooperatively in stage 1. Substituting (17) and (18) into (6) and (7) gives demands in terms of stage 1 qualities:

$$S_{Hj} = \overline{\theta} - z_j = \frac{q_{Hj}}{4q_{Hj} - q_{Lj}} \left(2\overline{\theta} - 2bq_{Hj} - bq_{Lj}\right) \tag{19}$$

$$S_{Lj} = z_j - x_{Lj} = \frac{q_{Hj}}{4q_{Hj} - q_{Lj}} \left(\overline{\theta} + bq_{Hj} - bq_{Lj}\right) \tag{20}$$

It is now straightforward to express firms' first stage profits as a function of quality levels, market size and the cost parameter:

$$\Pi_{Hj}(q_{Hj}, q_{Lj}) = (q_{Hj} - q_{Lj})\frac{q_{Hj}^2\left(2\overline{\theta} - 2bq_{Hj} - bq_{Lj}\right)^2}{(4q_{Hj} - q_{Lj})^2} \tag{21}$$

$$\Pi_{Lj}(q_{Hj}, q_{Lj}) = (q_{Hj} - q_{Lj})\frac{q_{Hj}q_{Lj}\left(\overline{\theta} + bq_{Hj} - bq_{Lj}\right)^2}{(4q_{Hj} - q_{Lj})^2} \tag{22}$$

The profit equations confirm that firms can only earn positive profits when a quality gap is established in stage 1. Profits are affected by quality choice in two ways. Firms trade off the cost of producing a higher quality good with the higher price made possible by the higher quality level, but also consider the disparity in quality levels, which affects the intensity of price competition. The quality levels in the unregulated equilibrium are found by solving the following system of first-order conditions, that captures these two effects:

$$\frac{\partial\Pi_{Hj}(q_{Hj}, q_{Lj})}{\partial q_{Hj}} = \frac{q_{Hj}\left(2bq_{Hj} + bq_{Lj} - 2\overline{\theta}\right)}{(4q_{Hj} - q_{Lj})^3}(24bq_{Hj}^3 - 22bq_{Hj}^2q_{Lj} + 5bq_{Hj}q_{Lj}^2 \tag{23}$$

$$+2bq_{Lj}^3 - 4q_{Hj}^2\overline{\theta} + 6q_{Hj}q_{Lj}\overline{\theta} - 8q_{Lj}^2\overline{\theta}) = 0$$

$$\frac{\partial\Pi_{Lj}(q_{Hj}, q_{Lj})}{\partial q_{Lj}} = \frac{q_{Hj}\left(\overline{\theta} + bq_{Hj} - bq_{Lj}\right)}{(4q_{Hj} - q_{Lj})^3}(4bq_{Hj}^3 - 19bq_{Hj}^2q_{Lj} + 17bq_{Hj}q_{Lj}^2 \tag{24}$$

$$-2bq_{Lj}^3 + 4q_{Hj}^2\overline{\theta} - 7q_{Hj}q_{Lj}\overline{\theta}) = 0$$

The first order conditions simplify to (25) and (26), which implicitly define the quality reaction functions of the two firms, $q_{Hj}\left(q_{Lj}\right)$ and $q_{Lj}\left(q_{Hj}\right)$:

$$24bq_{Hj}^3 - 22bq_{Hj}^2q_{Lj} + 5bq_{Hj}q_{Lj}^2 + 2bq_{Lj}^3 - 4q_{Hj}^2\overline{\theta} + 6q_{Hj}q_{Lj}\overline{\theta} - 8q_{Lj}^2\overline{\theta} = 0 \tag{25}$$

$$4bq_{Hj}^3 - 19bq_{Hj}^2q_{Lj} + 17bq_{Hj}q_{Lj}^2 - 2bq_{Lj}^3 + 4q_{Hj}^2\overline{\theta} - 7q_{Hj}q_{Lj}\overline{\theta} = 0 \tag{26}$$

The analytical expressions for $q_{Hj}\left(q_{Lj}\right)$ and $q_{Lj}\left(q_{Hj}\right)$ are not included in the main text due to their length, but can be found in Appendix A. The reaction functions are illustrated for parameter values $\overline{\theta} = 5$ and $b = \frac{1}{2}$ in figure (1), and shown to be positively sloped, indicating that firm quality levels are strategic complements. The intuition behind the upward sloping $q_{Hj}\left(q_{Lj}\right)$ reaction function is straightforward. A rise in q_{Lj} narrows the quality gap, thereby intensifying stage 2 price competition. The high quality firm thus has an incentive to increase its quality in order to widen the quality gap and alleviate competition. The convexity of costs with respect to quality ensures it is not optimal for the high quality firm to fully offset the impact of higher q_{Lj} and thus $q_{Hj}\left(q_{Lj}\right)$ has a slope less than 1.

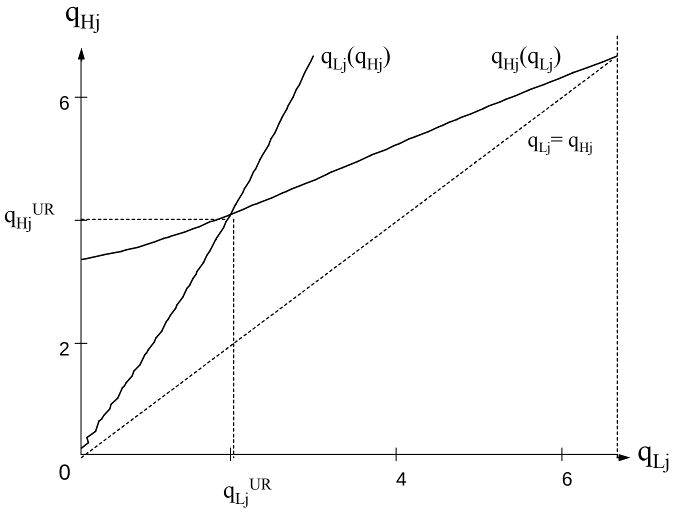

Figure 1: Unregulated Nash equilibrium in qualities.

The upward sloping reaction function of the low quality firm, $q_{Lj}\left(q_{Hj}\right)$, is less straightforward, since an increase in q_{Hj} widens the quality gap, relaxing price competition. The intuition behind the relationship is that the low quality firm's revenue is increasing in its own quality level, but its ability to raise q_{Lj} is constrained by the stronger price competition that ensues. The alleviation of price competition through a higher q_{Hj} thus permits an increase in q_{Lj}, that would otherwise not be optimal.

Since product differentiation relaxes *ex post* price competition[4], firms find it optimal to offer distinct quality levels in equilibrium. Solving (25) and (26) simultaneously yields the unregulated equilibrium quality levels $q_{Hj}^{UR} = 0.40976\frac{\overline{\theta}}{b}$ and $q_{Lj}^{UR} = 0.19936\frac{\overline{\theta}}{b}$. They are increasing in market size, but decreasing in the cost parameter of the model.

In the context of the two-country model, either high or low quality goods are imported by j. The larger the market size of country j, or the higher is the highest income level (depending on the interpretation of θ), then the higher the quality of traded goods of a given type. The results of the model are thus consistent with recent empirical studies that find a positive relationship between the quality of traded goods and country size and income (Hallak, 2006; Hummels

[4] This result is reminiscent of the well-known result of Kreps and Scheinkman (1983), where duopolists choose capacity constraints and then compete in prices. The incentive to constrain output in order to alleviate price competition gives rise to the Cournot outcome. Commitment to quality differentiation serves a similar purpose in the vertical product differentiation literature, but there are key differences; quality-differentiated goods command different prices, so firms are asymmetric in equilibrium. In contrast, capacity constraints serve to uniformly raise price above marginal cost preserving the symmetry between firms.

and Klenow, 2005).

Substituting equilibrium qualities $q_{Hj}^{UR} = 0.40976\frac{\overline{\theta}}{b}$ and $q_{Lj}^{UR} = 0.19936\frac{\overline{\theta}}{b}$ into the prices, sales, and profit equations fully characterises the unregulated equilibrium. The results are reported in table (1).

The consumer surplus in j, C_j, is comprised by the surplus of consumers of high quality goods H, denoted by C_{Hj}, and of consumers of low quality goods L, denoted by C_{Lj}. Integrating utility over the relevant range of consumers gives the expressions (27), (28) and (29), expressed in terms of firm quality levels and model parameters $\overline{\theta}$ and b. Substituting for equilibrium quality levels yields consumer surplus in the unregulated equilibrium, reported in table (2).

$$C_{Hj} = \int_{z_j}^{\overline{\theta}} (\theta q_{Hj} - p_{Hj})\, d\theta \tag{27}$$

$$= \frac{q_{Hj}^2 \left(2\overline{\theta} - 2bq_{Hj} - bq_{Lj}\right)}{2\left(4q_{Hj} - q_{Lj}\right)^2} \left(bq_{Hj}\overline{\theta} + bq_{Lj}\overline{\theta} - 2bq_{Lj}^2 - 2bq_{Hj}^2 + bq_{Lj}q_{Hj}\right)$$

$$C_{Lj} = \int_{x_{Lj}}^{z_j} (\theta q_{Lj} - p_{Lj})\, d\theta \tag{28}$$

$$= \frac{q_{Hj}^2 q_{Lj}}{2\left(4q_{Hj} - q_{Lj}\right)^2} \left(\overline{\theta} + bq_{Hj} - bq_{Lj}\right)^2$$

$$C_j = C_{Hj} + C_{Lj}$$

$$= \frac{q_{Hj}^2}{2\left(4q_{Hj} - q_{Lj}\right)^2} (3b^2 q_{Lj}^3 - 2bq_{Lj}q_{Hj}\overline{\theta} + 4b^2 q_{Hj}^3 + b^2 q_{Lj} q_{Hj}^2$$

$$+ b^2 q_{Lj}^2 q_{Hj} + 5q_{Lj}\overline{\theta}^2 - 8bq_{Lj}^2\overline{\theta} + 4q_{Hj}\overline{\theta}^2 - 8bq_{Hj}^2\overline{\theta}) \tag{29}$$

The Unregulated Market j		
Quality levels	$q_{Hj}^{UR} = 0.40976\frac{\overline{\theta}}{b}$	$q_{Lj}^{UR} = 0.19936\frac{\overline{\theta}}{b}$
Quality ratio	$r_j = 2.0554$	
Quality gap	$q_{Hj} - q_{Lj} = 0.2104\frac{\overline{\theta}}{b}$	
Prices	$p_{Hj} = 0.22666\frac{\overline{\theta}^2}{b}$	$p_{Lj} = 0.075010\frac{\overline{\theta}^2}{b}$
Quality-deflated prices	$x_{Hj} = 0.53314\overline{\theta}$	$x_{Lj} = 0.37625\overline{\theta}$
Marginal consumer	$z_j = 0.72075\overline{\theta}$	
Sales	$S_{Hj} = 0.27925\overline{\theta}$	$S_{Lj} = 0.3445\overline{\theta}$
Profits	$\Pi_{Hj} = 0.016407\frac{\overline{\theta}^3}{b}$	$\Pi_{Lj} = 0.012149\frac{\overline{\theta}^3}{b}$
Consumer surplus	$C_j = 0.046985\frac{\overline{\theta}^3}{b}$	

Table 1: The Unregulated Market

2.4 Firm Quality Rankings and Multiple Equilibria

Sections 2.2 and 2.3 solve for unregulated equilibrium prices and qualities in each market, without specifying which of the two firms, A or B, is the high or low quality supplier in each market. The assumption that firms can freely choose quality levels for domestic and export sales and the absence of transport costs gives rise to four possible equilibria:

1. Each firm supplies its home market with low quality goods and exports high quality goods, so $q_{AA} < q_{BA}$ and $q_{AB} > q_{BB}$. Countries trade in high quality goods.

2. Each firm supplies its home market with high quality goods and exports low quality goods, so $q_{AA} > q_{BA}$ and $q_{AB} < q_{BB}$. Countries trade in low quality goods.

3. Firm A is the world high quality supplier, so $q_{AA} > q_{BA}$ and $q_{AB} > q_{BB}$. Country B imports high quality goods from A while A imports low quality goods from B.

4. Firm B is the world high quality supplier, so $q_{AA} < q_{BA}$ and $q_{AB} < q_{BB}$. Country A imports high quality goods from B while B imports low quality goods from A.

Hence the model gives rise to three possible trade patterns. Countries may trade in high quality goods, low quality goods, or bilateral trade may be in goods of different quality levels (equilibria 3 and 4 are symmetric).

The welfare of a country is measured as the sum of consumer surplus and profits of the domestic firm from domestic sales and exports. The welfare of each country thus depends on the quality rankings of firms in each market, and hence on the pattern of trade in equilibrium. While world welfare, denoted by W, is unchanged between equilibria, the distribution of welfare between countries varies. Consumer surplus is symmetric between countries at $C_j = 0.046985\frac{\overline{\theta}^3}{b}$ but the higher profits earned from H sales in the unregulated equilibrium imply higher welfare from a higher quality ranking of firm j relative to the foreign firm.

Equations (30) to (33) give the welfare equations for country A under the four equilibrium configurations:

$$W^A_{|q_{AA}<q_{BA},q_{AB}>q_{BB}} = C_A + \Pi_{LA} + \Pi_{HB} \tag{30}$$
$$W^A_{|q_{AA}>q_{BA},q_{AB}<q_{BB}} = C_A + \Pi_{HA} + \Pi_{LB} \tag{31}$$
$$W^A_{|q_{AA}>q_{BA},q_{AB}>q_{BB}} = C_A + \Pi_{HA} + \Pi_{HB} \tag{32}$$
$$W^A_{|q_{AA}<q_{BA},q_{AB}<q_{BB}} = C_A + \Pi_{LA} + \Pi_{LB} \tag{33}$$

Correspondingly, equations (34) to (37) describe welfare for country B under the four equilibrium configurations:

$$W^B_{|q_{AA}<q_{BA},q_{AB}>q_{BB}} = C_B + \Pi_{HA} + \Pi_{LB} \tag{34}$$

$$W^B_{|q_{AA}>q_{BA},q_{AB}<q_{BB}} = C_B + \Pi_{LA} + \Pi_{HB} \tag{35}$$

$$W^B_{|q_{AA}>q_{BA},q_{AB}>q_{BB}} = C_B + \Pi_{LA} + \Pi_{LB} \tag{36}$$

$$W^B_{|q_{AA}<q_{BA},q_{AB}<q_{BB}} = C_B + \Pi_{HA} + \Pi_{HB} \tag{37}$$

Combining the unregulated market outcome reported in table (2) with welfare equations (30) to (33) and (34) to (37) yields the unregulated welfare levels in table (3) for the four equilibrium configurations.

Unregulated Equilibrium Welfare Distribution			
Firm Rankings	W^A	W^B	W
(1) $q_{AA} < q_{BA}$, $q_{AB} > q_{BB}$	$0.075541\frac{\overline{\theta}^3}{b}$	$0.075541\frac{\overline{\theta}^3}{b}$	$0.151082\frac{\overline{\theta}^3}{b}$
(2) $q_{AA} > q_{BA}$, $q_{AB} < q_{BB}$	$0.075541\frac{\overline{\theta}^3}{b}$	$0.075541\frac{\overline{\theta}^3}{b}$	$0.151082\frac{\overline{\theta}^3}{b}$
(3) $q_{AA} > q_{BA}$, $q_{AB} > q_{BB}$	$0.079799\frac{\overline{\theta}^3}{b}$	$0.071283\frac{\overline{\theta}^3}{b}$	$0.151082\frac{\overline{\theta}^3}{b}$
(4) $q_{AA} < q_{BA}$, $q_{AB} < q_{BB}$	$0.071283\frac{\overline{\theta}^3}{b}$	$0.079799\frac{\overline{\theta}^3}{b}$	$0.151082\frac{\overline{\theta}^3}{b}$

Table 2: Welfare distribution in the unregulated equilibria.

Table (3) shows the asymmetric distribution of welfare in equilibria (3) and (4) where national firms are either world quality leaders or world low quality suppliers. Equilibria (1) and (2) give rise to symmetric welfare effects in the unregulated equilibrium. This symmetry is not preserved, however, in the regulated equilibrium where governments set minimum standards non-cooperatively, as is made clear in the next section.

3 Non-Cooperative Minimum Quality Standards

This section endogenises the choice of minimum quality standards in the two countries, where these are the result of a non-cooperative standard-setting game between the governments of A and B. The objective function of each policy-maker is to maximise national welfare, taking as given the minimum standard of the other country, while anticipating the optimal quality response of the high quality firm and ensuing duopolistic price competition.

The industrial organisation literature on minimum quality standards has only recently endogenised the choice of national minimum quality standard (Ecchia and Lambertini,1997), prior to which standards were modelled as exogenous constraints. This paper extends the analysis to examine the incentives for standard-setting in an international context, thereby showing the effects of cross-country externalities and the role of trade patterns in shaping national incentives. Section 2.4 establishes the three possible trade patterns that arise as equilibria of the two-country model. These in turn correspond to three non-cooperative Nash equilibria in minimum standards.

The section first examines the effects of minimum quality standards on key market variables that influence national decisions. The government reaction functions in minimum standards are then examined and the Nash equilibria in minimum quality standards characterised. These are contrasted to the world optimum pair of quality standards and the role of unilateral standards as non-tariff barriers to trade is analysed.

3.1 The Effects of Minimum Quality Standards

The welfare improving effects of minimum quality standards in a single market with two price-competing duopolists was first found in Ronnen (1991) and is a feature of the subsequent literature, such as Crampes and Hollander (1995) and more recently Ecchia and Lambertini (1997). It is common to the literature that the intensity of price competition induces a greater degree of quality differentiation than is optimal from a social welfare perspective, which a minimum standard can correct by narrowing the quality gap between the two goods and raising both quality levels.

As the next few sections show, the incentive to regulate is also a feature of the two-country model, but the open economy characteristics of the framework distort policy-makers' incentives to correct the inefficiency in quality-differentiation. This section analyses the effects of a minimum quality standard, s^j, in country j, such that $s^j > q_{Lj}^{UR}$. The related industrial organisation literature usually examines the effects of 'mild' minimum standards as exogenous constraints, defined as a standard in between the two unregulated qualities, $q_{Hj}^{UR} > s^j > q_{Lj}^{UR}$. Since s^j is determined endogenously in this model as a result of a strategic game between policy-makers, we prefer not to restrict policy-makers' strategy space through *a priori* assumptions about whether unilaterally selected standard are 'mild' or 'severe', i.e. $s^j \geq q_{Hj}^{UR} > q_{Lj}^{UR}$. The effects of s^j on key market variables, for the range of values consistent with both firms remaining in market j, are summarised by the following:

(i) The quality levels of both firms increase and the degree of quality differentiation decreases: $q_{Lj} > q_{Lj}^{UR}$ as a result of the binding standard, and $q_{Hj}(s^j) > q_{Hj}^{UR}$ as a result of the strategic complementarity between quality levels. The standard has the effect of raising the quality of the low quality firm closer to that of its rival. As discussed in section 2.3, the optimal response for the high quality firm to raise its own quality level to alleviate the price competition induced by the implementation of a minimum quality standard. The convexity of costs ensures that the high quality firm's quality rises less than proportionally, as a result of the trade-off between the intensified price competition that a smaller quality gap implies and the convex costs of quality improvement. The high quality firm's quality response to minimum standard standard s^j is found by substituting $q_{Lj} = s^j$ into the high quality firm's reaction function, implicitly defined by (25), which yields $q_{Hj}(s^j)$, the optimal response of the high quality firm[5] to standard s^j. Figure (2) illustrates the path of quality levels and

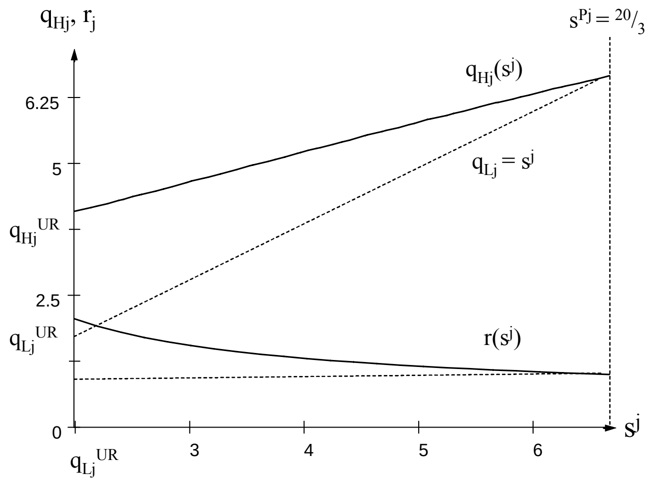

Figure 2: Regulated equilibrium qualities.

the quality ratio r^j with minimum standard s^j for $\overline{\theta} = 5$ and $b = \frac{1}{2}$. As the severity of the minimum standard increases, the quality ratio converges to 1, while the quality gap converges to zero. Let s^{Pj} denote the 'prohibitive' minimum standard in country j, at which quality levels are equal. The ensuing price competition is at its strongest and both firms earn zero profit. s^{Pj} is thus the highest standard consistent with the survival of both firms in market j. For standards $s > s^{Pj}$, firms would make losses[6] giving rise to exit. Solving $q_{Hj}(s^{Pj}) = q_{Lj} = s^{Pj}$ yields the general expression for s^{Pj}:

$$s^{Pj} = \frac{2\overline{\theta}}{3b} \tag{38}$$

The larger the market, or the lower is firm cost, then the higher the maximum standard consistent with a duopolistic outcome. For $\overline{\theta} = 5$ and $b = \frac{1}{2}$, $s^{Pj} = \frac{20}{3}$ as illustrated in figure (2).

(ii) Prices are increasing and converging over $s^j \in \left[q_{Lj}^{UR}, \frac{2\overline{\theta}}{3b}\right]$. There are two conflicting effects on price levels. First, a higher s^j implies higher quality levels for both firms and thus higher variable costs, that are increasing at

[5] The analytical expression for $q_{Hj}(s^j)$ can be found in Appendix A.

[6] Note that if firms incur a fixed costs of production in addition to the variable cost specification assumed, the threshold standard above which exit occurs is lower than s^{Pj}. For simplicity, fixed costs are set at zero.

an increasing rate due to the convexity assumption. Second, the convergence of quality levels intensifies price competition, moderating the impact of costs of price levels. The cost effects dominate under the assumptions of the model, in contrast to other contributions, where prices fall with standards (e.g. Ronnen, 1991, Boom, 1995). Substituting $q_{Lj} = s^j$ and $q_{Hj}(s^j)$ into price equations (17) and (18) yields $p_{Hj}(s^j, b, \overline{\theta})$ and $p_{Lj}(s^j, b, \overline{\theta})$, which are confirmed to be increasing in s^j, while the price gap is declining in s^j. Figure (3) illustrates $p_{Hj}(s^j, b, \overline{\theta})$ and $p_{Lj}(s^j, b, \overline{\theta})$ for $\overline{\theta} = 5$ and $b = \frac{1}{2}$.

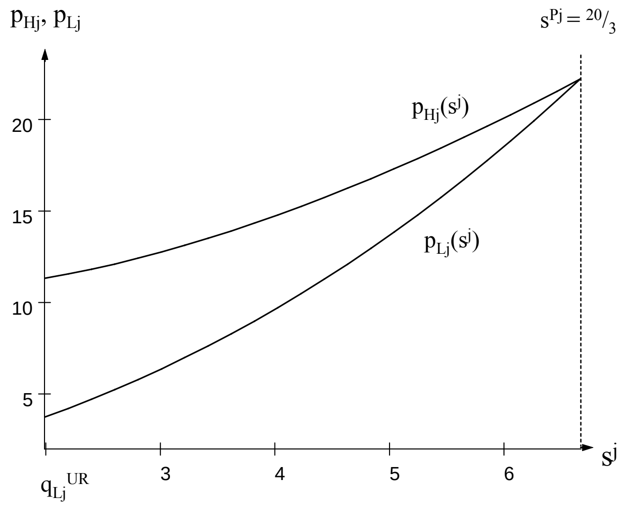

Figure 3: Regulated equilibrium prices.

(iii) Profits of the high quality supplier decrease with standard s^j and profits of the low quality increase with standards up to a certain threshold level, $\overline{s}$, above which they also decline. Substituting $q_{Lj} = s^j$ and $q_{Hj}(s^j)$ into the profit equations (21) and (22) yield $\Pi_{Hj}(s^j, b, \overline{\theta})$ and $\Pi_{Lj}(s^j, b, \overline{\theta})$, from which $\frac{\partial \Pi_{Hj}(s^j, b, \overline{\theta})}{\partial s^j} < 0$ is confirmed. Solving $\frac{\partial \Pi_{Lj}(s^j, b, \overline{\theta})}{\partial s^j} = 0$ and confirming the maximum yields threshold level:

$$\overline{s} = 0.27763 \frac{\overline{\theta}}{b} \tag{39}$$

Hence, $\frac{\partial \Pi_{Lj}(s^j, b, \overline{\theta})}{\partial s^j} > 0$ for $s^j \in \left[q_{Lj}^{UR}, \overline{s}\right]$ and $\frac{\partial \Pi_{Lj}(s^j, b, \overline{\theta})}{\partial s^j} < 0$ for $s^j \in \left[\overline{s}, s^{Pj}\right]$. The path of firm profits earned from high and low quality sales in j is illustrated for $\overline{\theta} = 5$ and $b = \frac{1}{2}$ in figure (4). The economic mechanism for these contrasting effects operates through the narrowing quality gap and price implications of s^j. As the quality gap narrows, some consumers switch from consuming the high quality good to consuming the low quality good. At the same time, the increasing prices imply some consumers switch from consuming low quality goods to not making any purchase. From (16), (15) and (25), $\frac{\partial z_j}{\partial s^j} > 0$ and $\frac{\partial x_{Lj}}{\partial s^j} > 0$. The implications of the increase in the preference parameter of the marginal consumers, is an unambiguous decline in demand for high quality goods with s^j, lowering Π_{Hj}. This negative relationship is common feature of the related literature. The low quality firm enjoys a larger overall market share for sufficiently low s^j but beyond a threshold $\widehat{\widehat{s}}$, the stronger price competition dominates the market share effect and profits decline. Expressing low quality sales in terms of s^j, b and $\overline{\theta}$ by substituting $q_{Lj} = s^j$ and $q_{Hj}(s^j)$ into (20) allows threshold level $\widehat{\widehat{s}}$ to be computed from $\frac{\partial S_{LJ}(s^j,b,\overline{\theta})}{\partial s^j} = 0$ in terms of model parameters:

$$\widehat{\widehat{s}} = 0.34104\frac{\overline{\theta}}{b} \qquad (40)$$

It thus follows that $\frac{\partial S_{LJ}(s^j,b,\overline{\theta})}{\partial s^j} > 0$ for $s^j \in \left[q_{Lj}^{UR}, \widehat{\widehat{s}}\right]$ and $\frac{\partial S_{LJ}(s^j,b,\overline{\theta})}{\partial s^j} < 0$ for $s^j \in \left[\widehat{\widehat{s}}, s^{Pj}\right]$. Ronnen (1991) and Crampes and Hollander (1995) find a similar pattern for profits, while Boom (1995) finds losses for both firms as a result of assumptions that keep market shares constant. The effects of s^j on firm profits and sales are illustrated in figures (4)-(6) for $\overline{\theta} = 5$ and $b = \frac{1}{2}$.

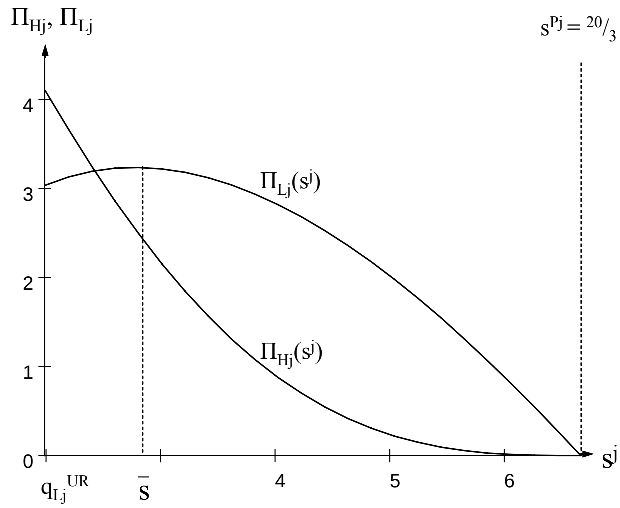

Figure 4: Regulated equilibrium profit levels.

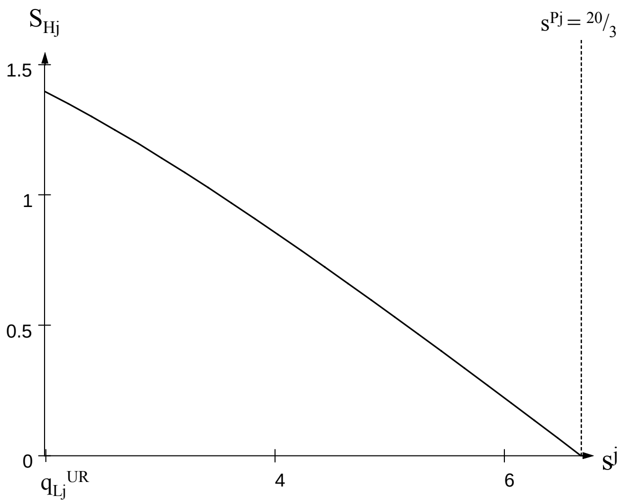

Figure 5: Regulated equilibrium high quality sales.

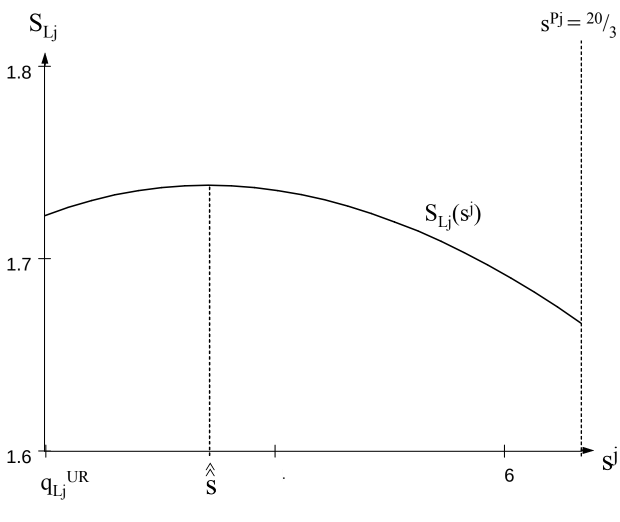

Figure 6: Regulated equilibrium low quality sales.

(iv) There are two conflicting effects of minimum quality standards on consumer surplus under variable quality costs. First, the convexity of unit costs implies higher prices as a result of higher quality levels, an effect which is exacerbated by firms' strategic responses to each others' price increases. Second, stronger price competition associated with diminished quality disparity has a positive effect on total consumer surplus. The pro-competitive effect of s^j dominates the cost effect for standards up to a threshold level $\widehat{s}$, above which the converse is true. Equation (29) describes total consumer surplus as a function of quality levels and parameters b and $\overline{\theta}$. Substituting $q_{Lj} = s^j$ and $q_{Hj}(s^j)$ into C_j yields $C_j(s^j, b, \overline{\theta})$. Solving $\frac{\partial C_j(s^j,b,\overline{\theta})}{\partial s^j} = 0$ and confirming the maximum yields threshold level:

$$\widehat{s} = 3.668\frac{\overline{\theta}}{b} \tag{41}$$

It follows that $\frac{\partial C_j(s^j,b,\overline{\theta})}{\partial s^j} > 0$ for $s^j \in \left[q_{Lj}^{UR}, \widehat{s}\right]$ and $\frac{\partial C_j(s^j,b,\overline{\theta})}{\partial s^j} < 0$ for $s^j \in \left[\widehat{s}, s^{Pj}\right]$. The path of consumer surplus is illustrated for $\overline{\theta} = 5$ and $b = \frac{1}{2}$ in figure (7). Note the effect of s^j on consumers is not uniform. Crampes and Hollander (1995) obtain the result that all consumers gain for sufficiently low minimum quality standards, under similar assumptions. For a higher standard, however, the higher costs and prices induce losses in high quality consumers, relative to low quality consumers, who increase in number as an increasing measure switches to purchasing the low quality good. Ecchia and Lambertini (1997) show that all consumers lose for a sufficiently high standard. Hence, as s^j rises over $s^j \in \left[q_{Lj}^{UR}, \widehat{s}\right]$, welfare is being redistributed from the supplier of high quality goods to the supplier of low quality goods and to consumers in aggregate, but also between consumers of high quality goods to consumers of low quality goods.

The effects of s^j on C_j and Π_{Hj} and Π_{Lj} described in this section shape the incentives of policy-makers in the standard-setting game. Section 3.2 examines these incentives more closely.

3.2 National Incentives

In stage 0, the governments of A and B are assumed to set minimum quality standards s^A and s^B simultaneously and non-cooperatively, under the assumption that both firms remain in the market, taking the strategic interaction of the firms and the resulting effects on market variables as given. In section 3.1 the 'prohibitive' standard, s^{Pj}, which defines the highest minimum quality standard consistent with the survival of both firms in market j, is found to be $s^{Pj} = \frac{2\overline{\theta}}{3b}$. Hence, the strategy space of each policy-maker of country j is $s^j \in \left[q_{Lj}^{UR}, s^{Pj}\right]$. The policy-maker of each country j chooses s^j from within this strategy space to maximise its national welfare, W^j, taking the standard of the other country as given.

Recall that policy decision s^j, gives rise to a strategic response of the high quality firm in market j, $q_{Hj}(s^j)$. Substituting the reaction function $q_{Hj}(s^j)$ implicit[7] in (25) and $q_{Lj} = s^j$ into equations (29), (21) and (22), yields consumer surplus and profits from the sale of high and low quality goods in market j, as functions of policy variable s^j and market parameters $\overline{\theta}$ and b. These are defined generally as $C_j(s^j, \overline{\theta}, b)$, $\Pi_{Hj}(s^j, \overline{\theta}, b)$ and $\Pi_{Lj}(s^j, \overline{\theta}, b)$.

Consider welfare equations (42) and (43) that describe the objective functions of governments A and B in terms of s^A, s^B and parameters $\overline{\theta}$ and b:

$$W^A\left(s^A, s^B, \overline{\theta}, b\right) = C_A(s^A, \overline{\theta}, b) + \Pi_{AA}(s^A, \overline{\theta}, b) + \Pi_{AB}(s^B, \overline{\theta}, b) \tag{42}$$

$$W^B\left(s^A, s^B, \overline{\theta}, b\right) = C_B(s^A, \overline{\theta}, b) + \Pi_{BB}(s^B, \overline{\theta}, b) + \Pi_{BA}(s^A, \overline{\theta}, b) \tag{43}$$

Suppressing market and cost parameters b and $\overline{\theta}$ for convenience, the governments' reaction functions are implicitly defined by (44) and (45):

$$\frac{\partial W^A(s^A, s^B)}{\partial s^A}_{|s^B} = \frac{\partial C_A(s^A)}{\partial s^A} + \frac{\partial \Pi_{AA}(s^A)}{\partial s^A} = 0 \tag{44}$$

$$\frac{\partial W^B(s^A, s^B)}{\partial s^B}_{|s^A} = \frac{\partial C_B(s^B)}{\partial s^B} + \frac{\partial \Pi_{BB}(s^B)}{\partial s^B} = 0 \tag{45}$$

For a pair of standards (s^{A*}, s^{B*}) to constitute a Nash equilibrium in minimum standards, the pair must solve both (44) and (45). Since the distribution of consumers is symmetric in the two markets, the choice of the minimum standard is influenced symmetrically by its effect $C_j(s^j)$ in the two countries. Recall from section 3.1 that $\frac{\partial C_j(s^j)}{\partial s^j} > 0$ holds for a range of values $s^j \in \left[q_L^{UR}, \widehat{s}\right]$, where $\widehat{s} = 3.668\frac{\overline{\theta}}{b}$, providing incentives to regulate. Asymmetries in incentives for setting minimum quality standards hinge on the quality of its domestic sales. If firm A supplies its home market with high quality goods, then domestic profit is unambiguously lowered by the implementation of $s^A > q_L^{UR}$, since $\frac{\partial \Pi_{AA}(s^A)}{\partial s^A} = \frac{\partial \Pi_{HA}(s^A)}{\partial s^A} < 0$. In contrast, if firm A is a supplier of low quality goods then profit from domestic sales is increasing with s^A for sufficiently low minimum standards, $s^A \in \left[q_L^{UR}, \overline{s}\right]$, where $\overline{s} = 0.27763\frac{\overline{\theta}}{b}$. Similar arguments apply for country B.

Moreover, inspection of the implicit reaction functions of A and B, given by (44) and (45), respectively, reveals that while the level of W^A and W^B depend on both s^A and s^B, the optimal responses of the two policy-makers depend only on the quality ranking of the national firm in the domestic market and parameters b and $\overline{\theta}$. The policy-makers' optimal choice of minimum standard thus involves a trade-off between the gains to domestic consumers and the effects on domestic profit, which is unaffected by the foreign standard but depends on the quality of domestically produced goods. The discussion is summarised by proposition (1).

[7] The analytical expression for $q_{Hj}(s^j)$ can be found in Appendix A.

Proposition 1 *A country's optimal unilateral minimum quality standard is higher when the domestic firm is the low quality supplier in the domestic market, than if the domestic firm is the high quality supplier.*

Proof. Let W_H^j denote the welfare of a country j when the domestic firm is the high quality supplier in j and W_L^j denote welfare when the domestic firm is the low quality supplier in j. Further, let Π_{ji} denote the profit of firm j from exports (of unspecified quality) to i, where $i \neq j$. Hence (suppressing market and cost parameters b and $\overline{\theta}$):

$$W_H^j\left(s^i, s^j\right) = C_j\left(s^j\right) + \Pi_{Hj}\left(s^j\right) + \Pi_{ji}\left(s^i\right) \tag{46}$$

$$W_L^j\left(s^i, s^j\right) = C_j\left(s^j\right) + \Pi_{Lj}\left(s^j\right) + \Pi_{ji}\left(s^i\right) \tag{47}$$

Let s_H^j and s_L^jdenote the optimal unilateral standard when $W^j = W_H^j$ and when $W^j = W_L^j$, respectively, given s^i. Since $\Pi_{ji}\left(s^i\right)$ is not a function of the domestic standard s^j, optimal standard $s_H^j = \arg\max_{s^j} W_H^j\left(s^i, s^j\right) = \arg\max_{s^j} \widehat{W}_H^j\left(s^j\right)$ and $s_L^j = \arg\max_{s^j} W_L^j\left(s^i, s^j\right) = \arg\max_{s^j} \widehat{W}_L^j\left(s^j\right)$, where $\widehat{W}_H^j\left(s^j\right) = C_j\left(s^j\right) + \Pi_{Hj}\left(s^j\right)$ and $\widehat{W}_L^j\left(s^j\right) = C_j\left(s^j\right) + \Pi_{Lj}\left(s^j\right)$. Recall that $\frac{\partial \Pi_{Hj}\left(s^j\right)}{\partial s^j} < 0$ for all s^j and $\frac{\partial \Pi_{Lj}\left(s^j\right)}{\partial s^j} > 0$ for $s^j \in \left[q_L^{UR}, \overline{s}\right]$, while $\frac{\partial C_j\left(s^j\right)}{\partial s^j} > 0$ for $s^j \in \left[q_L^{UR}, \widehat{s}\right]$. It follows that $\arg\max_{s^j} \widehat{W}_H^j\left(s^j\right) < \arg\max_{s^j} \widehat{W}_L^j\left(s^j\right)$ and hence $s_H^j < s_L^j$. ■

In general, the policy-maker finds it optimal to set s_H^j that solves (48), or s_L^j that solves (49), depending on whether the domestic firm is a high or low quality supplier in j:

$$\frac{\partial C_j(s^j, \overline{\theta}, b)}{\partial s^j} + \frac{\partial \Pi_{Hj}(s^j, \overline{\theta}, b)}{\partial s^j} = 0 \tag{48}$$

$$\frac{\partial C_j(s^j, \overline{\theta}, b)}{\partial s^j} + \frac{\partial \Pi_{Lj}(s^j, \overline{\theta}, b)}{\partial s^j} = 0 \tag{49}$$

Solving (48) and (49) yields non-cooperative standards $s_H^j = 0.23995\frac{\overline{\theta}}{b}$ and $s_L^j = 0.34691\frac{\overline{\theta}}{b}$, respectively. In the former case, the policy-maker sets a relatively 'soft' unilateral standard, while in the latter case a relatively 'tough' standard is set. Symmetry across countries implies that $s_H^A = s_H^B = s^S = 0.23995\frac{\overline{\theta}}{b}$ and $s_L^A = s_L^B = s^T = 0.34691\frac{\overline{\theta}}{b}$, where s^S denotes the 'soft' unilateral quality standard and s^T 'tough' unilateral standard. Both s^S and s^T lie between the unregulated high and low quality levels, so unilaterally selected minimum standards are, indeed, mild.

Proposition 2 *Unilateral minimum quality standards are always mild.*

Proof. Since $\frac{\partial C_j\left(s^j\right)}{\partial s^j} = 0$ at $\widehat{s} = 3.668\frac{\overline{\theta}}{b}$ and $\frac{\partial \Pi_{Lj}(s^j)}{\partial s^j} = 0$ at $\overline{s} = 0.27763\frac{\overline{\theta}}{b}$, then s_L^j that solves a convex combination of these in (49) must satisfy $\overline{s} < s_L^j <$

$\widehat{s}$. Moreover, since $\overline{s} > q_L^{UR}$ and $\widehat{s} < q_H^{UR}$ it is also true that $q_L^{UR} < s_L^j < q_H^{UR}$. Hence, s_L^j is mild. Following a similar line of argument for s_H^j and noting that $s_H^j > 0$, it is straightforward to show that s_H^j is also mild. ■

Tables (4) and (5) report the regulated market outcome under s^S and s^T, respectively. They show that consumer surplus is higher and profit from high quality sales lower under s^T than under s^S. Furthermore, the tougher standard corresponds to a smaller quality gap, indicating the lower degree of product differentiation. Prices for both high and low quality goods are higher with the tougher standard, as the convex variable costs effect from the higher quality levels outweighs the pro-competitive effect of stronger price competition.

Regulated Equilibrium with High Quality Domestic Sales		
Quality levels	$q_{Hj} = 0.42856\frac{\overline{\theta}}{b}$	$q_{Lj} = s_H^j = s^S = 0.23995\frac{\overline{\theta}}{b}$
Quality ratio	$r_j = 1.8318$	
Quality gap	$q_{Hj} - q_{Lj} = 0.18861\frac{\overline{\theta}}{b}$	
Prices	$p_{Hj} = 0.23487\frac{\overline{\theta}^2}{b}$	$p_{Lj} = 0.091475\frac{\overline{\theta}^2}{b}$
Quality-deflated prices	$x_{Hj} = 0.548805\overline{\theta}$	$x_{Lj} = 0.391\overline{\theta}$
Marginal consumer	$z_j = 0.736685\overline{\theta}$	
Sales	$S_{Hj} = 0.263158\overline{\theta}$	$S_{Lj} = 0.345858\overline{\theta}$ (imports)
Profits	$\Pi_{Hj} = 0.013476\frac{\overline{\theta}^3}{b}$	$\Pi_{Lj} = 0.012702\frac{\overline{\theta}^3}{b}$
Consumer surplus	$C_j = 0.050122\frac{\overline{\theta}^3}{b}$	

Table 3: Regulated Equilibrium with High Quality Domestic Sales.

Regulated Equilibrium with Low Quality Domestic Sales		
Quality levels	$q_{Hj} = 0.49272\frac{\overline{\theta}}{b}$	$q_{Lj} = s_L^j = s^T = 0.34691\frac{\overline{\theta}}{b}$
Quality ratio	$r_j = 1.4203$	
Quality gap	$q_{Hj} - q_{Lj} = 0.14581\frac{\overline{\theta}}{b}$	
Prices	$p_{Hj} = 0.27231\frac{\overline{\theta}^2}{b}$	$p_{Lj} = 0.15604\frac{\overline{\theta}^2}{b}$
Quality-deflated prices	$x_{Hj} = 0.552678\overline{\theta}$	$x_{Lj} = 0.449798\overline{\theta}$
Marginal consumer	$z_j = 0.797438\overline{\theta}$	
Sales	$S_{Hj} = 0.202578\overline{\theta}$ (imports)	$S_{Lj} = 0.347648\overline{\theta}$
Profits	$\Pi_{Hj} = 0.0059831\frac{\overline{\theta}^3}{b}$	$\Pi_{Lj} = 0.012407\frac{\overline{\theta}^3}{b}$
Consumer surplus	$C_j = 0.055502\frac{\overline{\theta}^3}{b}$	

Table 4: Regulated Equilibrium with Low Quality Domestic Sales.

4 Nash Equilibria in Minimum Quality Standards

Section 3.2 establishes minimum quality standards $s^S = 0.23995\frac{\overline{\theta}}{b}$ and $s^T = 0.34691\frac{\overline{\theta}}{b}$ as the optimal unilateral policy decisions of national welfare-maximising policy-makers in countries whose national firm supplies the domestic market with high or low quality goods, respectively. Examination of the four configurations of firm quality rankings show that there exist four non-cooperative Nash equilibria in minimum standards: two symmetric Nash equilibria, where national minimum standards are either both 'tough' ($s^A = s^B = s^T$) or both 'soft' ($s^A = s^B = s^S$), and two asymmetric Nash equilibria where one country sets the soft standard and the other the 'tough' standard ($s^A = s^S$ and $s^B = s^T$, or $s^A = s^T$ and $s^B = s^S$).

The multiplicity of non-cooperative Nash equilibria in minimum standards arises from the multiplicity of equilibria of the firms' strategic interaction in prices and quality levels. It is interesting to note that asymmetric national standards can arise endogenously even though markets are symmetric and the duopolists have access to the same technology.

Consider the four configurations of firm quality rankings in A and B:

1. If $q_{AA} < q_{BA}$ and $q_{AB} > q_{BB}$, then each firm supplies its home market with low quality goods and trade is in high quality goods. Policy-makers' incentives are symmetric and give rise to a symmetric Nash equilibrium pair of standards $\left(s^{A*}, s^{B*}\right) = \left(s^T, s^T\right)$.

2. If $q_{AA} > q_{BA}$ and $q_{AB} < q_{BB}$, then each firm supplies its home market with high quality goods and trade is in low quality goods. Policy-makers' incentives are again symmetric, but standards are less stringent due to the negative effect on the profits of the domestic firm. The Nash equilibrium pair of standards is thus $\left(s^{A*}, s^{B*}\right) = \left(s^S, s^S\right)$.

3. If $q_{AA} > q_{BA}$ and $q_{AB} > q_{BB}$, then firm A is the world high quality supplier. Country B imports high quality goods from A while A imports low quality goods from B. Policy-makers' incentives are asymmetric such that the policy maker in A has an incentives to set the 'soft' standard to protect the interests of the high quality producing A firm, while policy-maker B sets the 'tough' standard. The Nash equilibrium pair of standards is thus $\left(s^{A*}, s^{B*}\right) = \left(s^S, s^T\right)$.

4. If $q_{AA} < q_{BA}$ and $q_{AB} < q_{BB}$, then firm B is the world high quality supplier and A exports low quality goods to country B. The Nash equilibrium is again asymmetric, where $\left(s^{A*}, s^{B*}\right) = \left(s^T, s^S\right)$.

These results are summarised in proposition (3).

Proposition 3 *Non-cooperative Nash equilibrium minimum quality standards are higher when countries trade in high quality goods than if they trade in low* *quality goods. If trade flows vary in quality, then a higher minimum standard is set by the country importing high quality goods than by the country importing low quality goods.*

Proof. If countries trade in high quality goods then national firms are low quality suppliers in their home markets. Conversely, if trade is in low quality goods, then national firms are high quality suppliers in their home market. Moreover, if one country imports high quality goods and the other low quality goods, then the national firm of the high quality importing country is the world low quality supplier, while the other firm is the world high quality supplier. The proposition then follows directly from proposition (1). ■

The key difference between the international duopoly and having both duopolists in a single country is that only the profits of the national firm are incorporated into each policy-maker's objective function. At the same time, the trade links between countries give rise to cross-country externalities from standard-setting as each standard affects the profits of the foreign firm.

In contrast to the widely explored negative terms-of-trade externalities of the strategic tariff-formation literature (e.g. Bagwell and Staiger, 1999, 2002; Staiger and Tabellini, 1987), the cross-country externalities arising from mild quality standards can be either positive or negative, depending on the quality of traded goods. Profits from low quality exports are increasing in foreign minimum standards, provided these are not too severe, yielding a positive cross-country externality. Profits from high quality exports unambiguously decrease with foreign minimum standards, giving rise to a negative cross-country externality. The four Nash equilibria thus correspond to the four different combinations of externalities that may arise between the two countries: symmetric positive externalities, symmetric negative externalities, or asymmetric positive and negative externalities.

More formally, the externalities between countries A and B are reflected in (50) and (51), which describe the impact that s^B and s^A have on W^A and W^B, respectively, through their effect on profit flowing abroad.

$$\frac{\partial W^A}{\partial s^B} = \frac{\partial \Pi_{AB}}{\partial s^B} \gtreqless 0 \quad (50)$$

$$\frac{\partial W^B}{\partial s^A} = \frac{\partial \Pi_{BA}}{\partial s^A} \gtreqless 0 \quad (51)$$

The sign of $\frac{\partial \Pi_{AB}}{\partial s^B}$ and $\frac{\partial \Pi_{BA}}{\partial s^A}$, respectively, depends on the quality of traded goods, and thus on the pattern of trade. For example, if A exports high quality goods to B, then even a very mild minimum standard s^B imposes a negative externality on A. Conversely, if low quality goods are exported, then for sufficiently low s^B, the externality on country A is positive. Since these positive or negative external effects do not factor into unilateral decision-making, the Nash equilibrium standards are inefficiently high or inefficiently low relative to the world optimum pair of standards that internalises these effects.

To examine the efficiency characteristics of the Nash equilibria, we derive the efficiency condition for pairs of minimum quality standards. Then the world-welfare maximising pair of standards is calculated and contrasted with the non-cooperative policy outcome. This paves the way for the analysis of international cooperation in quality standards that forms the rest of the paper.

4.1 Efficiency

Consider the welfare level of A from a given pair (s^A, s^B).

$$W^A = W^A(s^A, s^B) \tag{52}$$

Consider an iso-welfare contour for A, that describes all the combinations of national standards that yield the welfare level described in (52). Along the iso-welfare contour, it must hold that:

$$\frac{\partial W^A}{\partial s^A} ds^A + \frac{\partial W^A}{\partial s^B} ds^B = 0 \tag{53}$$

Hence, the slope of the iso-welfare contour of A is given by:

$$\left[\frac{ds^A}{ds^B}\right]_{|dW^A=0} = -\frac{\partial W^A / \partial s^B}{\partial W^A / \partial s^A} \tag{54}$$

Similarly along an iso-welfare contour for B, for constant welfare $W^B = W^B(s^A, s^B)$, it must hold that:

$$\frac{\partial W^B}{\partial s^B} ds^B + \frac{\partial W^B}{\partial s^A} ds^A = 0 \tag{55}$$

Hence, the slope of the iso-welfare contour of B is given by:

$$\left[\frac{ds^A}{ds^B}\right]_{|dW^B=0} = -\frac{\partial W^B / \partial s^B}{\partial W^B / \partial s^A} \tag{56}$$

Substituting (44) and (45) into (54) and (56) allows the slopes of the country A and B iso-welfare contours to be expressed in terms marginal effects of national standards on consumer surplus and profit flows:

$$\left[\frac{ds^A}{ds^B}\right]_{|dW^A=0} = -\frac{\partial \Pi_{AB} / \partial s^B}{\partial C_A / \partial s^A + \partial \Pi_{AA} / \partial s^A} \tag{57}$$

$$\left[\frac{ds^A}{ds^B}\right]_{|dW^B=0} = -\frac{\partial C_B / \partial s^B + \partial \Pi_{BB} / \partial s^B}{\partial \Pi_{BA} / \partial s^A} \tag{58}$$

For a pair of minimum quality standards (s^A, s^B) to be efficient, there must be no possible Pareto improvement from (s^A, s^B), so the iso-welfare contours must be tangential to each other at (s^A, s^B). The efficiency requirement is thus:

$$\left[\frac{ds^A}{ds^B}\right]_{|dW^A=0} = \left[\frac{ds^A}{ds^B}\right]_{|dW^B=0} \tag{59}$$

Results from the examination of the Nash equilibria against efficiency condition (59) are summarised in Proposition (4).

Proposition 4 *The Nash equilibria in minimum quality standards are inefficient.*

Proof. Recall the condition for efficiency $\left[\frac{ds^A}{ds^B}\right]_{|dW^A=0} = \left[\frac{ds^A}{ds^B}\right]_{|dW^B=0}$ that implies (57) and (58) must be equal for Nash equilibrium pair $\left(s^{A^*}, s^{B^*}\right)$ to be efficient. Moreover, in order for the pair to constitute a Nash equilibrium, it must be true that it solves the government reaction functions, (44) and (45). However, if $\left(s^{A^*}, s^{B^*}\right)$ satisfies both (44) and (45), then $\left[\frac{ds^A}{ds^B}\right]_{|dW^A=0} = \infty >$ $\left[\frac{ds^A}{ds^B}\right]_{|dW^B=0} = 0$, thus violating the condition for efficiency. ■

4.2 World Optimum Minimum Standards

Let pair $\left(s^A, s^B\right) = \left(s_A^{WO}, s_B^{WO}\right)$ denote the pair of minimum standards that maximise world welfare $W\left(s^A, s^B\right)$, given by (60), where:

$$\begin{aligned} W\left(s^A, s^B\right) &= W_A\left(s^A, s^B\right) + W_B\left(s^A, s^B\right) \\ &= C_A\left(s^A\right) + \Pi_{AA}\left(s^A\right) + \Pi_{BA}\left(s^A\right) + C_B\left(s^B\right) + \Pi_{BB}\left(s^B\right) + \Pi_{AB}\left(s^B\right) \end{aligned} \tag{60}$$

Since each market has a low and high quality supplier with symmetric costs and consumer preferences are identical across markets of equal size $\overline{\theta}$, then by symmetry $s_A^{WO} = s_B^{WO} = s^{WO}$, where $s^{WO} = \arg\max_s W(s) = 2\left[C_j(s) + \Pi_{Hj}(s) + \Pi_{Lj}(s)\right]$. Thus s^{WO} solves:

$$\frac{\partial W}{\partial s} = \frac{\partial C_j(s)}{\partial s} + \frac{\partial \Pi_{Hj}(s)}{\partial s} + \frac{\partial \Pi_{Lj}(s)}{\partial s} = 0 \tag{61}$$

Rearranging (61) yields the efficiency condition:

$$-\frac{\partial \Pi_{Hj}(s) \,/\, \partial s}{\partial C_j(s) \,/\, \partial s + \partial \Pi_{Lj}(s) \,/\, \partial s} = -\frac{\partial C_j(s) \,/\, \partial s + \partial \Pi_{Lj}(s) \,/\, \partial s}{\partial \Pi_{Hj}(s) \,/\, \partial s} = 1 \tag{62}$$

It follows directly from (62) that efficiency is satisfied at the world optimum. Hence, the world welfare-maximising pair of minimum standards is shown to be both symmetric and efficient. The implication is that world welfare is maximised at a unique point, where both countries harmonise their standards at s^{WO}. Since the world optimum does not constitute a non-cooperative Nash equilibrium, it may only be reached through cooperative agreement. The feasibility of international cooperation at $(s^A, s^B) = (s^{WO}, s^{WO})$ is analysed in the section 4.

Solving (61) yields the world optimum common standard $s^{WO} = 0.25241\frac{\overline{\theta}}{b}$. It is observed to lie between the two optimal unilateral minimum standards $s^S = 0.23995\frac{\overline{\theta}}{b}$ and $s^T = 0.34691\frac{\overline{\theta}}{b}$. This leads to Proposition (5).

Intuitively, the cross-country externalities imply that when a government of a country imposes a minimum quality standard, part of the costs (or benefits) of the standard are borne by the trading partners of that country. As a result, each government faces less than the full costs (or benefits) of the standard and hence over (or under) provides regulation of quality relative to the world optimum minimum standard that internalises the cross-country effects.

Proposition 5 *The world optimum standard* (s^{WO}) *lies between the unilateral 'soft' standard* (s^S) *and 'tough' standard* (s^T)*.*

Proof. Since $s^{WO} = \arg\max_s \widehat{W}(s)$, $s_H^j = \arg\max_s \widehat{W}_H^j$ and $s_L^j = \arg\max_s \widehat{W}_L^j$, where $\widehat{W}(s) = C_j(s) + \Pi_{Hj}(s) + \Pi_{Lj}(s)$, $\widehat{W}_H^j = C_j\left(s^j\right) + \Pi_{Hj}\left(s^j\right)$ and $\widehat{W}_L^j = C_j\left(s^j\right) + \Pi_{Lj}\left(s^j\right)$, then from the properties of Π_{Lj}, Π_{Hj} and C_j it follows that $s_H^j < s^{WO} < s_L^j$. ■

Table (6) reports the solutions to all market variables under s^{WO}, the world welfare maximising (common) minimum quality standard.

World Welfare Maximising Market Outcome		
Quality levels	$q_{Hj} = 0.43885\frac{\overline{\theta}}{b}$	$q_{Lj} = s^j = s^{WO} = 0.25241\frac{\overline{\theta}}{b}$
Quality ratio	$r_j = 1.7386$	
Quality gap	$q_{Hj} - q_{Lj} = 0.18644\frac{\overline{\theta}}{b}$	
Prices	$p_{Hj} = \frac{\overline{\theta}^2}{b}$	$p_{Lj} = \frac{\overline{\theta}^2}{b}$
Quality-deflated prices	$x_{Hj} = 0.54676\overline{\theta}$	$x_{Lj} = 0.39958\overline{\theta}$
Marginal consumer	$z_j = 0.74601\overline{\theta}$	
Sales	$S_{Hj} = 0.25399\overline{\theta}$	$S_{Lj} = 0.34642\overline{\theta}$
Profits	$\Pi_{Hj} = 0.012028\frac{\overline{\theta}^3}{b}$	$\Pi_{Lj} = 0.012869\frac{\overline{\theta}^3}{b}$
Consumer surplus	$C_j = 0.051511\frac{\overline{\theta}^3}{b}$	

Table 5: Market Outcomes Under the World Optimum Standard.

4.3 Non-cooperative Standard-Setting and Trade

Consider the implications of the over- or under-regulation of quality on the trade flows between A and B. When countries trade in high quality goods, the Nash equilibrium is symmetric and characterised by 'tough' standards in both countries. These are more stringent than is optimal from a world-welfare perspective, however, as a result of the bilateral negative externalities. Since demand for high quality goods is decreasing in the minimum quality standard, over-regulation implies lower demand for high quality goods in each country and thus lower bilateral trade in these goods than is efficient. The tougher standards also imply the quality of traded goods is higher than is efficient.

Conversely, trade in low quality goods gives rise to a symmetric Nash equilibrium in which both countries set 'soft' standards, which are laxer than is optimal from a world-welfare maximising perspective. For low quality goods, however, laxer standards imply less demand in each country, and thus lower bilateral trade in low quality goods than is efficient. Moreover, the quality of traded goods is lower than is efficient.

Similar arguments apply for the asymmetric Nash equilibria for the flows of high and low quality exports, respectively. It follows that irrespective of the quality level of traded goods, and thus for all patterns of trade, the inefficiency in unilateral decision-making in quality standards operates as a non-tariff barrier to trade. Moreover, the result follows without any of the usual assumptions that generate non-tariff barrier effects of minimum standards, such as certification or labelling costs for firms to meet different national standards or quality modification costs that prohibit the customisation of quality to different markets.

The discussion is summarised by proposition (6).

Proposition 6 *Trade flows are lower under Nash equilibrium quality standards than under world optimum standards.*

Proof. Recall that $\frac{\partial S_{Hj}}{\partial s^j} < 0$ and $\frac{\partial S_{Lj}}{\partial s^j} > 0$ for $s \in \left(q_L^{UR}, \widehat{\widehat{s}}\right)$ where $\widehat{\widehat{s}} = 3.4104\frac{\overline{\theta}}{b}$. If both countries export high quality goods, then Nash equilibrium standards are $s^{A*} = s^{B*} = s^T$. From Proposition (5) it follows that $s^T > s^{WO}$, so exports must be lower than under world optimum standards. If countries trade in low quality goods, then Nash equilibrium standards are $s^{A*} = s^{B*} = s^S$. Proposition (5) implies $s^S < s^{WO}$. Moreover, since $s^{WO} < \widehat{\widehat{s}}$ then $\frac{\partial S_{Lj}}{\partial s^j} > 0$ holds in the region of the Nash equilibrium and world optimum. Hence low quality exports are lower in the Nash equilibrium than under world optimum standards. Finally, if A exports high quality goods and B exports low quality goods, then $s^{A*} = s^S < s^{WO}$ and $s^{B*} = s^T > s^{WO}$. Thus high quality exports of country A are lower under $s^{B*} = s^T$ than under $s^{B*} = s^{WO}$. Furthermore, country B's low quality exports are lower under $s^{A*} = s^S$ than under $s^{A*} = s^{WO}$. ■

5 International Cooperation in Quality Standards

Section 3 establishes the inefficiency of the non-cooperative Nash equilibria in minimum quality standards, as well as the efficiency of harmonisation of quality standards at the world optimum. This section analyses the potential gains from international cooperation between governments under the three distinct trade patterns: trade in high quality goods, trade in low quality goods, and bilateral trade in goods of different qualities. A common feature of all three cases is the Prisoners' Dilemma structure in the incentives of the two policy-makers. While countries stand to gain through a cooperative agreement, this does not constitute a Nash equilibrium. Taking as given the minimum quality standard of the other country, each policy-maker has an incentive to defect from the cooperative agreement. The analysis follows the general approach used in the analysis of cooperative agreements in tariffs (Bagwell and Staiger, 1999,

2002) by examining Pareto-improving reciprocal adjustment of minimum quality standards as a means of establishing the scope for cooperative agreement.

5.1 Bargaining from Symmetric Nash Equilibria

The two distinct trade patterns that give rise to a symmetric Nash equilibrium are analysed in turn.

Trade in High Quality Goods

Proposition 7 *If countries trade in high quality goods, then a cooperative agreement in quality standards must involve a reciprocal lowering of minimum quality standards from the non-cooperative Nash equilibrium.*

Proof. If countries trade in high quality goods, then the national firms are low quality suppliers in their home market. It follows from propositions (1) and (5) that A and B set 'tough' standards unilaterally, denoted by $s^{A^*} = s^{B^*} = s^T > s^{WO}$.
For a pair of standards $\left(s_0^A, s_0^B\right)$ to be welfare improving for both A and B relative to the Nash standards $\left(s^T, s^T\right)$, it is necessary that $s_0^A < s^T$ and $s_0^B < s^T$. This is shown to be true by considering the effect of s^B on W^A. The minimum standard in B affects the welfare of A through its effect on profit from high quality exports. From the properties of Π_{Hj} it follows that W^A is decreasing in s^B. A symmetric argument applies for B, so W^B is decreasing in s^A. The cross-country negative externalities are summarised by:

$$\frac{\partial W^A}{\partial s^B} = \frac{\partial \Pi_{AB}}{\partial s^B} < 0 \tag{63}$$

$$\frac{\partial W^B}{\partial s^A} = \frac{\partial \Pi_{BA}}{\partial s^A} < 0 \tag{64}$$

While each country's welfare is decreasing in the quality standard of its trading partner, the implicit reaction functions (44) and (45) imply that $\frac{\partial W^A}{\partial s^A}_{|s^B}$ and $\frac{\partial W^B}{\partial s^B}_{|s^A}$ are independent of s^B and s^A, respectively. The best responses of governments A and B are thus $s^{A*}\left(s^B\right) = s^T \ \forall s^B$ and $s^{B*}\left(s^A\right) = s^T \ \forall s^A$, respectively. Hence, if $s_0^B > s^T$, (63) implies the best attainable welfare for A given s_0^B is:

$$W^A\left(s^{A*}\left(s_0^B\right), s_0^B\right) = W^A\left(s^T, s_0^B\right) < W^A\left(s^T, s^T\right) \tag{65}$$

Similarly, if $s_0^A > s^T$, (64) implies the best attainable welfare for B given s_0^A is:

$$W^B\left(s_0^A, s^{B*}\left(s_0^A\right)\right) = W^B\left(s_0^A, s^T\right) < W^B\left(s^T, s^T\right) \tag{66}$$

Inequalities (65) and (66) imply that if $s_0^A > s^T$ or $s_0^B > s^T$ then $\left(s_0^A, s_0^B\right)$ cannot be Pareto improving relative to $\left(s^T, s^T\right)$ for both A and B and thus cannot be the outcome of a cooperative agreement in standards. Hence for $\left(s_0^A, s_0^B\right)$ to be a cooperative agreement both $s_0^A < s^T$ and $s_0^B < s^T$ must hold. ■

Figure (8) illustrates the incentives of the two policy-makers under the configuration of firm qualities that generates trade in high quality goods. The curves illustrated are plotted for parameter values $b = \frac{1}{2}$ and $\overline{\theta} = 5$ using the profit equations for high and low quality goods, consumer surplus and the quality reaction function of the high quality firm given in Appendix A.

The origin of the figure corresponds to no regulation, where $s^A = s^B = q_L^{UR}$. Iso-welfare contours W^{A*} and W^{B*} are drawn for the welfare level attained in the symmetric Nash equilibrium, denoted by NE, where $\left(s^{A*}, s^{B*}\right) = \left(s^T, s^T\right)$, while contours $\widetilde{W}^A$ and $\widetilde{W}^B$correspond to the welfare of A and B from a cooperative agreement at the world optimum (WO), where $s^A = s^B = s^{WO} < s^T$. Moreover, the dotted contour W^* reflects iso-world-welfare contour at the Nash equilibrium level of welfare $W^* = W^{A*} + W^{B*}$.

Consider the iso-welfare contours for each country. Higher welfare levels correspond to contours closer to the axes, reflecting the cross-country negative externalities that apply. For each country, the unique, optimal unilateral standard is s^T, which reflects the optimal reply of each country to any standard set by the other. The welfare level of each is decreasing in the standard of the other, so the highest welfare point is $\left(s^A, s^B\right) = \left(s^T, q_L^{UR}\right)$ for A and $\left(s^A, s^B\right) = \left(q_L^{UR}, s^T\right)$ for B.

The efficiency locus is denoted by EE, which plots all pairs of minimum standards at which the iso-welfare contours of A and B are tangent. WO is the efficient, symmetric pair, which maximises world welfare. The inefficiency of NE is confirmed since the iso-welfare contours of the two countries are not tangential at NE, indicating scope for Pareto improvement. The core, enclosed by W^{A*} and W^{B*}, gives the set of all Pareto-improving points relative to NE, within which the darker segment reflects the contract curve of A and B, along which cooperative pairs $\left(s^A, s^B\right)$ are both efficient and Pareto-improving relative to NE.

Consider the opportunities for cooperation reflected in the figure. While $\left(s^T, s^T\right)$ is a Nash equilibrium, mutual gains can be reaped through a reciprocal adjustment of minimum quality standards downwards, as follows from proposition (7). Each reciprocal adjustment places countries on a lower, symmetric contour (reflecting higher welfare), through which all gains from bargaining are exhausted at WO.

The analysis confirms the potential welfare gains from cooperation, but also highlights the Prisoners' Dilemma structure of incentives. Points D^A and D^B illustrated optimal defection points from cooperation for A and B, respectively. If $s^B = s^{W0}$, then country A's optimal reply is to defect to D^A, by setting $s^A = s^T$ and thereby attaining a higher welfare level. While the scope for Pareto-improving cooperation is established, the analysis raises concerns over the enforceability of such cooperation.

In practice, national quality standards are developed by National Standards Bodies. 153 of these national bodies are members of the International Organization for Standardization (ISO), the world's largest developer of standards. While the ISO has greatly contributed to the development of international standards alongside national standards, it has no legal authority to enforce the implementation of its standards. Despite the ISO's large membership, and the impetus it creates for the implementation of international standards, there are still widespread differences in national standards.

Trade in Low Quality Goods

Proposition 8 *If countries trade in low quality goods, then a cooperative agreement in quality standards must involve a reciprocal raising of minimum quality standards from the non-cooperative Nash equilibrium.*

Proof. If countries trade in low quality goods, it follows from propositions (1) and (5) that A and B set 'soft' standards unilaterally, denoted by $s^{A^*} = s^{B^*} = s^S < s^{WO}$. Moreover, the implicit reaction functions (44) and (45) yield $s^{A*}\left(s^B\right) = s^S\ \forall s^B$ and $s^{B*}\left(s^A\right) = s^S\ \forall s^A$, respectively.
For a pair of standards $\left(s_0^A, s_0^B\right)$ to be welfare improving for both A and B relative to the Nash standards $\left(s^S, s^S\right)$, it is necessary that $s_0^A > s^S$ and $s_0^B > s^S$. If these conditions do not both hold, then at least on country has lower welfare under $\left(s_0^A, s_0^B\right)$ than under the Nash equilibrium standards. From the properties of Π_{Lj} and since $\overline{s} > s^S$ it follows that W^A is increasing in s^B and W^B increasing in s^A in the region of the Nash equilibrium. The cross-country externalities are thus positive and summarised by:

$$\frac{\partial W^A}{\partial s^B} = \frac{\partial \Pi_{AB}}{\partial s^B} > 0 \text{ for } s^B \in \left(q_L^{UR}, \overline{s}\right) \tag{67}$$

$$\frac{\partial W^B}{\partial s^A} = \frac{\partial \Pi_{BA}}{\partial s^A} > 0 \text{ for } s^A \in \left(q_L^{UR}, \overline{s}\right) \tag{68}$$

Hence, if $s_0^B < s^S$ the best attainable welfare for A given s_0^B is:

$$W^A\left(s^{A*}\left(s_0^B\right), s_0^B\right) = W^A\left(s^S, s_0^B\right) < W^A\left(s^S, s^S\right) \tag{69}$$

Similarly, if $s_0^A < s^S$ the best attainable welfare for B given s_0^A is:

$$W^B\left(s_0^A, s^{B*}\left(s_0^A\right)\right) = W^B\left(s_0^A, s^S\right) < W^B\left(s^S, s^S\right) \tag{70}$$

From (69) and (70) it follows that if $s_0^A < s^S$ or $s_0^B < s^S$, then $\left(s_0^A, s_0^B\right)$ cannot be Pareto improving relative to $\left(s^S, s^S\right)$ for both A a

nd B and thus cannot be the outcome of a cooperative agreement in standards. Hence for $\left(s_0^A, s_0^B\right)$ to be a cooperative agreement both $s_0^A > s^S$ and $s_0^B > s^S$ must hold. ■

Proposition 9 *From a symmetric Nash equilibrium in minimum standards, mutually beneficial reciprocal adjustment of national standards increases national welfare monotonically for both countries until the world optimum is reached.*

Proof. Consider reciprocal changes in standards ds^A and ds^B from an initial bargaining position at Nash equilibrium standards, $\left(s^{A^*}, s^{B^*}\right)$. If trade is in high quality goods, then $s^{A^*} = s^{B^*} = s^T > s^{WO}$ and from Proposition (7) adjustments $ds^A < 0$ and $ds^B < 0$ from the Nash equilibrium are mutually beneficial. Similarly, if low quality goods are traded, then $s^{A^*} = s^{B^*} = s^S < s^{WO}$ and from Proposition (8) adjustments $ds^A > 0$ and $ds^B > 0$ from the Nash equilibrium are mutually beneficial. Since $s^{A^*} = s^{B^*}$, reciprocal adjustments give rise to symmetric Pareto improvements until $s^{A^*} + \sum ds = s^{B^*} + \sum ds = s^{WO}$, where standards $\left(s^{WO}, s^{WO}\right)$ are efficient. ■

Figure (9) illustrates the strategic incentives of the two policy-makers where trade is in low quality goods. As before, the curves illustrated are plotted for parameter values $b = \frac{1}{2}$ and $\overline{\theta} = 5$ using the profit equations for high and low quality goods, consumer surplus and the quality reaction function of the high quality firm given in Appendix A. All notation is as in figure (8).

The iso-welfare contours for countries that trade in low quality goods are elliptical, as illustrated in the figure. In particular, the iso-welfare contours for A and B form concentric ellipses that correspond to higher welfare as they converge to the unique, preferred point of each country.

Consider the welfare of country A. Welfare level W^{A*} is attained at the Nash equilibrium (NE), where both countries set the 'soft' standard $s^S < s^{WO}$. Welfare $\widetilde{W}^A$ from a cooperative agreement at the world optimum (WO) corresponds to an elliptical iso-welfare contour that lies within the contour corresponding to the Nash equilibrium $\left(s^{A^*}, s^{B^*}\right) = \left(s^S, s^S\right)$. The unique, preferred point of country A is denoted by $\overline{\overline{W}}^A$, corresponding to the pair of minimum standards $\left(s^A, s^B\right) = \left(s^S, \overline{s}\right)$. The intuition behind the shape of the iso-welfare contours and preferred point $\overline{\overline{W}}^A$ lies in the positive cross-country externalities between countries for minimum standards $s^j \in \left(q_L^{UR}, \overline{s}\right)$, which become negative for $s^j \in \left(\overline{s}, s^P\right)$, where $\overline{s} = 0.27763\frac{\overline{\theta}}{b} = 2.7763$ and $s^P = \frac{20}{3}$. Hence, at $s^B = \overline{s} = 2.7763$, the profit from firm A's low quality exports is maximised, yielding the highest attainable welfare for A at $\left(s^A, s^B\right) = \left(s^S, \overline{s}\right)$. Similar arguments apply for country B.

The dotted contour reflects the iso-world-welfare contour through the Nash equilibrium point, corresponding to welfare level $W^* = W^{A*} + W^{B*}$, and centred around the world welfare maximising WO point. The core, enclosed by the intersection contours W^{A*} and W^{B*}, gives the set of Pareto-improving cooperative agreements, the efficient of which lie on the contract curve, that forms a subset of the efficiency locus EE.

Propositions (8) and (9) are reflected by reciprocal increases in standards s^A and s^B, which increase welfare by 'internalising' the positive externalities drive firms to under-regulate at the NE, relative to WO. These Pareto-improving adjustments shift countries onto smaller and smaller concentric circles from NE, which correspond to higher welfare levels, until efficiency is achieved at WO where both iso-welfare contours are tangent. As with trade in high quality goods, the Prisoners' Dilemma structure exists, since countries A and B have an incentive to defect to D^A and D^B, respectively, from a cooperative agreement at WO.

5.2 Bargaining from Asymmetric Nash Equilibria

This section examines the incentives and scope for cooperative agreement between the two countries from an initial asymmetric Nash equilibrium in minimum quality standards. This corresponds to the trade pattern where one firm ranks as the high quality leader in both markets, and the other firm is the world low quality supplier. The resulting trade pattern is where one country exports high quality goods, and finds it optimal to set minimum quality standard $s^S < s^{WO}$, while the other exports low quality goods, and sets $s^T > s^{WO}$.

The results point to scope for mutual gains from reciprocal adjustment in minimum standards, but show that the asymmetric welfare measures and externalities (positive for one country and negative for the other) make a cooperative agreement at the world optimum infeasible. The asymmetries between A and B are such that the world optimum does not offer a Pareto gain to both countries and hence does not lie on the contract curve. In the absence of lump-sum transfers that can correct for the asymmetries, the models shows that harmonisation of minimum quality standards cannot form a cooperative agreement. This result is similar to Mayer (1981) and Kennan and Riezman (1988), who show in the context of tariff negotiations that free trade may be unattainable if countries are sufficiently asymmetric[8] in size.

The results are summarised by general propositions (10) to (14) and then illustrated for particular parameter values.

Proposition 10 *If trade flows vary in quality, then a cooperative agreement reached from the non-cooperative Nash equilibrium must involve a higher standard in the high quality exporting country and a lower standard in the low quality exporting country .*

Proof. Suppose A exports high quality goods and B exports low quality goods (or *vice versa*). It follows from propositions (1) and (5) that A sets a 'soft' standard and B a 'tough' standard unilaterally, where $s^{A^*} = s^S < s^{WO}$ and $s^{B^*} = s^T > s^{WO}$. The implicit reaction functions (44) and (45) yield $s^{A*}\left(s^B\right) = s^S \ \forall s^B$ and $s^{B*}\left(s^A\right) = s^T \ \forall s^A$, respectively. Equations (63) and (68) imply a negative externality on A from $s^{B^*} = s^T$ and a positive externality on B from $s^{A^*} = s^S$. Hence for standards $\left(s_0^A, s_0^B\right)$ to be welfare improving for both A and B relative to the Nash standards it is necessary that $s_0^A > s^S$ and $s_0^B < s^T$. If these conditions are not both satisfied, then at least one country has lower welfare under $\left(s_0^A, s_0^B\right)$ than under $\left(s^S, s^T\right)$, as shown by (69) and (66), and $\left(s_0^A, s_0^B\right)$ cannot be the result of a cooperative agreement. ■

[8] An important difference is that asymmetric Nash equilibria arise endogenously as a feature of the vertical product differentiation in this paper, and not as a result of assymetric assumptions in country or firm characteristics.

Lemma 11 *The world optimum does not lie on the contract curve of governments whose initial bargaining position is an asymmetric Nash equilibrium in minimum standards.*

Proof. Consider the asymmetric Nash equilibrium where A exports high quality goods and B exports low quality goods, where Nash equilibrium standards are $s^{A^*} = s^S < s^{WO}$ and $s^{B^*} = s^T > s^{WO}$. For the world optimum to lie on the contract curve it must be both (i) efficient and (ii) Pareto improving. The world optimum is shown to be efficient in section 3.3.2. Agreement at the world optimum is shown not to be Pareto improving, however, by examination of country welfare levels at the Nash equilibrium and at the world optimum:
Substituting $s^S = 0.23395\frac{\overline{\theta}}{b}$ and $s^T = 0.34691\frac{\overline{\theta}}{b}$ into equation (25) yields Nash equilibrium high qualities $q_{HA}(s^S) = 0.42856\frac{\overline{\theta}}{b}$ and $q_{HB}(s^T) = 0.49272\frac{\overline{\theta}}{b}$. Firm quality rankings imply $q^*_{AA} = q_{HA}(s^S) = 0.42856\frac{\overline{\theta}}{b}$, $q^*_{AB} = q_{HB}(s^T) = 0.49272\frac{\overline{\theta}}{b}$, $q^*_{BB} = s^T = 0.34691\frac{\overline{\theta}}{b}$ and $q^*_{BA} = s^S = 0.23395\frac{\overline{\theta}}{b}$. Substitution of the equilibrium values in (42) and (43) yields Nash welfare levels $W^{A*} = \left(6.9585 \times 10^{-2}\right)\frac{\overline{\theta}^3}{b}$ and $W^{B*} = \left(8.0616 \times 10^{-2}\right)\frac{\overline{\theta}^3}{b}$, respectively.
At the world optimum low qualities are $q_{LA} = q_{LB} = s^{WO} = 0.25241\frac{\overline{\theta}}{b}$. From (25) the high quality best responses are $q_{HA}(s^{WO}) = q_{HB}(s^{WO}) = 0.43885\frac{\overline{\theta}}{b}$. It follows that3 $q^{WO}_{AA} = q^{WO}_{AB} = 0.43885\frac{\overline{\theta}}{b}$ and $q^{WO}_{BB} = q^{WO}_{BA} = 0.25241\frac{\overline{\theta}}{b}$. Substituting into (**??**) and (**??**) yields welfare levels at the world optimum $\widetilde{W}^A = \left(7.5567 \times 10^{-2}\right)\frac{\overline{\theta}^3}{b}$ and $\widetilde{W}^B = \left(7.7249 \times 10^{-2}\right)\frac{\overline{\theta}^3}{b}$, respectively.
$\widetilde{W}^A > W^{A*}$ and $\widetilde{W}^B < W^{B*}$ imply the world optimum is not Pareto improving relative to the asymmetric Nash equilibrium and thus cannot lie on the contract curve. ■

Proposition 12 *From an initial asymmetric Nash equilibrium in minimum standards, an agreement at the world optimum cannot be reached through Pareto improving reciprocal adjustment of national standards.*

Proof. This follows directly from lemma (11). ■

Lemma 13 *From initial asymmetric Nash equilibrium minimum standards a lump-sum transfer from the high quality to the low quality exporting country can ensure mutual gains from a cooperative agreement at the world optimum.*

Proof. Consider the asymmetric Nash equilibrium where A exports high quality goods and B exports low quality goods. The proof of lemma (11) confirms that $\widetilde{W}^A - W^{A*} > W^{B*} - \widetilde{W}^B$. Thus any lump-sum transfer L^{AB} from A to B where $L^{AB} \in \left(W^{B*} - \widetilde{W}^B, \widetilde{W}^A - W^{A*}\right)$ ensures mutual gains from an agreement at the world optimum. ■

Proposition 14 *If lump sum transfers between countries are possible, then the world optimum can be reached through international cooperation for all configurations of firm quality rankings.*

Proof. This follows directly from propositions (9) and (13). ■

Figure (10) illustrates the strategic incentives and opportunities for cooperative bargaining from the asymmetric Nash equilibrium where $s^A = s^S$ and $s^B = s^T$, corresponding to a quality ordering in each market where firm A is the high quality supplier. As before, the curves illustrated are plotted for parameter values $b = \frac{1}{2}$ and $\overline{\theta} = 5$ using the profit equations for high and low quality goods, consumer surplus and the quality reaction function of the high quality firm given in Appendix A.

The asymmetric Nash equilibrium depicted contains elements of figures (8) and (9) of the previous sections. Country A exports high quality goods, and thus always loses welfare from the implementation of a binding standard in country B, through the negative effect on export profit. The iso-welfare contours for A are thus increasing in welfare for lower s^B, and centred around $s^A = s^S$, the optimal minimum standard for A. Welfare level W^{A*} is attained at the asymmetric Nash equilibrium.

Country B is an exporter of low quality goods to country A and thus experiences a positive welfare effect from the implementation of $s^A \in \left(q_L^{UR}, \overline{s}\right)$, and a negative welfare effect for $s^P \in \left(\overline{s}, s^P\right)$, giving rise to elliptical iso-welfare contours. Welfare W^{B*} corresponds to the welfare level at the Nash equilibrium.

The concentric dotted iso-world-welfare contours are centred around WO and the efficiency locus EE passes through WO and into the core formed by the two (reservation) iso-welfare contours at NE. The main observation is that WO is not on the countries' contract curve, so in the absence of lump sum transfers, this point cannot be reached through reciprocal adjustment of s^A and s^B. While country A gains from WO (relative to NE), country B experiences a loss in welfare, since $\widetilde{W}^B < W^{B*}$. Mutual gains from a cooperative agreement are possible, for example at C, but the resulting agreement does not entail harmonisation of standards and corresponds to a world welfare level lower than at WO. Note that the Prisoners' Dilemma structure in incentives continues to apply, with D^A and D^B reflecting the defection points of A and B, respectively.

If lump-sum transfers are possible between countries, then a lump sum transfer $L^{AB} = W^{B*} - \widetilde{W}^B$ is the smallest transfer consistent with cooperation of B at WO. Under L^{AB}, country B is indifferent between NE and WO, while A gains welfare relative to the non-cooperative Nash equilibrium.

Meza and Tombak (2007) introduce asymmetries in marginal costs and Jinji and Toshimitsu (2004) assume asymmetric fixed quality-development costs to obtain an endogenously determined quality ranking. For sufficiently small cost differentials, they each find a unique duopoly equilibrium in which the low cost firm offers high quality. Their results suggest that even small cost asymmetries can eliminate symmetric Nash equilibria. If the quality ranking of firms is preserved across markets through a cost advantage of one firm over another, then only the asymmetric equilibria discussed survive.

5.3 Cooperative Standard-Setting and Trade

Proposition 15 *International cooperation in standard-setting raises trade volume relative to the non-cooperative Nash equilibrium for all configurations of firm quality rankings.*

Proof. Proposition (6) establishes that trade flows are lower under the Nash equilibrium than under world optimum standards. Under symmetric initial conditions, Proposition (9) establishes that reciprocal mutual adjustments in standards allow the world optimum to be reached. Hence international cooperation from a symmetric Nash equilibrium raises or lowers standards towards the world optimum, thereby raising trade flows. Moreover, if lump sum transfers can be made between countries, then Proposition (14) establishes that the world optimum can be reached even under asymmetric initial conditions.
Pareto improving cooperation is possible even in the absence of lump-sum transfers, however. Proposition (10) establishes that such cooperation must raise the standard of the high quality exporting country and lower the standard of the low quality exporting country, albeit not to the world optimum level. Since $\frac{\partial S_{Hj}}{\partial s^j} < 0$ and $\frac{\partial S_{Lj}}{\partial s^j} > 0$ for $s \in \left(q_L^{UR}, \widehat{\widehat{s}}\right)$, any cooperative agreement from an asymmetric Nash equilibrium is trade enhancing. ■

6 Conclusion

This paper extends a well-established vertical product differentiation model to an international setting where international duopolists compete in two segmented markets. The framework is used to analyse governments' incentives for the unilateral setting of minimum quality standards, as well as the scope and effects of international cooperation on welfare and international trade. Firms compete in qualities and prices internationally and incur variable costs of quality improvement, allowing quality of domestic sales and exports to be differentiated. National standards are endogenous and result from a standard-setting game between governments whose objective function is to maximise national welfare.

Multiple equilibria arise as a feature of the underlying vertical product differentiation model. Four non-cooperative Nash equilibria in minimum standards are shown to exist, two symmetric and two asymmetric, depending on the quality ranking of firms in each market. The framework delivers several new propositions. First, the analysis establishes that in all four cases, unilaterally selected minimum quality standards are inefficient as a result of cross-country externalities. Second, trade flows are shown to be lower under non-cooperative Nash equilibrium standards than under a mutually beneficial cooperative agreement, suggesting higher trade flows between countries that cooperate in standard-setting than between countries that set minimum standards unilaterally. Unilateral minimum standards are thus shown to operate as non-tariff barriers to trade.

In contrast to the widely explored negative terms-of-trade externalities of the strategic tariff-setting literature, the cross-country externalities arising from mild quality standards can be are either positive or negative, depending on the quality of traded goods. Profits from low quality exports are increasing in foreign minimum standards, provided these are not too severe, yielding a positive cross-country externality. Profits from high quality exports unambiguously decrease with foreign minimum standards, giving rise to a negative cross-country externality. The four Nash equilibria thus correspond to the four different combinations of externalities that may arise between the two countries: symmetric positive externalities, symmetric negative externalities, or asymmetric positive and negative externalities. Hence unilateral minimum standards may be inefficiently high or inefficiently low relative to the efficient world optimum symmetric standards.

Third, the existence of Pareto improving cooperative agreements from an initial bargaining position at any of the four Nash equilibria, is established. Moreover, the world welfare maximising symmetric standard can be reached through reciprocal adjustments in national minimum standards from either of the two symmetric Nash equilibria. These correspond to firm rankings that give rise to trade in high quality goods only, or trade in low quality goods only. While the underlying Prisoners' Dilemma structure of the standard-setting game raises concerns about enforcement of cooperative agreements, the theoretical results show that an efficient cooperative agreement to harmonise minimum quality standards is feasible and mutually beneficial for countries that trade in goods of similar quality levels.

Finally, the potential scope for mutually beneficial cooperation is shown to be significantly restricted when cross-country externalities are asymmetric. New propositions establish that although asymmetric countries can mutually gain from cooperation, the resulting cooperative standards are asymmetric and do not maximise world welfare. Cross-country asymmetries that arise endogenously in equilibrium, and not by assumption, correspond to the setting where trade is between a country who is a high quality leader and a country that supplies both markets with low quality. The resulting contract curve does not include the symmetric world optimum. While lump-sum transfers can correct for this asymmetry, a mutually beneficial cooperative agreement at the world optimum cannot be reached in their absence. The results suggest that successful cooperation in the setting of minimum standards between high quality and low quality exporting countries is less likely, particularly if the agenda for cooperation is to harmonise minimum standards.

The paper provides a motivation for international cooperation in minimum standards that stems from the inefficiencies of national decisions in an international context where countries are linked through trade, but also points to potential difficulties in the realisation of successful cooperation as international asymmetries hinder the incentives to implement jointly, but not individually, beneficial harmonised standards.

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Appendix A. Quality Reaction Functions

The full expression for the high quality firm's optimal quality response to an unregulated low quality, $q_{Hj}(q_{Lj})$, or response $q_{Hj}(s^j)$ to a minimum standard $s^j \in \left[q_{Lj}^{UR}, s^{Pj}\right]$, is given below. Due to its length the country subscript j is dropped and $q_{Hj}(\cdot)$ is given as $q_H(s)$. It is expressed in terms of the standard, s, and the ratio of cost to market size, $\frac{\overline{\theta}}{b}$, denoted by m

$$q_H(s) = \frac{1}{9}m + \frac{11}{36}s + A - \frac{1}{A}\left(\frac{5}{324}ms - \frac{1}{81}m^2 - \frac{31}{1296}s^2\right)$$

where:

$$A = \left(\frac{1}{729}m^3 - \frac{1049}{23\,328}s^3 + \frac{503}{7776}ms^2 - \frac{5}{1944}m^2 s + B\right)^{\frac{1}{3}}$$

and:

$$B=\left(\frac{1999}{995\,328}s^{6}-\frac{1441}{248\,832}ms^{5}+\frac{9803}{2239\,488}m^{2}s^{4}-\frac{119}{279\,936}m^{3}s^{3}+\frac{23}{139\,968}m^{4}s^{2}\right)^{\frac{1}{2}}$$

The low quality firm's reaction function with $q_{Lj}\left(q_{Hj}\right)$ can be expressed in terms of high quality q_{Hj} and the ratio of market size to cost denoted m. For expositional convenience the country subscript j is dropped.

$$q_{L}\left(q_{H}\right)=\frac{17}{6}q_{H}+D-\frac{1}{D}\left(\frac{7}{6}mq_{H}-\frac{175}{36}q_{H}^{2}\right)$$

where:

$$D=\left(\frac{1111}{108}q_{H}^{3}-\frac{95}{24}mq_{H}^{2}+\left(\frac{343}{216}m^{3}q_{H}^{3}-\frac{7225}{1728}m^{2}q_{H}^{4}+\frac{365}{288}mq_{H}^{5}-\frac{579}{64}q_{H}^{6}\right)^{\frac{1}{2}}\right)^{\frac{1}{3}}$$

The unregulated Nash equilibrium quality levels reported in the text can be found by solving $q_{Hj}\left(q_{Lj}\right)$ and $q_{Lj}\left(q_{Hj}\right)$ simultaneously. The polynomial expressions yield a number of solutions. All negative and complex solutions are discarded, as well as those for which $q_{Hj}<q_{Lj}$. There is a unique real solution for which $q_{Hj}>q_{Lj}>0$.

The minimum quality standards s^{s}, s^{T}, s^{WO} and threshold standards $\overline{s}$, $\widehat{s}$ and $\widehat{\widehat{s}}$ referred to in the main text are found by substituting $q_{Hj}\left(s^{j}\right)$ into the relevant equations for welfare, profit, sales and consumer surplus, which are then expressed in terms of s^{j} and market parameters b and $\overline{\theta}$ only. Applying optimisation techniques to these expressions, with respect to s^{j}, yields the solutions. All solutions described in the text have been computed using *Scientific Workplace*.

Furthermore, all figures in the paper are plotted by substituting $q_{Hj}\left(s^{j}\right)$ into the relevant equations and setting parameter values $b=\frac{1}{2}$ and $\overline{\theta}=5$.

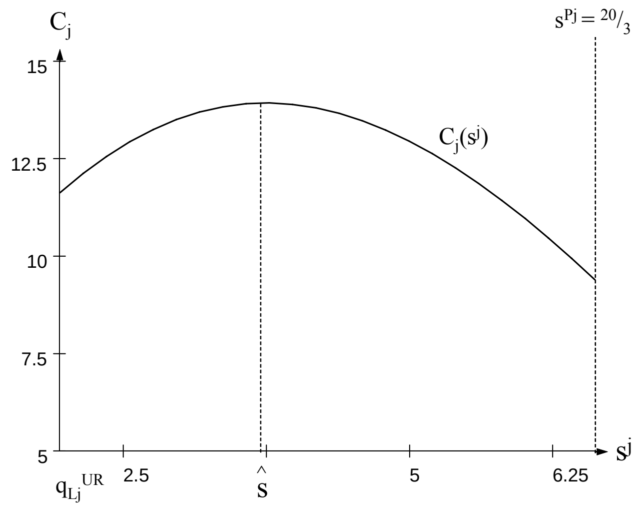

Figure 7: Regulated equilibrium consumer surplus.

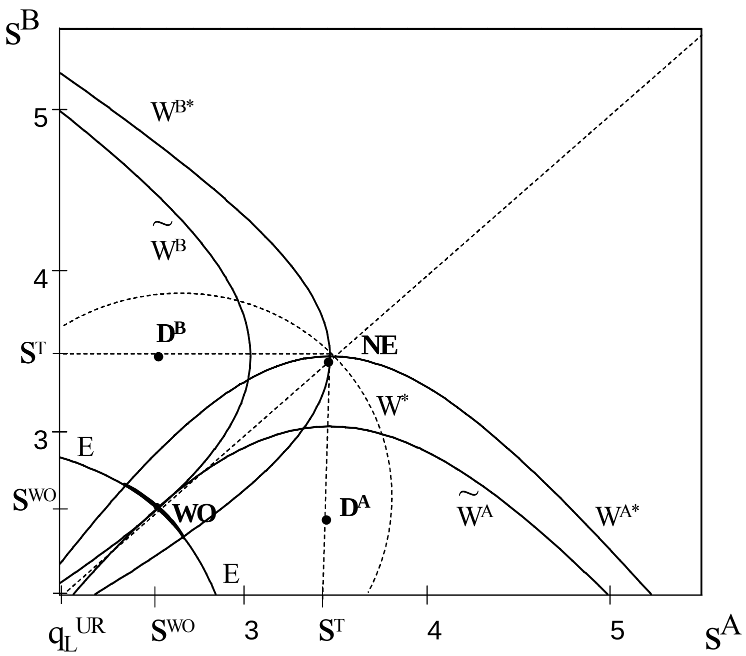

Figure 8: Cooperative agreement in standards under trade in high quality goods.

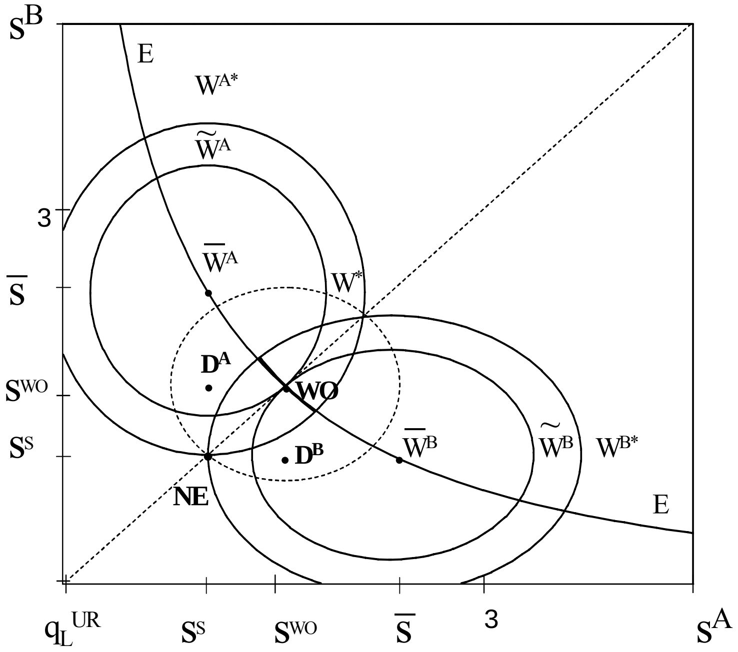

Figure 9: Cooperative agreement in standards under trade in low quality goods.

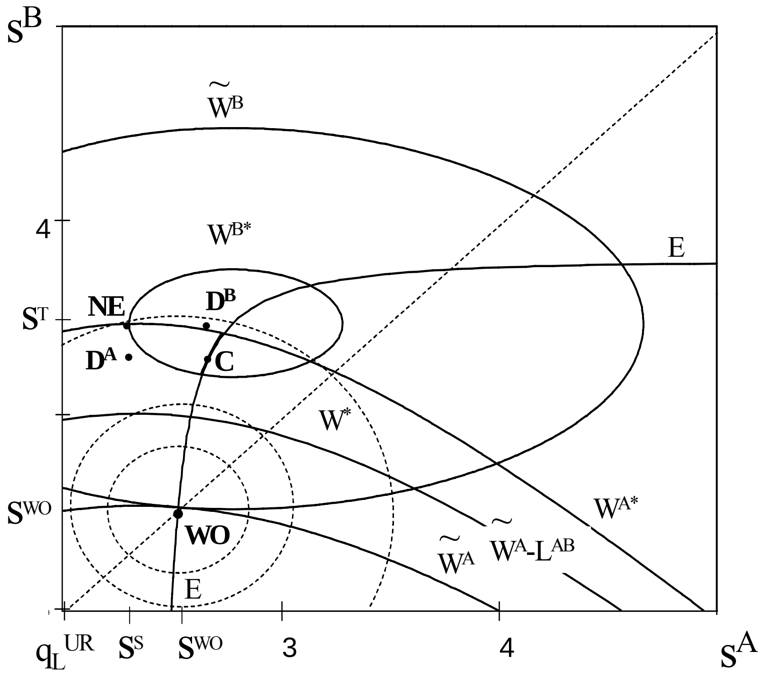

Figure 10: Cooperative agreement in standards when countries trade high for low quality goods.