On Subsidies in Trade Agreements*

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Abstract

The role of production subsidies in trade agreements has long been neglected by trade economists. To fill this gap, Bagwell and Staiger (2006) analyze this issue and show that, quite generally, the sole variable efficient trade agreements need to address is market access and that, moreover, the de facto prohibition of subsidies by prevailing WTO legislation is inefficient. The present paper shows that their argument fails when trade agreements are required to be self-enforceable. Under the self-enforcement constraint, welfare-maximizing trade agreements entail subsidy rules. Moreover, in a scenario argued to be the most realistic one, production subsidies are prohibited by the efficient trade agreement. Any trade agreement that addresses market access only is necessarily inefficient. In this sense, the paper makes a strong case for the WTO subsidy rules.

Keywords: Trade Agreement, Subsidy, Self-enforceability.

JEL Classifications: F10, F13.

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1 Introduction

Production subsidies plague trade negotiations for a long time already. Baldwin (2006) observes that "negotiations at Cancun collapsed [...] in the absence of greater commitments by the developed countries to reduce agricultural subsidies and lower import barriers on agricultural products." In fact, by blocking international cooperation, subsidies might induce economic losses that exceed even their substantial direct costs (see Anderson (2004)). Despite their obvious importance for trade talks, trade theorists have neglected the role of production subsidies in trade agreements until very recently. In a laudable attempt to fill this gap, Bagwell and Staiger (2006) provide a first formal analysis of the issue, addressing the de facto prohibition of production subsidies by current WTO legislation. Efficient trade agreements, so their central message, target market access only. Their argument builds on the fact that all cross-border inefficiencies travel through world prices and that, moreover, world prices are uniquely determined by market access. Consequently, negotiating mutual market access is sufficient to resolve all cross-border inefficiencies and any additional restriction – e.g. prohibiting subsidies – can only generate inefficiencies.

The present paper shows that this line of argument fails when trade agreements are required to be self-enforceable. To impose the self-enforceability requirement means to acknowledge the fact that countries cannot be forced into trade agreements but join them – and respect them – only if this is individually beneficial. This assumption is truly restrictive, since large countries have incentives to defect on trade agreements by raising tariffs to distort world prices to their favour. Fortunately, however, countries refrain from doing so when the benefits of today's defection come at the cost of a breakdown of international trade cooperation in subsequent periods. Accordingly, the central precondition – formalized by the self-enforcement constraint – requires that the dynamic benefits of honoring an agreement outweigh those of defection.

Under this self-enforcement requirement, optimal trade agreements generally target subsidies of individual countries because of two fundamental reasons. First, the self-enforcement requirement does not constrain the policy choice of the individual country but the policies a trade agreement can successfully implement. Hence, the self-enforcement constraint must be addressed by the designers of trade agreements – e.g. by a supranational institution as the WTO – and not by the countries individually. Second, the value of cooperation and the value of defection, and thus the self-enforcement constraint, are affected by the output structure of member countries and, in particular, by subsidies. Consequently, the optimal trade agreement requires a certain level of production subsidies, which is to be specified by the optimal trade agreements.

In sum, the requirement that trade agreements be self enforcing makes a general case for targeting subsidies in trade agreements. To exemplify this general principle and to evaluate the WTO subsidy rules in the light of self-enforceability, the present paper develops a 2-country 2-good competitive general equilibrium model, where benevolent governments employ import tariffs and production subsidies to maximize their citizens' welfare. Under the assumption that the self-enforcement constraints bind marginally, the model offers two new insights. First, production subsidies for import competing sectors are zero. Second, trade agreements that target market access only are necessarily inefficient.

The intuition for this optimal subsidy rule is the following. If production reacts to prices with a minimal delay – e.g. due to time-to-build requirements – a production subsidy affects output some time ahead. Thus, by the means of subsidies, a country can create artificial competition in its import market in the medium term. This makes the country less vulnerable to uncooperative tariffs of its trade partner in future periods, which decreases the threat of a breakdown of cooperation and thus increases the country's defection temptation. Such an increase in defection temptation unambiguously deteriorates the trade agreement.

With its focus on the role of production subsidies in trade agreements, the present paper is intimately related to Bagwell and Staiger (2006). Unlike this earlier study, the present paper, via the introduction of the self-enforcement constraint, provides a rational to directly address subsidies in trade agreements. Moreover, and in stark contrast to Bagwell and Staiger (2006) it offers a rational to prohibit subsidies altogether. Thus, the present analysis may serve a useful complement for a balanced evaluation of the prevailing WTO legislation.

Since the early work of Yarbrough and Yarbrough (1986) and Dixit (1987), trade theory generally understands trade agreements as a set of rules that encourage trade integration in absence of execution power and which, therefore, must be self-enforcing. Prominent contributions include Devereux (1997), Maggi (1999), Bagwell and Staiger (2000), Park (2000), and Bond and Park (2002). Within this literature, an important branch highlights the effects of adjustment costs of output for optimal trade agreements. In presence of such rigidities a change of regime from cooperative to non-cooperative policies is generally prolonged and more costly. Hence, the consequences of a defection of trade agreements are typically harsher, which, in turn, makes a defection less attractive. Via this channel adjustment costs can generate endogenous gradualism in trade liberalization when output changes sluggishly (Staiger (1994) and Furusawa and Lai (1999)). At the same time, adjustment costs induce endogenous shifts in outside options and bargaining positions, which, in turn, can generate an aggravated version of a hold-up problem. Such a scenario is presented in McLaren (1997), where trade "can make the small country worse off than it would have been if its trade partner did not exist". Crucial to these results is the assumption that the supply side of the world economy is entirely decentralized. The present paper departs from this latter assumption and analyzes when and how governments should intervene in decentralized production in order to alleviate the potential efficiency losses induced by the combination of adjustment costs and the self-enforcement constraint.

The remainder of the paper is organized as follows. Section 2 introduces the general setup and formalizes the incentives to defect on trade agreements. Section 3 characterizes the optimal trade agreements and presents the main results of the paper. Section 4 concludes.

2 The Model

The model shall illustrate international cooperation on trade in a repeated game between two countries.

2.1 The Basic Setup

There are two countries, Home (no *) and Foreign (*), populated by individuals of masses L and L^*, respectively. Individuals in both countries consume two final goods X_1 and X_2.

Demand. Consumers are infinitely lived and derive lifetime utility

$$U^{(*)} = \sum_{t \geq 0} \beta^t \ u\left(c_{2,t}^{(*)}, c_{2,t}^{(*)}\right) \tag{1}$$

where $c_{i,t}^{(*)}$ is consumption of good X_i at time t. The momentaneous utility u is continuously differentiable and gives rise to constant and equal expenditure shares on the goods X_1 and X_2. Aggregate consumption in either country is thus

$$c_1^{(*)} = I^{(*)}/2p_1^{(*)} \qquad c_2^{(*)} = I^{(*)}/2p_2^{(*)} \tag{2}$$

where $I^{(*)}$ are national incomes and $p_i^{(*)}$ are local prices. Here and whenever there is no risk of confusion, time indices will be dropped.

Supply. Competitive firms in both countries produce the goods X_i using a constant returns to scale technology and labor and sector-specific intermediate goods Z_i as the factors

$$x_i^{(*)} = a_i^{(*)} f_i(z_i^{(*)}/L_i^{(*)}) L_i^{(*)}. \tag{3}$$

Here L_i and L_i^* stand for the countries' labor allocation to sector i while z_i and z_i^* represent the quantities of the intermediate goods Z_i. The functions f and g are twice continuously differentiable and satisfy $f_i(0) = 0$, $f_i' > 0$, and $f_i'' < 0$.

Home is assumed to have a comparative advantage in X_1-production, reflected by

$$\frac{a_1}{a_2} > \frac{a_1^*}{a_2^*}. \tag{4}$$

Intermediate goods Z_i are produced with the constant returns to scale technology

$$z_i^{(*)} = L_{z_i}^{(*)}. \tag{5}$$

Until further notice markets are competitive in both countries. The technologies (3) and (5) imply that labor is the only true production factor and assumption (4) introduces Ricardian motives of trade.

Integrated Economy. Intermediate goods Z_i are produced competitively through (5) so that the price of the intermediates equals the wage. The intermediate-to-labor ratio in final good production will be denoted by $\xi_i = z_i/L_i$. Cost minimization of firms in the final goods sector implies[1]

$$1 = f(\xi_i)/f_i'(\xi_i) - \xi_i \tag{6}$$

as long as output in the relevant sector is positive. These conditions determine the ratios ξ_i. By $f_i'' < 0$ and $f_i > 0$ the expressions $f_i(\xi_i)/f_i'(\xi_i) - \xi_i$ are increasing in ξ_i and the ratios ξ_i are unique.

In the following X_1 is chosen as the numeraire so that the domestic prices of X_2 coincides with the relative price between X_2 and X_1, denoted by p. With this convention, a competitive labor market together with technologies (3) and (5) implies $a_1 f_1'(\xi_1) = p a_2 f_2'(\xi_2)$ so that the equilibrium price is unique:

$$p = \frac{p_2}{p_1} = \frac{a_1 f_1'(\xi_1)}{a_2 f_2'(\xi_2)} \tag{7}$$

Together with aggregate income $I = wL = a_1 f_1'(\xi_1) L$ the price (7) determines aggregate consumption c_i by equations (2). Total labor allocation (including labor employed in intermediate production) in the X_i-sector is

$$(1+\xi_1)L_1 = L/2 \qquad \text{and} \qquad (1+\xi_2)L_2 = L/2. \tag{8}$$

By the first fundamental welfare theorem the equilibrium, thus defined, is efficient.

Free Trade. When final goods are costlessly tradable Home and Foreign specialize according to comparative advantage. It will be convenient to simplify the formulation of the aggregate production functions in each country, writing

$$x_i = A_i L_i \qquad \text{and} \qquad x_i^* = A_i^* L_i^* \tag{9}$$

where

$$A_i^{(*)} = a_i^{(*)} \frac{f_i(\xi_i)}{1+\xi_i}.$$

[1] Solve $\min_{L_i,\xi_i} L_i(1+\xi_i)$ s.t. $a_i f(\xi_i) L_i \geq 1$.

Notice that ξ_i are determined by (6) and do not differ across countries or trade regimes, which implies that the comparative advantage is still determined by condition (4). In equilibrium the value of world expenditure on X_1 equals the value of supply of X_1. Under constant expenditure and equal shares this condition is $p_1(x_1 + x_1^*) = (p_1(x_1 + x_1^*) + p_2(x_2 + x_2^*))/2$ and determines the relative price of X_2 to X_1 as

$$p = \frac{p_2}{p_1} = \frac{x_1 + x_1^*}{x_2 + x_2^*}. \tag{10}$$

At the same time cost minimization of firms implies

$$p \in \begin{cases} \frac{A_1}{A_2} & if\ x_1, x_2 > 0 \\ \left[\frac{A_1}{A_2}, \frac{A_1^*}{A_2^*}\right] & if\ x_2 = x_1^* = 0 \\ \frac{A_1^*}{A_2^*} & if\ x_1^*, x_2^* > 0. \end{cases} \tag{11}$$

Equations (10) and (11) determine the unique world price p of the respective regime. Labor allocation and output by (3), (6), and $\xi_i = z_i/L_i$ and technologies (9). Finally, national incomes $I^{(*)} = (x_1^{(*)} + px_2^{(*)})$ uniquely determine consumption through (2).

As in standard Ricardian models three possible patterns of international specialization emerge. First, partial specialization with Home producing X_1 and X_2 and Foreign producing X_2 only, second, full international specialization with Home producing X_1 only and Foreign producing X_2 only, and third partial specialization with Home producing X_1 only and Foreign producing X_1 and X_2. Notice that at least one of the countries completely specializes on production of one of the goods. Throughout the paper the comparative advantage is assumed to be strong enough to generate full specialization under free trade. This amounts to assuming

$$1 < \frac{A_1 L}{A_1^* L^*} \quad \text{and} \quad 1 < \frac{A_2^* L^*}{A_2 L} \tag{12}$$

This limitation is not an entirely artificial one. Crucial for the results below is that under free trade each country covers the world supply of one or several goods. This pattern of specialization emerges in a great variety of standard trade models (see e.g. Dornbusch et al (1977), Dornbusch et al (1980), Acemoglu and Ventura (2002), and Romalis (2004)) and is, in this sense, a natural one.

2.2 Government Policies

In the present paper governments are assumed to set production subsidies and import tariffs, definition of which will be given next.

Import Tariffs. Governments of Home and Foreign can set gross ad valorem import tariffs T and T^*. Throughout the paper Home's domestic price of good X_1 is taken as the numeraire and the world price of X_1 denoted with p. Thus, domestic prices in Home and Foreign for goods X_1 and X_2 are

$$p_1^{Home} = 1 \quad p_2^{Home} = Tp \quad \text{and} \quad p_1^{Foreign} = T^* \quad p_2^{Foreign} = p.$$

Home's national income includes tariff revenues and equals $I = x_1 + Tpx_2 + (T-1)p(c_2 - x_2)$ so that with $c_2 = I/(2Tp)$ from (2)

$$I = 2\frac{T(x_1 + px_2)}{T+1}. \tag{13}$$

Foreign's income is $I^* = T^* x_1^* + px_2^* + (T^* - 1)(c_1^* - x_1^*)$ or

$$I^* = 2\frac{T^*(x_1^* + px_2^*)}{T^*+1}. \tag{14}$$

The trade balance $p\,(c_2 - x_2) = c_1^* - x_1^*$ together with (2), (13), and (14) determines relative prices

$$p = \frac{x_1(T^*+1) + x_1^* T^*(T+1)}{x_2 T(T^*+1) + x_2^*(T+1)}. \tag{15}$$

Production Subsidies. Recognizing the myriad ways of production subsidies the World Trade Organization gives a very broad definition of subsidies. Article 1 of the Agreement on Subsidies and Countervailing Measures defines a subsidy as "a financial contribution by a government or any public body", where financial contributions can consist of "a direct transfer of funds", "revenue that is otherwise due... [but] not collected" or the provision of "goods or services other than general infrastructure" (see WTO (1995)). The present paper adopts this last version as a definition of a subsidy. Following the WTO code, a subsidy will be defined as a public provision of the sector-specific input Z_i. More precisely, to subsidize sector X_i, a government purchases the amount $\bar{z}_i \geq 0$ of the intermediate good Z_i from one or more private firms in the intermediate sector. This purchase is realized through a price-guarantee the government gives the Z_i-producers for the pre-determined quantity $\bar{z}_i$. The guaranteed price weakly exceeds the firms' production costs w. The government-controlled quantity of the intermediate goods, $\bar{z}_i$, is distributed to a set of final good firms without charge; the costs are financed through lump-sum taxes.[2]

Since government activities are usually thought to be inefficient, a fraction of the intermediate good is assumed to be lost in the process of subsidization and the effective unit labor requirement is $\gamma > 1$ for production of the subsidized intermediate goods Z_i. Throughout the analysis, subsidies will be handed to import-competing sectors only, i.e. $\bar{z}_1 = \bar{z}_2^* = 0$.[3]

[2] The price-guarantee for Z_i-producer as well as the distribution of the $\bar{z}_i$ may generate positive profits. Under homothetic preferences total income is the only determinant for aggregate demand and the distribution of profits can be neglected.

[3] This is a convenient but innocent simplification, since the present paper's main mechanism is exclu-

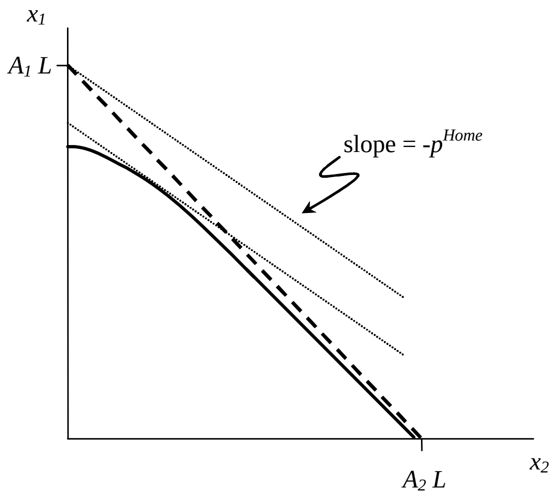

Figure 1: Production Possibility Frontier with subsidies (solid line) and without (dashed line).

Figure 1 illustrates the impact of a subsidy $\bar{z}_2 > 0$ in Home on its the production possibility frontier. There are two main consequences of the subsidy. First, the production possibilities are strictly reduced due to the inefficiency in centralized production ($\gamma > 1$). Second, the subsidy implies that production of good X_2 is positive at low relative prices p^{Home} when it would be zero in absence of subsidies. In fact, the condition $\lim_{x\to\infty} f_i(x) = \infty$ implies that domestic production of X_i is positive at all finite prices $p^{Home} \in (0, \infty)$ whenever $\bar{z}_2 > 0$.

Production under Subsidies and Tariffs. Under positive subsidies the intermediate labor ratio in Home's sector X_2 is not necessarily determined by (6) any more. In general, profit maximization in the competitive domestic market implies

$$Tpa_2 \left[g(\bar{\xi}_2) - \bar{\xi}_2 g'(\bar{\xi}_2) \right] = w \tag{16}$$

for the distorted ratio $\bar{\xi}_2$. This condition implies $\bar{\xi}_2 > 0$ for finite prices $Tp \in (0, \infty)$. There are two cases to distinguish. First, final good firms do not demand input good Z_2 in addition to centrally provided, i.e. $\bar{\xi}_2 = \bar{z}_2/L_2$, or second, final good firms do purchase additional input Z_2 and $\bar{\xi}_2 > \bar{z}_2/L_2$. In the first case total output in the X_2-sector is $a_2 g(\bar{\xi}_2)L_2$ while total labor input (including production of intermediates) is $(1 + \gamma\bar{\xi}_2)L_2$. Hence, aggregate labor productivity in the subsidized sector is $\bar{A}_2 = a_2 g(\bar{\xi}_2)/(1+\gamma\bar{\xi}_2)$. In the second case where $\bar{\xi}_2 > \bar{z}_2/L_2$ the optimality conditions with respect to intermediates and labor in final good production imply $\bar{\xi}_2 = \xi_2$ and ξ_2 is again determined by (6). Total

sively driven by the creation of import-competiting production. It may also reflect the fact that state intervention tends to support import competiting industries.

output in this second case is $a_2 g(\xi_2) L_2$ while total labor input is $(1+\xi_2) L_2 + (\gamma-1)\bar{z}_2$. This determines aggregate labor productivity and total labor productivity in the two cases is, respectively,

$$\bar{A}_2 = \begin{cases} \frac{a_2 g(\bar{\xi}_2)}{1+\gamma\bar{\xi}_2} & \text{if } \bar{\xi}_2 = \bar{z}_2/L_2 \\ \frac{a_2 g(\xi_2)}{1+\xi_2+(\gamma-1)(\bar{z}_2/L_2)} & \text{if } \bar{\xi}_2 > \bar{z}_2/L_2. \end{cases} \tag{17}$$

Notice that in the second case where $\bar{\xi}_2 > \bar{z}_2/L_2$ holds, the domestic price p^{Home} is not affected by the subsidy, since marginal productivity in Home's X_2-sector is A_2 and $A_2 p^{Home} = A_1$ holds. In this case the sole effect of a subsidy is the loss of national income though the waste of resources by $\gamma > 1$.

Observe also that subsidies can generate positive production in sectors that would be idle without government intervention. More precisely, Home and Foreign can induce import competing production at the marginal rates of substitution of, respectively,

$$A = \frac{\bar{A}_2}{A_1} = \frac{1}{A_1}\frac{a_2 g(\bar{\xi}_2)}{1+\gamma\bar{\xi}_2} \qquad \text{and} \qquad A^* = \frac{\bar{A}_1^*}{A_2^*} = \frac{1}{A_2^*}\frac{a_1^* f(\bar{\xi}_1^*)}{1+\gamma\bar{\xi}_1^*} \tag{18}$$

where $\bar{A}_1^*$ and $\bar{\xi}_1^*$ are Foreign's equivalents to (17) and $\bar{\xi}_2$. Obviously, under zero subsidies the A coincides with the ratio A_2/A_1 and A^* with A_1^*/A_2^*, respectively and hence (18) gives a general description of the marginal rates of transformation. Thus, the condition (11) on the world price p generalizes to

$$p \in \begin{cases} \frac{A_1}{A_2} & if\ x_1, x_2 > 0 \\ \left[\frac{A_1}{A_2}, \frac{A_1^*}{A_2^*}\right] & if\ x_2 = x_1^* = 0 \\ \frac{A_1^*}{A_2^*} & if\ x_1^*, x_2^* > 0. \end{cases} \tag{19}$$

Equation (16) implies that under positive domestic prices of the import good ($0 < Tp < \infty$) the variable $\bar{\xi}_2$ is strictly positive. Thus, the marginal rate of transformation A defined in (18) is positive and finite. The same reasoning applies to A^*.

3 Trade Agreements

It is well known that efficient trade agreements may implement non-zero tariffs, as long as relative prices are undistorted (see e.g. Dixit (1987) or McLaren (1997)). In the present framework, this means that the first best trade agreements are characterized by $p_1^{Home}/p_2^{Home} = p_1^{Foreign}/p_2^{Foreign}$ or $TT^* = 1$. Under this condition tariffs simply serve to transfer income from one country to another, without distorting neither supply nor demand.[4] The actual amount and the direction of these transfers depend on the countries' gains from trade, their outside options, and respective bargaining power.

[4] Such transfers can of course be realized through side-payments without involving negative tariff rates.

This paper, however, started from the premises that the first best trade agreement is not self-enforceable but countries would defect on the optimal agreement instead. Fundamental to the concept of self-enforceable trade agreements is the optimal tariff argument, according to which large countries benefit from charging tariffs unilaterally, thus distorting the terms of trade to their favor. To put it differently, countries have incentives to defect, or cheat, on a trade agreement by charging tariffs unilaterally. Such a defection, however, is typically assumed to come at the cost of a breakdown of future cooperation. The self-enforcement requirement is then met, if, in a dynamic sense, the value of respecting a trade agreement be higher than the value of defecting on it. This constraint will be formalized next.

3.1 Self Enforcement Constraint

Under a self enforceable trade agreement both countries receive weakly more utility from respecting the agreement than from defecting on it. For a general formalization of this concept, write $\bar{u}^{(*)}$ for the momentaneous utility under cooperation, u^D ($u^{D,*}$) under one-sided defection of Home (Foreign), and $u^{N,(*)}$ under uncooperative (or Nash) policies on both sides. With this notation and with the total utility (1) the self-enforcement constraints can be written as

$$\sum_{s \geq t} \beta^t \bar{u}_s^{(*)} \geq u_t^{D,(*)} + \sum_{s \geq t+1} \beta^t u_{s,t}^{N,(*)}. \tag{20}$$

The constraints for both countries need to be satisfied at all periods $t \geq 0$.[5] This infinite set of constraints collapses to two constraints – one for Home and one for Foreign – when all parameters and equilibrium policies are time-invariant. The following analysis will be conducted under this convenient restriction to time-invariant trade agreements.[6] Hence, the self-enforcement constraint in period $t = 0$ stands for the self-enforcement constraint of all periods.

The impact of tariffs and subsidies on the different components of (20) will be central in the following. The net gains from defection, and defection utility $u^{D,(*)}$ in particular, crucially depend on the timing of actions, which will be specified in turn.

The Timing. The literature's standard interpretation of defection is a unilateral deviation to the individually optimal policy in one period – the defection period – by one of the countries. This deviation is an off-equilibirum action and is thus unanticipated by other

[5] Here, the strongest possible punishment scheme is adopted, according to which cooperation breaks down in all periods following defection and all policies are set non-cooperatively. Notice also that the punishment utility $u_{t,s}^{N,(*)}$ may depend on the actual period t, and on s the period of defection.

[6] The restriction to time-invariant agreements is not an innocent one, as shown by the work of McLaren (1997), Park (2000), and Bond and Park (2002). It may be justified, however, by the restrictions trade negotiators face.

players. Hence, all players other than the defecting one cannot react within the same defection period but adapt their strategies a period later. Consequently, the tariffs of the country which is defected on remain at the levels fixed by the agreement. The same holds true for private firms, which cannot react within the period of defection but need time to adapt their output.[7] Since this principle applies to firms in both countries, the world output structure, summarized by the vector

$$X = (x_1, x_2, x_1^*, x_2^*) \in \mathbb{R}_+^4$$

is fix and taken as given within the defection period. Production subsidies, in the sense specified above, do not resolve this rigidity, since they work through price incentives for private firms as well.

The strictly positive reaction time of the economic agents that are hit by the unanticipated defection is an essential assumption of the repeated trade game – actually it defines the length of the game's periods. In standard trade models, where the import tariffs are the only policies that government set, this definition is unambiguous and clear. In the present model, however, where import tariffs as well as output adapts to price changes, the central question arises whether tariffs and output structures are equally fast to change. Notably, the time needed to adapt import tariffs may generally differ from the time to change the industrial structure of an entire economy and it is hardly surprising that in reality it does. Firms usually have extended adjustment periods to realize changes in output plans. Capacity-building or start-up periods substantially limit private firms's reaction time to price changes. Consequently, empirical literature confirms that adjustment of output is sluggish. Thus, Koeva (2000) estimates "that the average construction lead time for new plants is around two years in most industries". Compared to time spans of these dimensions tariffs are set and adapted rather fast.[8]

The model picks up these facts through the assumption that governments can change the tariffs on a period by period basis while firms need $M > 1$ periods to adapt their output plans. This assumption has important implications for the timing of events in case of a defection on trade agreements: after an unanticipated defection firms in both countries need M periods to adapt production. Consequently, following a defection in period t_0, national output is unchanged for the periods $t \in \{t_0, t_0 + 1, .., t_0 + M\}$ in both countries. From period $t_0 + M + 1$ onward, the output structure in both economies adapt according to production incentive (i.e. prices and subsidies). In sum, a defection is followed by two qualitatively different punishment phases: the first punishment phase – representing the medium term – during which uncooperative behavior is limited to tariffs

[7] This is a crucial difference to the setup in Devereux (1997).

[8] Even under a lengthy WTO dispute settlement process the standard procedure takes about a year (see WTO (2007)). A clear-cut defection in the game-theoretic sense is likely to generate much quicker reactions.

while output is still at its cooperation levels. A second phase – represents the long term and is characterized by uncooperative tariffs and subsidies with private firms producing accordingly.

With these assumptions about the timing the self-enforcement constraints (20) take a particular structure, which will be formalized with the following notation. First, let $\bar{T}^{(*)}$ stand for the tariffs set by the trade agreement and $\bar{X}$ for the equilibrium world output structure under tariffs and subsidies of the trade agreement. Further, write $T^{BR}(T^*, X)$ and $T^{BR,*}(T, X)$ for Home's and Foreign's unilaterally optimal tariff given the respective other country's tariffs and given the world output structure. Moreover, let $T^{N,(*)}(X)$ be the tariffs of the Nash Equilibrium of the tariff game at given output X (i.e. $T^N(X) = T^{BR}(T^{BR,*}(T, X), X)$ and $T^{N,*}(X) = T^{BR,*}(T^{BR}(T^*, X), X)$). Finally, define Home's and Foreign's momentaneous utilities as functions of tariffs T and T^* and output X by

$$w^{(*)}(T, T^*, X) = u(c_1^{(*)}(p(T, T^*, X), T, X), c_2^{(*)}(p(T, T^*, X), T, X))$$

Since consumption (2), incomes (13), (14), and prices (15), are smooth functions of $T^{(*)}$ and X and since u is continuously differentiable w is continuously differentiable as well. With this notation, the utilities under a trade agreement are $w^{(*)}(\bar{T}, \bar{T}^*, \bar{X})$, Home's (Foreign's) defection utility on the trade agreement is $w(T^{BR}(\bar{T}^*, \bar{X}), \bar{T}^*, \bar{X})$ $(w^{(*)}(\bar{T}, T^{BR,*}(\bar{T}, \bar{X}), \bar{X}))$. Further, utilities in the first of the punishment phases are $w^{(*)}(T^N(\bar{X}), T^{N,*}(\bar{X}), \bar{X})$, while utilities of the second punishment phase, when tariffs and subsidies are set uncooperatively and react to the price changes, will simply be denoted by $w^{N,(*)}$. With this notation Home's self-enforcement constraint (20) of a time-invariant trade agreement can be written as

$$\begin{aligned} \frac{w(\bar{T}, \bar{T}^*, \bar{X})}{1-\beta} &\geq w(T^{BR}(\bar{T}^*, \bar{X}), \bar{T}^*, \bar{X})... \\ &... + \frac{\beta - \beta^M}{1-\beta} w(T^N(\bar{X}), T^{N,*}(\bar{X}), \bar{X}) + \frac{\beta^M}{1-\beta} w^N \end{aligned} \tag{21}$$

while the self-enforcement constraint for Foreign is

$$\begin{aligned} \frac{w^*(\bar{T}, \bar{T}^*, \bar{X})}{1-\beta} &\geq w^*(\bar{T}, T^{BR,*}(\bar{T}, \bar{X}), \bar{X})... \\ &... + \frac{\beta - \beta^M}{1-\beta} w^*(T^N(\bar{X}), T^{N,*}(\bar{X}), \bar{X}) + \frac{\beta^M}{1-\beta} w^{N,*} \end{aligned} \tag{22}$$

For given output the best response strategies on tariffs $T^{BR}(T^*, X)$ and $T^{BR,*}(T, X)$ generally involve lengthy expressions (see e.g. Kennan and Riezman (1988) or Devereux (1997)). It is clear that incorporating subsidies and the reaction of decentralized firms in a game between governments is a demanding exercise. Fortunately, however, Dixit (1987) shows that there is always at least one Nash equilibrium in pure strategies, which is characterized by prohibitive tariffs on all sides. Applying this idea to the framework of the present model, the corresponding equilibrium consists of infinite tariffs $T = T^* = \infty$ and zero subsidies. The corresponding equilibrium is just a replication of the respective autarkic economies. For the following analysis it is of little importance which of the potentially many equilibria prevails in the second punishment phase. It is, however, important that none of these potential equilibria is affected by the tariffs and subsidies of the trade agreement and, in particular, independent of the output $\bar{X}$.

3.2 Best Response Tariffs

With the introduction of adjustment periods in production, the last paragraphs highlighted the importance of those cases where firms cannot react to short-term price changes and output is exogenous to within-period tariffs. Consequently, the following paragraphs analyze a scenario where output $X = (x_1, x_2, x_1^*, x_2^*)$ is given while tariffs are charged uncooperatively. Under this assumption, the individually optimal – or best response – tariffs that maximize the citizens' welfare can be shown to be (see appendix)

$$T^{BR}(T^*, X) = \sqrt{\frac{\frac{x_1}{x_1^*}(T^*+1)/T^*+1}{\frac{x_2}{x_2^*}(T^*+1)+1}} \tag{23}$$

for Home and

$$T^{BR,*}(T, X) = \sqrt{\frac{\frac{x_2^*}{x_2}\,(T+1)\,/T+1}{(T+1)\frac{x_1^*}{x_1}+1}} \tag{24}$$

for Foreign. These expressions have a number of important implications. First of all, they show that the interior best response tariffs are uniquely defined. Second, (23) and (24) have singularities at $x_1^* = 0$ and $x_2 = 0$, respectively. More precisely, in the limit of diminishing import competing production, the exporter's best response tariffs grows unbounded. This is easily verified by the expressions above, which imply

$$\lim_{x_1^* \to 0} \sqrt{x_1^*} T^{BR} \in (0, \infty) \qquad \text{and} \qquad \lim_{x_2 \to 0} \sqrt{x_2} T^{BR,*} \in (0, \infty) \tag{25}$$

Third, at constant output the resulting Nash Equilibrium of the tariff game is described by

$$T^N(X) = \sqrt{\frac{x_1 + x_1^*}{x_1^*} \frac{x_2^*}{x_2 + x_2^*}} \qquad \text{and} \qquad T^{N,*}(X) = \sqrt{\frac{x_2^* + x_2}{x_2} \frac{x_1}{x_1^* + x_1}} \tag{26}$$

which finally implies

$$\lim_{x_1^* \to 0} \sqrt{x_1^*} T^N \in (0, \infty) \qquad \text{and} \qquad \lim_{x_2 \to 0} \sqrt{x_2} T^{N,*} \in (0, \infty) \tag{27}$$

and

$$\lim_{x_1^* \to 0} \sqrt{x_1^*}^3 \frac{dT^N}{dx_1^*} \in (-\infty, 0) \qquad \text{and} \qquad \lim_{x_2 \to 0} \sqrt{x_2}^3 \frac{dT^{N,*}}{dx_2} \in (-\infty, 0) \tag{28}$$

With these properties of the best response and Nash tariffs, one can turn to the different components of the self-enforcement constraint and, in particular, the utilities both countries can derive from defection.

3.3 Defection Utilities

In the limit $x_1^* \to 0$ ($x_2 \to 0$) Home's (Foreign's) defection utility exhibits a singularity, the degree of which is classified by the following

Claim 1 *Assume Home's marginal rate of transformation between both goods is finite and T^* is constant. Then, its defection utility satisfies*

$$\lim_{x_1^* \to 0} \sqrt{x_1^*} \frac{d}{dx_1^*} w(T^{BR}(T^*, X), T^*, X) \in (-\infty, 0) \tag{29}$$

$$\lim_{x_2 \to 0} \frac{d}{dx_2} w(T^{BR}(T^*, X), T^*, X) \in \mathbb{R} \tag{30}$$

Similarly, if Foreign's marginal rate of transformation between both goods is finite and T is constant, its defection utility satisfies

$$\lim_{x_2 \to 0} \sqrt{x_2} \frac{d}{dx_2} w^*(T, T^{BR,*}(T, X), X) \in (-\infty, 0) \tag{31}$$

$$\lim_{x_1^* \to 0} \frac{d}{dx_1^*} w^*(T, T^{BR,*}(T, X), X) \in \mathbb{R} \tag{32}$$

Proof. See Appendix ■

Equations (29) and (31) of the claim show that the first unit of a country's import-competing output induces unbounded loss of its trade partner's defection utility. Thus, small amounts of output of X_1 in Foreign's are very effective in depressing Home's defection incentives. Intuitively, small amounts of X_1-production in Foreign heavily reduce Home's market power in its export market and strongly curb Home's one-shot gains from defection.

Compared to these strong effects, the impact of a country's first unit of import-competing output on its own defection utility is negligible, as shown by (30) and (32).

3.4 Punishment Utilities

As discussed above, punishment decomposes in two phases, reflecting the short and the long run after a defection. The strategies in the second phase (the long run) are set according to one of the (possibly many) equilibria of the tariff plus subsidy game. The according utilities, denoted by $w^{N,(*)}$ in (21) and (22), are independent of $\bar{X}$, which stands for the output structure under the trade agreement.

In the first punishment phase, however, the output structures of both economies are inherited form the trade agreement and hence the utilities shortly after a defection period do depend on $\bar{X}$. The behavior of these punishment utilities will be looked at next Similarly to the defection utilities, these punishment utilities exhibit singularities at $x_1^* = 0$ and $x_2 = 0$. The degree of these singularities is classified in the following

Claim 2 *Assume Home's marginal rate of transformation between both goods is finite. Then, its punishment utility of the first phase satisfies*

$$\lim_{x_2 \to 0} \sqrt{x_2} \frac{d}{dx_2} w(T^N(X), T^{N,*}(X), X) = \infty \tag{33}$$

$$\lim_{x_1^* \to 0} \sqrt{x_1^*} \frac{d}{dx_1^*} w(T^N(X), T^{N,*}(X), X) \in \mathbb{R} \tag{34}$$

Similarly, if Foreign's marginal rate of transformation between both goods is finite, its punishment utility of the first phase satisfies

$$\lim_{x_1^* \to 0} \sqrt{x_1^*} \frac{d}{dx_1^*} w^*(T^N(X), T^{N,*}(X), X) = \infty \tag{35}$$

$$\lim_{x_2 \to 0} \sqrt{x_2} \frac{d}{dx_2} w^*(T^N(X), T^{N,*}(X), X) \in \mathbb{R}. \tag{36}$$

Proof. See Appendix. ■

Equations (33) and (35) of the claim shows that the adverse impact of the uncooperative tariffs in the first punishment phase can be substantially reduced by small amounts import competing production. Indeed, comparing with (29) and (31) reveals that the positive effect of the first unit of import competing production on a country's punishment utility is of higher degree than its adverse effect on the trade partner's defection utility. This qualitative difference will be important for the design of the efficient trade agreement presented below. Finally, (34) and (36) show that the first unit of import-competing production has a stronger impact on the very country's punishment utility than on that of the trade partner.

Claims 1 and 2 describe the impact of small amounts of import competing production on the utilities under defection and in the first punishment phase. With these qualitative assessments one can turn to the main part of the paper, the optimal design of trade agreements.

3.5 Constrained Optimal Trade Agreements

The previous subsection has shown that the output structure strongly affects the defection temptation and hence the self-enforcement constraints, which implies that subsidies can play an important role in optimal trade agreements. The following two subsections present the main results of the paper by characterizing the Pareto optimal time-invariant and self-enforceable trade agreements. Formally, a trade agreement is defined by the tariffs and subsidies it implements, i.e. by the policy vector $(\bar{T}, \bar{T}^*, \bar{z}_2, \bar{z}_1^*)$. For brevity the class of Pareto optimal, time-invariant, and self-enforceable trade agreement will be simply referred to as "optimal trade agreements".

Under these definitions, an optimal trade agreement $(\bar{T}, \bar{T}^*, \bar{z}_2, \bar{z}_1^*)$ maximizes the weighted sum the two countries' welfare subject to both self-enforcement constraints, i.e. $(\bar{T}, \bar{T}^*, \bar{z}_2, \bar{z}_1^*)$ solves the program

$$\max_{\bar{T}^{(*)}, \bar{z}_2, \bar{z}_1^*} \sigma w(\bar{T}, \bar{T}^*, \bar{X}) + (1-\sigma) w^*(\bar{T}, \bar{T}^*, \bar{X}) \quad s.t. \ \ (21) \text{ and } (22) \tag{37}$$

for one parameter $\sigma \in (0,1)$. The self-enforcement constraints of Home and Foreign will be rewritten as non-negativity restrictions on the functions $\Gamma^{(*)}$, which are defined, respectively, by

$$\begin{aligned} \Gamma = w(\bar{T}, \bar{T}^*, \bar{X}) - (1-\beta) w(T^{BR}(\bar{T}^*, \bar{X}), \bar{T}^*, \bar{X}) ... \\ ... - \left(\beta - \beta^M\right) w(T^N(\bar{X}), T^{N,*}(\bar{X}), \bar{X}) - \beta^M w^N \end{aligned} \tag{38}$$

and

$$\begin{aligned} \Gamma^* = w^*(\bar{T}, \bar{T}^*, \bar{X}) - (1-\beta) w^*(\bar{T}, T^{BR,*}(\bar{T}, \bar{X}), \bar{X}) ... \\ ... - \left(\beta - \beta^M\right) w^*(T^N(\bar{X}), T^{N,*}(\bar{X}), \bar{X}) - \beta^M w^{N,*} \end{aligned} \tag{39}$$

Combining these expression renders the Lagrangian of the optimization problem

$$\mathcal{L} = \sigma w(\bar{T}, \bar{T}^*, \bar{X}) + (1-\sigma) w^*(\bar{T}, \bar{T}^*, \bar{X}) + \lambda \Gamma + \lambda^* \Gamma^* + \nu \bar{z}_2 + \nu^* \bar{z}_1^* \tag{40}$$

where $\lambda \geq 0$ and $\lambda^* \geq 0$ stand for the Lagrange multipliers on Home's and Foreign's self-enforcement constraint, respectively, and $\nu, \nu^* \geq 0$ are the Lagrange multipliers for the non-negativity constraints on $\bar{z}_2$ and $\bar{z}_1^*$, respectively.

The analysis of subsidies in constrained trade agreements starts with some observations concerning the unconstrained trade agreement. It has been discussed at the start of this section that unconstrained efficient trade agreements implement no subsidies $\bar{z}_2 = \bar{z}_1^* = 0$ and a pair of tariffs satisfying $\bar{T}\bar{T}^* = 1$. Remember further that full specialization is the outcome in an undistorted world economy by assumption (12). Together, this implies that full specialization emerges under the unconstrained optimal trade agreement.[9] As a point

[9] This statement can be verified with (9) and (15).

of reference, define T_σ as Home's tariff of the unconstrained optimal trade agreement for $\sigma \in (0,1)$. In other words, T_σ is the solution of the problem (37) in absence of (21) and (22). Define further $\bar{\beta}_\sigma$ as the minimum discount factor for which the self-enforcement constraints does not bind under $\bar{z}_i = \bar{z}_i^* = 0$, i.e.

$$\bar{\beta} \equiv \min\left\{\beta \in [0,1] \mid \text{(21) and (22) hold under } \left(\bar{T},\bar{T}^*\right) = \left(T_\sigma, 1/T_\sigma\right) \text{ and } \bar{z}_i = \bar{z}_i^* = 0\right\}$$

The self-enforcement constraints hold trivially in the limit $\beta \to 1$, which implies $\bar{\beta} \in (0,1)$. By construction of $\bar{\beta}$, the agreement $(\bar{T},\bar{T}^*,\bar{z}_2,\bar{z}_1^*) = (T_\sigma, 1/T_\sigma, 0, 0)$ solves the constrained problem (37) for all $\beta \in [\bar{\beta},1]$. With these definitions one can formulate the first central result of the paper, which is summarized in the following proposition.

Proposition 1 *There is an $\varepsilon > 0$ so that for all $\beta \in (\bar{\beta}-\varepsilon,\bar{\beta})$ the Pareto optimal, time invariant, self-enforcing trade agreement prohibits subsidies to import-competing sectors of the countries whose self-enforcement constraints bind. In these countries import-competing production in zero.*

Proof. Since $\beta < \bar{\beta}$ assume wlog $\lambda > 0$. Check with (9) and (15) that

$$\frac{A_2 L}{A_2^* L^*} < TT^* < \frac{A_1 L}{A_1^* L^*} \tag{41}$$

implies full specialization. Define

$$\mathcal{T} = \left\{(T,T^*) \middle|\ T > T_\sigma,\ T^* > T_\sigma^*,\ \text{and (41) holds}\right\}$$

as the set of tariff-pairs exceeding the unconstrained optimal tariffs consistent with full specialization. Equation (12) and $T_\sigma T_\sigma^* = 1$ imply $\mathcal{T} \neq \varnothing$. For $(T,T^*) \in \mathcal{T}$ equation (18) and the finite price pT_σ under the trade agreement imply $dx_2/d\bar{z}_2 > 0$. Thus, the derivative of the Lagrangian (40) w.r.t. $\bar{z}_2$ is

$$\begin{aligned}\frac{d\mathcal{L}}{d\bar{z}_2} &= \left[(\sigma+\lambda)\frac{dw(\bar{T},\bar{T}^*,\bar{X})}{dx_2} + (1-\sigma+\lambda^*)\frac{dw^*(\bar{T},\bar{T}^*,\bar{X})}{dx_2}\right]\frac{dx_2}{d\bar{z}_2}\ldots \\ &\quad \ldots - (1-\beta)\left[\lambda\frac{dw(T^{BR}(\bar{T}^*,\bar{X}),\bar{T}^*,\bar{X})}{dx_2} + \lambda^*\frac{dw^*(\bar{T},T^{BR,*}(\bar{T},\bar{X}),\bar{X})}{dx_2}\right]\frac{dx_2}{d\bar{z}_2} \\ &\quad \ldots - \left(\beta-\beta^M\right)\left[\lambda\frac{dw^*(T^N(\bar{X}),T^{N,*}(\bar{X}),\bar{X})}{dx_2} + \lambda^*\frac{dw^*(T^N(\bar{X}),T^{N,*}(\bar{X}),\bar{X})}{dx_2}\right]\frac{dx_2}{d\bar{z}_2} + \nu_2\end{aligned}$$

Since w is differentiable

$$\left|\frac{dw^{(*)}(\bar{T},\bar{T}^*,\bar{X})}{dx_2}\right| < \infty$$

holds so that, by (30), (31), (33), (36) and $\lambda > 0$

$$\lim_{x_2 \to \infty} \frac{d\mathcal{L}}{d\bar{z}_2} = -\infty$$

holds. This implies that there is a $\tilde{z} > 0$ so that $d\mathcal{L}/d\bar{z}_2 = 0$ implies either $\bar{z}_2 = 0$ or $\bar{z}_2 \geq \tilde{z}$ for all $(T, T^*) \in \mathcal{T}$. By optimality of $\bar{z}_2 = 0$ the condition $\bar{z}_2 \geq \tilde{z}$ establishes a lower bound of the welfare loss $\Delta W' > 0$ under $\bar{z}_2 \geq \tilde{z}$ relative to the unconstrained optimal agreement $(T_\sigma, 1/T_\sigma, 0, 0)$.

Now observe with $W = \sigma w(T, T^*, \bar{X}) + (1-\sigma) w^*(\bar{T}, \bar{T}^*, \bar{X})$ that

$$\left.\frac{dW}{dT}\right|_{(\bar{T},\bar{T}^*)=(T_\sigma,1/T_\sigma)} = 0 \qquad \text{and} \qquad \left.\frac{dW}{dT^*}\right|_{(\bar{T},\bar{T}^*)=(T_\sigma,1/T_\sigma)} = 0 \tag{42}$$

holds. Under full specialization $c_1 = I/2 = x_1 T/(T+1)$ is increasing in T and (with (15)) $c_2 = I/(2pT) = x_2^*/(T^*+1)$ is constant in T. Hence, with $X_0 = (x_1, 0, 0, x_2^*)$

$$\left.\frac{dw(T, T^*, X_0)}{dT}\right|_{(\bar{T},\bar{T}^*)=(T_\sigma,1/T_\sigma)} > 0$$

Thus, (42) implies

$$\left.\frac{dw(T, T^*, X_0)}{dT^*}\right|_{(\bar{T},\bar{T}^*)=(T_\sigma,1/T_\sigma)} < 0$$

and one can define $\Delta, \Delta^* > 0$ so that

$$\left.\frac{dw(T_\sigma + \delta\Delta, 1/T_\sigma + \delta\Delta^*, X_0)}{d\delta}\right|_{\delta=0} = 0$$

and hence by (42)

$$\left.\frac{dw^*(T_\sigma + \delta\Delta, 1/T_\sigma + \delta\Delta^*, X_0)}{d\delta}\right|_{\delta=0} = 0$$

When defecting (with $T \to \infty$) Home consumes $c_1 = I/2 = x_1$ and $c_2 = I/(2pT) = 2x_2^*/(T^*+1)$ and hence its defection utility $w(T^{BR}(T^*, X_0), T^*, X_0)$ is strictly decreasing in T^*. Together, this implies

$$\left.\frac{d\Gamma}{d\delta}\right|_{\delta=0} = -(1-\beta)\frac{dw(T^{BR}(T^*, X_0), T^*, X_0)}{dT^*}\Delta > 0$$

for Γ from (38). Similarly,

$$\left.\frac{d\Gamma^*}{d\delta}\right|_{\delta=0} = -(1-\beta)\frac{dw^*(T, T^{BR,*}(T, X_0), X_0)}{dT}\Delta^* > 0$$

holds. Thus, for $\delta \in (0, \bar{\delta})$ with $\bar{\delta} > 0$ small enough $\Gamma^{(*)}$ is strictly increasing in δ and, moreover, $(T_\sigma + \delta\Delta, 1/T_\sigma + \delta\Delta^*) \in \mathcal{T}$ holds. Since $\Gamma^{(*)}$ from (38) and (39) are continuous and strictly decreasing in β, this implies that for all $\delta \in (0, \bar{\delta})$ $\exists$ $\varepsilon > 0$ so that $\Gamma^{(*)} \geq 0$ hold for $\beta \in (\bar{\beta} - \varepsilon, \bar{\beta})$ under the agreement $(T_\sigma + \delta\Delta, 1/T_\sigma + \delta\Delta^*, X_0)$.

Finally, let the welfare loss of the agreement $(T_\sigma + \delta\Delta, 1/T_\sigma + \delta\Delta^*, X_0)$ relative to unconstrained optimal agreement $(T_\sigma, 1/T_\sigma, 0, 0)$ be defined as $\Delta W(\delta)$. By incomes (13), (14), prices (15) consumption (2) and continuity of the utility u, $\Delta W(\delta)$ is increasing and continuous in δ. Hence, there is a $\tilde{\delta} \in (0, \bar{\delta}]$ so that $\Delta W' > \Delta W(\tilde{\delta})$. With the corresponding $\tilde{\varepsilon} > 0$ this proves that $\bar{z}_2 = 0$ is optimal. Finally, $(T_\sigma + \delta\Delta, 1/T_\sigma + \delta\Delta^*) \in \mathcal{T}$ and $\bar{z}_2 = 0$ imply $x_2 = 0$. ■

Proposition 1 highlights the impact of subsidies on the efficiency of trade agreements. It shows that under marginally binding self-enforcement constraints, production subsidies to import-competing sectors are prohibited altogether. The intuition of that strong result is the following. Since subsidies to import-competing sectors affect output of some periods ahead, they generate domestic supply of the import good in the periods following potential defection. In so doing, production subsidies mitigate the consequences of defection for the subsidizing country itself, reducing its dynamic costs of defection and increasing its temptation to defect. In this sense, subsidizing domestic production of the import good can be read as an offensive move to mitigate the consequences of a planned defection on trade agreements.

Proposition 1 suggests that production subsidies play an important role in optimal trade agreements whereas, quite contrary, Bagwell and Staiger (2006) argue that efficient trade agreements shall not address them. Both results point in different directions but, nevertheless, do not contradict each other. In particular, Proposition 1 does not show that an optimal trade agreement actually needs to address subsidies directly and hard-wire them in its rules. More precisely, the present paper' model might represent a case where optimal subsidies are zero but nevertheless do not need to be specified by the legal code of the agreement since in any case it is individually optimal for countries not to subsidize. Under these circumstances, trade agreements that target, say, market access only might generate efficient outcomes and impeding subsidies does neither good nor harm. It will be shown next, however, that this is not the case.

3.6 GATT versus WTO Legislation

In their recent work Bagwell and Staiger (2006) analyze and compare the GATT with the WTO subsidy rules. According to this study, the current WTO legislation that essentially impedes production subsidies generates inefficient equilibria, while the former GATT rules that addressed market access only, were efficient. The present paper's model does not capture the precise mechanisms of the GATT and WTO dispute settlement system. Nevertheless, it is possible to define a mapping of the GATT and WTO subsidy rules to the present model. This mapping closely follows the description of the respective subsidy rules in Bagwell and Staiger (2006).

According to Bagwell and Staiger (2006), the WTO Agreement on Subsidies and Countervailing Measures allows a member country to challenge and enforce the removal of other members' production subsidies. In the current framework, any production subsidy that increases import-competing production affects the terms of trade (15) and harms the respective trade partner through a reduction in consumption of the import good (2). Hence, any positive production subsidy will always be challenged by the trade partner and consequently, the WTO subsidy rules are captured by the subsidy rule $(\bar{z}_2, \bar{z}_1^*) = (0, 0)$.[10]

The GATT subsidy rules, in contrast, mainly rely on the notion of market access. According to Bagwell and Staiger (2006) the GATT rules are violated whenever "government has bound a tariff in a GATT negotiation [...] and then subsequently alters its domestic policies in a way that diminishes the market access implied by that original tariff negotiation." Observing with the expressions for consumption (2), income (13), and technology (19) that Foreign's access to Home's market, $M = c_1^* - x_1^*$ is a function of Foreign's policies $(T^*, \bar{z}_1^*)$ and the world price p only and that, similarly, Home's access to Foreign's market $M^* = c_2 - x_2$, is a function of Home's policies $(T, \bar{z}_2)$ and the world price p, one can define the a trade agreement of the GATT type by its terms of trade $\bar{p}$. Since M is decreasing in p and M^* is increasing in p one can further define that Home's policy deviation $(\tilde{T}, \tilde{z}_2)$ that induces the world price $\tilde{p}$ is a violation of the GATT-type agreement if $\tilde{p} < \bar{p}$ and similarly, Foreign's deviation $(\tilde{T}^*, \tilde{z}_1^*)$ that induces the world price $\tilde{p}^*$ is a violation if $\tilde{p}^* > \bar{p}$.[11]

With this description of the GATT rules, one can clearly separate the finding of Proposition 1 from those of Bagwell and Staiger (2006) by the following statement.

Proposition 2 *Assume $\beta \in (\bar{\beta} - \varepsilon, \bar{\beta})$ with $\varepsilon > 0$ from Proposition 1. Then, any Pareto optimal, time invariant, self-enforcing trade agreement that targets market access is inefficient, i.e. it generates less welfare that the optimal agreement targeting tariffs and subsidies.*

Proof. Assume the trade agreement described by its equilibrium world price $\bar{p}$ is efficient and let its underlying policies be denoted by $(\bar{T}, \bar{T}^*, \bar{z}_2, \bar{z}_1^*)$. (If the policies are not unique, consider one element of the set of possible policies.) As $\beta < \bar{\beta}$ assume wlog that $\lambda > 0$, so that efficiency implies $x_2 = \bar{z}_2 = 0$ by Proposition 1. Further, $\lambda > 0$ implies $\Gamma = 0$

[10] This is true for negligible costs of non-violation claims only.

[11] Notice that, but in slight deviation from Bagwell and Staiger (2006), a tariff change that does not decrease the trade partner's market access is not considered a defection. In presence of policy redundancy as in Bagwell and Staiger (2006), this difference is entirely irrelevant since tariffs can be set and all effective choices are compensated by the remaining policies. In any case, it remains in in accordance with the GATT legislation (see GATT (1986) Article XXIII, For discussion and interpretation of the code concerning the legal basis for disputes see also http://www.wto.org/english/tratop_e/dispu_e/disp_settlement_cbt_e/c4s2p1_e.htm).

with Γ from (38). Consider Home's deviation $(\bar{T} - \delta\Delta_T, \bar{T}^*, \delta\Delta_z, \bar{z}_1^*)$, with $\delta > 0$ and Δ_T and Δ_z so that implied world price p satisfies $dp/d\delta = 0$ at $\delta = 0$. For infinitesimal $\delta > 0$ this deviation does not violate the trade agreement. By $x_2 = 0$ (15) and (18) imply $0 < \Delta_T, \Delta_z < \infty$. Properties (29) and (33) imply further that at $\delta = 0$ Home's defection value is strictly increasing in δ, i.e.

$$\frac{d}{d\delta}\left[w(T^{BR}(\bar{T}^*, \bar{X}), \bar{T}^*, \bar{X}) + \frac{\beta - \beta^M}{1-\beta} w(T^N(\bar{X}), T^{N,*}(\bar{X}), \bar{X}) + \frac{\beta^M}{1-\beta} w^N\right]_{\delta=0} = +\infty$$

Thus, at $\delta > 0$ small enough the value of defection on $(\bar{T} - \delta\Delta_T, \bar{T}^*, \delta\Delta_z, \bar{z}_1^*)$ lies above the cooperation value of the trade agreement. This contradicts self-enforceability of the agreement $\bar{p}$ and proves the statement. ■

Proposition 2 marks a strong dividing line between Proposition 1 and the earlier result on subsidies in trade agreements by Bagwell and Staiger (2006). While latter study argues that efficient trade agreements essentially target market access only, Proposition 2 shows that this limitation necessarily leads to inefficiencies. The key element that generates these diametrically opposed results is the self-enforcement requirement. Via their effect of specialization pattern, subsidies impact the countries' defection incentives and hence the self-enforcement constraints. Since the self-enforcement constraints need to be accounted for by the designers of the trade agreement – and not the individual countries – this means that subsidies have to be addressed by trade agreements directly.

In a nutshell, a trade agreement that determines the world price p only and leaves countries the freedom to choose their individual policy mix to grant p generates efficiency gains in the setting of Bagwell and Staiger (2006) but can undermine self-enforceability in as in the current. In this sense, the present paper contradicts the earlier findings on the role of subsidies in trade agreements.

The results presented in Propositions 1 and 2 have been derived under a number of assumptions and confinements that might appear very specific and which therefore need some words of justification. This will be done next.

3.7 Discussion of the Results

The main results of the paper, formulated in Proposition 1 and 2, describe subsidy rules of Pareto optimal, time-invariant and self-enforcing trade agreements. In order to assess the findings and their relevance and to place them in the literature on subsidies in trade agreements, a discussion of the preconditions and the general modeling framework is needed. This discussion starts with a critical review of the crucial assumptions.

First, Proposition 1 and 2 rely on assumption (12) that implies full international specialization. Complete specialization, however, is just one of three possible specialization patterns in a 2-good 2-country model so that such a restriction appears to be quite demanding. Yet, the paper's results rely on the fact that, in absence of subsidies, each country covers world supply of at least one traded good. That is a notion of international specialization, which arises in most standard models under a variety of setups under mild restrictions on transportation costs and if the number of goods produced in the world economy is sufficiently large (e.g. Dornbusch et al (1977), Dornbusch et al (1980), Acemoglu and Ventura (2002), and Romalis (2004)). In this sense, international specialization in this sense appear to be a natural result.

Second, the statements of Proposition 1 and 2 hold when the discount factor β falls marginally short of the level that grants an undistorted world economy (i.e. $\beta \in (\bar{\beta} - \varepsilon, \bar{\beta})$). This appears to be a major confinement. Notice, however, that the case of marginally binding self-enforcement constraints is precisely the relevant case for today's world economy: average import tariffs substantially dropped in the last decades and were about 5% around the turn of the century (see e.g. Subramanian and Weil (2007)). This impressive record of trade liberalization suggests that some of the relevant constraints that restrict trade negotiators bind, but only marginally so. Hence, that precondition of Propositions 1 and 2 seems realistic. In addition, modern economic history illustrates the economic relevance of the effects described Proposition 1. According to the standard interpretation of the European Coal and Steel Community its foundation relied on a mutual dependence on trade that raised the dynamic costs of defective actions and forested the adherence to international cooperation. In this historic case, the pooling of steel, coal, and, to some extend, wheat was meant to create a mutual dependence between the six western European member nations and aimed to make cooperation indispensable (see Gillingham (1991)).

A third important assumption concerns demand, which is assumed to give rise to constant expenditure shares. This assumption generates strong effects of import-competing output on best response tariffs and thus on utilities. The set of goods with the key property – positive expenditure shares at unbounded prices – seems to be quite exclusive, comprising little more than food and energy. Yet again, the merits of the propositions shall not be prematurely discounted. The key assumption, a pronounced dependence of countries on imports, a strong resulting vulnerability to import shortages and thus a high willingness to pay for imports, is not too exotic an assumption. In particular, extending the view of mere trade in consumption goods to vertical integration, one must notice that dependence on import goods arises between specialized countries, which perform intermediate production steps in an increasingly unbundled production chain. In this accelerating process the national dependence and vulnerability comes along with national specialization and imports of intermediate goods essential to domestic production .[12] Finally, and more generally, one has to keep in mind that the model's strong assumptions are made to exemplify the general principle that subsidies play an important role in trade agree-

[12] Yi (2003) estimates substantial levels and growth rates of cross-border vertical integration.

ments. While alternations in the specific setup may change the way how exactly optimal subsidy-rules should be designed, but they will not affect the basic principle this paper aims to highlight.

In sum, the key preconditions of this paper's results, formulated in Propositions 1 and 2, give a rough but after all a not too exotic description of today's world economy and its trading system. Consequently, the paper's basic message is encouraging for the WTO subsidy legislation and its de facto prohibition of production subsidies. It argues, in particular, that production subsidies for import-competing sectors can be an indispensable part of the legal code of optimal trade agreements.[13]

With its theoretical support for a prohibition of the WTO subsidy rules, the present paper strongly contradicts the results of Bagwell and Staiger (2006), who argue that impeding subsidies in trade agreements "may ultimately do more harm than good to the multilateral trading system." The diametrically opposed results of these earlier findings and the present paper's go back to the nature of the self-enforcement requirement. First, the self-enforcement requirement does not constrain the policy choice of individual countries but the policies a trade agreement can successfully implement. Since, moreover, the self-enforcement constraint is strongly affected by the patterns of international specialization, which, in turn, are largely driven by production subsidies, these subsidies must be addressed and accounted for by those supranational institutions that write the legal code of trade agreements.

While addressing the same questions as Bagwell and Staiger (2006), the present paper departs in some important points from this earlier work. Thus, the consumption tax, which generates the policy redundancy that drives the results in Bagwell and Staiger (2006) is absent from the present paper's the model. Yet, this departure is innocent, since the introduction of a redundancy of policies in the present framework (e.g. by taxes) simply leaves the additional policy variable as a residual does not alter the optimal policy choice (see also footnote 11). More importantly, the present paper did not model explicitly the rules for non-violation claims under the GATT or WTO rules. This choice is largely motivated by the complexity of either of the modeling choices – the multi-stage game in the setup of Bagwell and Staiger (2006) or the repeated game in the present one. As argued at the beginning of subsection 3.6, however, there is a straight forward mapping of the respective subsidy rules to the present paper's setting. Finally, the present paper abstracted entirely from all potential positive effects of production subsidies on national welfare. In particular, its modelling framework is stripped of the governments' objectives other than those maximizing welfare and all economic and political motives for non-trivial subsidies, which the general setup of Bagwell and Staiger (2006) accounts for and that drive

[13] This interpretation of the results obviously follows the standard assumption that trade agreements need to explicitly address the self-enforceable rules and policies and that cooperation is not automatically achieved as in the case of tacit collusion.

the results in this earlier study, have been eliminated. Nevertheless, I do not apologize for the bias in the setup. After all, the paper did not aim to disproof the argument outlined in Bagwell and Staiger (2006) but sought to present a mechanism that justifies the inclusion of subsidies in trade agreements and, in particular the tough standing of the WTO subsidy rules. A balanced evaluation of the WTO rules will take both arguments into account and weight their relative importance.

4 Conclusion

This paper has used the framework of self-enforcing trade agreements to analyze the role of subsidies in trade agreements, in which a number of new results emerge. First, and generally, trade negotiators who aim to maximize national welfare must address subsidies in their agreements. Second, production subsidies are either used big time or not at all. Consequently, when self-enforcement constraints bind only marginally, the optimal trade agreements ban production subsidies. This last scenario, which is argued to be a rough but fair description of today's world economy, stands in stark contrast to the findings of Bagwell and Staiger (2006), who argue that the WTO's ban on all subsidies is too much of a good thing and the "WTO subsidy rules may ultimately do more harm than good to the multilateral trading system". In this sense the present paper's findings contradicts the ones in Bagwell and Staiger (2006) and provides a useful complement for a balanced evaluation of the WTO rules.

A Appendix

Proof. of the Best Response Tariffs (23) and (24). Write the indirect utility of Home as $v(\pi, I)$ with $\pi = pT$ the price of Home's import good. $e(\pi, u)$ is the according expenditure function. Take derivatives w.r.t. π of the identity $v(\pi, e(\pi, u)) = u$ to get $v_\pi + v_I e_\pi = 0$. (Subscripts stand for partial derivatives.) Combining this equation with the optimality condition for T leads to

$$\frac{d}{dT}v(\pi, I) = v_I \frac{dI}{dT} + v_\pi \frac{d\pi}{dT} = v_I \left(\frac{dI}{dT} - e_{\pi_i} \frac{d\pi}{dT} \right) = 0$$

Using Shephard's Lemma ($e_\pi(\pi, u) = c_2$), and $c_2 = I/2\pi$ leads to

$$\frac{d}{dT} \ln(I) = \frac{1}{2} \frac{d}{dT} \ln(\pi)$$

The optimality condition thus depends on income and prices only and the solution presented in Kennan and Riezman (1988) and Sauré (2004) generalize to the present scenario. This proves (23) and (24). ■

Proof of Claim 1. Define Home's domestic relative prices as $\pi(T^*, X) = pT^{BR}(T^*, X)$, where p is from (15) under $T = T^{BR}$. Use (2) to compute the partial derivatives $c_{1,I} = 1/2$, $c_{2,I} = 1/2\pi$, $c_{1,\pi} = 0$, and $c_{2,\pi} = -I/2\pi^2$. This implies

$$\frac{dw(T^{BR}, T^*, X)}{dx_i^{(*)}} = u_1(c_1, c_2) \left\{ \frac{dI}{dx_i^{(*)}} - \frac{I}{2} \frac{d\ln(\pi)}{dx_i^{(*)}} \right\} = \frac{u_2(c_1, c_2)}{\pi} \left\{ \frac{dI}{dx_i^{(*)}} - \frac{I}{2} \frac{d\ln(\pi)}{dx_i^{(*)}} \right\} \tag{A1}$$

For (A1) the optimality condition $u_2 = \pi u_1$ was used. By the Envelope Theorem T^{BR} can be treated as a constant. The superscripts ^{BR} will be omitted in the following.

(i) Show (29). Use (13) to derive $dI/dx_1^* = 2x_2/(T+1)\,(d\pi/dx_1^*)$. Hence (A1) renders

$$\frac{dw(T^{BR}, T^*, X)}{dx_1^*} = u_1(c_1, c_2) \left\{ \frac{2x_2}{T+1}\pi - \frac{I}{2} \right\} \left(\frac{d}{dx_1^*} \ln(\pi) \right)$$

Now use (15) to get

$$\frac{d\ln(\pi)}{dx_1^*} = \frac{T^*(T+1)}{x_1(T^*+1) + x_1^* T^*(T+1)} + \frac{\bar{A}^*(T+1)/T}{x_2(T^*+1) + x_2^*(T+1)/T}$$

where $\bar{A}^*$ is Foreign's finite marginal rate of transformation between X_1 and X_2. Combining these expressions implies with (13), (15), and (25)

$$\lim_{x_1^* \to 0} \frac{1}{T^{BR}} \frac{dw(T^{BR}, T^*, X)}{dx_1^*} = \left(\lim_{x_1^* \to 0} u_1(c_1, c_2) \right) \{-x_1\} \left(\frac{T^*}{x_1(T^*+1)} \right)$$

The limits $\lim_{x_1^* \to 0} c_i > 0$ imply $\lim_{x_1^* \to 0} u_1(c_1, c_2) \in (0, \infty)$. This proves (29); (31) follows by symmetry.

(ii) Show (30). Check with (15)

$$\begin{aligned} \lim_{x_2 \to 0} \pi &= T\frac{x_1(T^*+1) + x_1^* T^*(T+1)}{x_2^*(T+1)} \\ \lim_{x_2 \to 0} \frac{d\ln(\pi)}{dx_2} &= \frac{-\bar{A}(T^*+1)}{x_1(T^*+1) + x_1^* T^*(T+1)} - \frac{T(T^*+1)}{x_2^*(T+1)} \end{aligned}$$

where $T = \sqrt{x_1(T^*+1)/(x_1^* T^*) + 1}$ according to (23). Note that both expressions are bounded for all $x_1^* \geq 0$. Thus, (13) implies

$$\lim_{x_2 \to 0} I = \frac{2T}{T+1} x_1 \qquad \lim_{x_2 \to 0} \frac{dI}{dx_2} = \frac{2}{T+1}(-\bar{A}T + \pi)$$

where $\bar{A}$ is Home's finite marginal rate of transformation between X_1 and X_2. Again, both expressions are bounded for all $x_1^* \geq 0$. Combining these expressions with (A1) leads to

$$\lim_{x_2 \to 0} \frac{dw(T^{BR}, T^*, X)}{dx_2} = \left(\lim_{x_2 \to 0} u_1(c_1, c_2) \right) \left\{ 2\frac{-\bar{A}T + \pi}{T+1} - \frac{T}{T+1} x_1 \frac{d\ln(\pi)}{dx_2} \right\}$$

By the reasoning above the expression in the slanted brackets is bounded for all $x_1^* \geq 0$. Finally, since $c_1 = I/2$ and $c_1 = I/2\pi$ are both positive at $x_2 \to 0$, $\lim_{x_1^* \to 0} u_1(c_1, c_2)$ is finite. This proves (30); (32) follows by symmetry. ■

Proof of Claim 2. Define Home's domestic relative price as $\pi(T^N, T^{N,*}, X) = pT^N$ with p from (15) under $T^{(*)} = T^{N,(*)}$. Equation (A1) still applies. By the Envelope Theorem T^N can be treated as a constant. The superscripts ^{N} will be omitted in the following.

(i) Show (33). If $x_1^* > 0$ use (15) and (26) to compute

$$\begin{aligned} \lim_{x_2 \to 0} \pi &= \frac{x_1 + x_1^*(T+1)}{x_2^*(T+1)} \lim_{x_2 \to 0} T^* \\ \lim_{x_2 \to 0} \frac{d\ln(\pi)}{dx_2} &= \frac{-\bar{A}(T^*+1)}{x_1(T^*+1) + x_1^* T^*(T+1)} - \frac{T(T^*+1)}{x_2^*(T+1)} ... \\ & ... + \left\{ \frac{x_1 + x_1^*(T+1)}{x_1(T^*+1) + x_1^* T^*(T+1)} - \frac{T x_2}{x_2^*(T+1)} \right\} \lim_{x_2 \to 0} \frac{dT^*}{dx_2} \end{aligned}$$

where $\bar{A}^*$ is Foreign's finite marginal rate of transformation between X_1 and X_2. With (26) and (28) the second expression implies

$$\lim_{x_2 \to 0} x_2 \frac{d\ln(\pi)}{dx_2} \in (-\infty, 0) \tag{A2}$$

Further, (13) and (26) lead to

$$\lim_{x_2\to 0} I = \frac{2Tx_1}{T+1} \qquad \lim_{x_2\to 0}\frac{dI}{dx_2} = \frac{2(\pi - \bar{A}T)}{T+1} + \frac{2}{T+1}\lim_{x_2\to 0}\left(\frac{x_2}{\pi}\frac{d\ln(\pi)}{dx_2}\right) = \frac{2(\pi - \bar{A}T)}{T+1}$$

Combining these expressions with (A1) leads to

$$\lim_{x_2\to 0}\sqrt{x_2}\frac{dw(T^N, T^{N,*}, X)}{dx_2} = \left(\lim_{x_2\to 0}\frac{u_2(c_1,c_2)}{\sqrt{x_2}\pi}\right)\left\{-\frac{Tx_1}{T+1}\lim_{x_2\to 0} x_2\frac{d\ln(\pi)}{dx_2}\right\}$$

With (A2) the term in the slanted brackets is finite and positive; by (15) and (26) $\lim_{x_2\to 0}\sqrt{x_2}\pi$ is finite. Since finally, $\lim_{x_2\to 0} c_1 = \lim_{x_2\to 0} I/2 > 0$ and $\lim_{x_2\to 0} c_2 = \lim_{x_2\to 0} I/2\pi = 0$ leads to $\lim_{x_2\to 0} u_2(c_1,c_2) = \infty$, which shows (33) for $x_1^* > 0$.

For the case $x_1^* = 0$ take (13), (15) and (26) to check

$$\lim_{x_1^*\to 0}\pi = \frac{x_1(T^*+1)}{x_2(T^*+1)+x_2^*} \qquad \text{and} \qquad \lim_{x_1^*\to 0} I = 2x_1$$

Hence,

$$\frac{dI}{dx_2} = -2\bar{A} \qquad \frac{d\ln(\pi)}{dx_2} = \frac{-\bar{A}}{x_1} - \frac{T^*+1}{x_2(T^*+1)+x_2^*} + \left(\frac{1}{T^*+1} - \frac{x_2}{x_2(T^*+1)+x_2^*}\right)\frac{dT^{N,*}}{dx_2}$$

With (26) this last expression shows that (A2) holds in the case $x_1^* = 0$ as well. Thus

$$\lim_{x_2\to 0}\sqrt{x_2}\frac{dw(T^N, T^{N,*}, X)}{dx_2} = \left(\lim_{x_2\to 0}\frac{u_2(c_1,c_2)}{\sqrt{x_2}\pi}\right)\left\{-x_1\lim_{x_2\to 0} x_2\frac{d\ln(\pi)}{dx_2}\right\}$$

By (15) and (27) $\lim_{x_2\to 0}\sqrt{x_2}\pi$ is finite. Finally, observe that $\lim_{x_2\to 0} c_1 = \lim_{x_2\to 0} x_1/2 > 0$ while $\lim_{x_2\to 0} c_2 = \lim_{x_2\to 0} x_1/2\pi = 0$. Thus, $\lim_{x_2\to 0} u_2(c_1,c_2) = \infty$ This completes the proof of (33); (35) follows by symmetry.

(ii) Show (34). If $x_2 > 0$ equations (13) and (15) imply

$$\lim_{x_1^*\to 0}\pi = \frac{x_1(T^*+1)}{x_2(T^*+1)+x_2^*} \qquad \text{and} \qquad \lim_{x_1^*\to 0} I = 2x_1$$

and

$$\lim_{x_1^*\to 0}\frac{d\ln(\pi)}{dx_1^*} = \left(\lim_{x_1^*\to 0} T\right)\frac{T^*}{x_1(T^*+1)} + \frac{A^*}{x_2(T^*+1)+x_2^*} + \left(\frac{1}{T^*+1} - \frac{x_2}{x_2(T^*+1)+x_2^*}\right)\frac{dT^*}{dx_1^*}$$

Now, (26) implies $dT^*/dx_1^* < \infty$ for $x_2 > 0$ so that

$$\lim_{x_1^*\to 0}\sqrt{x_1^*}\frac{d\ln(\pi)}{dx_1^*} = \left(\lim_{x_1^*\to 0}\sqrt{x_1^*}T\right)\frac{T^*}{x_1(T^*+1)} \in (0,\infty)$$

With

$$\lim_{x_1^* \to 0} \frac{dI}{dx_1^*} = 2 \lim_{x_1^* \to 0} \frac{x_2}{T} \frac{d\pi}{dx_1^*} \in (0, \infty)$$

and (A1) this leads to

$$\lim_{x_1^* \to 0} \sqrt{x_1^*} \frac{dw(T^N, T^{N,*}, X)}{dx_1^*} = \left(\lim_{x_1^* \to 0} u_1(c_1, c_2) \right) \left\{ \left(2 \lim_{x_1^* \to 0} \frac{x_2 \pi}{T} - \frac{x_1}{2} \right) \frac{d \ln(\pi)}{dx_1^*} \right\}$$

The expression in the slanted brackets is finite. Finally, $\lim_{x_1^* \to 0} c_1 = x_1 > 0$ shows $\lim_{x_1^* \to 0} u_1(c_1, c_2) \geq 0$, which proves (34) for $x_2 > 0$.

For the case $x_2 = 0$ take (13), (15) and (26) to check

$$\lim_{x_2 \to 0} c_1 = \lim_{x_2 \to 0} I/2 = T/(T+1) \qquad \text{and} \qquad \lim_{x_2 \to 0} c_2 = I/(2\pi) = 0$$

Hence,

$$\lim_{x_1^* \to 0} \sqrt{x_1^*} \frac{dw(T^N, T^{N,*}, X)}{dx_1^*} = u_1 \left(\tfrac{T}{T+1}, 0 \right) \lim_{x_1^* \to 0} \left\{ \frac{\sqrt{x_1^*}}{(T+1)^2} \frac{dT}{dx_1^*} \right\}$$

By (26) and (28) the term in slanted brackets is finite. As $u_1(c_1, c_2)$ is bounded for positive c_1 this proves (34); (36) follows by symmetry ■

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