



Trade Policy, Environmental Policy, and the Sustainability of International Cooperation

By

Peiying Tian

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Abstract

This study analyses trade wars and the sustainability of cooperation under both perfect competition and oligopoly using the game theory approach. In chapter two, a trade policy game under perfect competition between two countries with endowment asymmetries is studied. In a trade war, modelled as the interior Nash equilibrium, the outcome in the symmetric case is that both countries lose, but when asymmetries are allowed, a country may win the trade war. Hence, in an infinitely-repeated game, asymmetries make it difficult to sustain free trade. It is shown that both countries minimaxing each other by setting prohibitive trade taxes is also a Nash equilibrium that results in each country obtaining autarky welfare, and it is easier to sustain free trade using infinite minimax reversion than using infinite Nash reversion.

In chapter three, the trade policy game is re-examined under perfect competition among multi countries with a symmetric endowment allocation. All the countries are worse off in the interior Nash equilibrium than under free trade. In an infinitely-repeated game, more countries make it more difficult to sustain free trade using infinite Nash reversion but make it easier using infinite minimax reversion. Since there are two Nash equilibria, free trade can also be sustained in a finitely-repeated game.

In chapter four, by allowing for environmental spillovers in a Cournot duopoly model with differentiated products, it is shown that an international environmental agreement under free trade is sustainable in an infinitely-repeated game, provided that the relative environmental damage is not too great. There is a unique Nash equilibrium that results in autarky welfare for both countries if the environmental damage is large enough, in which case more environmental spillover effect makes it easier to sustain cooperation.

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Chapter 1 : Introduction

An international economic policy usually has an impact on other countries and causes unintended policy externalities. For externalities that have a transboundary nature and a global scope, there are needs for international economic cooperation. In international trade, using a trade tax is a beggar-thy-neighbour policy, and it has a negative terms of trade externality. If countries use trade taxes that are too high, then in the symmetric case there will be a Prisoners' Dilemma: each country individually has an incentive to follow such a policy, thereby making everyone worse off. It underlines the importance of international trade agreements. Trade expansions often have environmental implications. Trading on goods that generate pollutants could increase environmental damage at the regional or global level. As a result, countries often impose a levy on the output of the polluting industry. A tax for environmental purposes such as an emission tax reduces pollution and has a positive externality. Countries use emission taxes that are too low and there is also a Prisoners' Dilemma: each country may have an incentive to be a free rider thus exacerbating environmental pollution and leaving all countries worse off. To avoid such a Prisoners' Dilemma, countries could cooperate through international environmental agreements (IEAs). In both cases, policy externality provides an essential role for international cooperation.

The first modern trade agreement was signed between Britain and France in 1860, the so-called Cobden-Chevalier Treaty. After Britain began free trade policies in 1846, there remained tariffs with France. In this treaty, France committed to removing import barriers on British industrial goods, coal and iron, and Britain, in turn, eliminated tariffs on main items of trade – wine, brandy, and silk goods. In 1948 when the General Agreement on Tariffs and Trade (GATT) took effect, more than 45,000 tariff concessions were signed by its original 23 signatories. The GATT's successor, the World Trade Organization (WTO) was formed in The Uruguay Round, which was signed by 123 parties and went into effect in 1995 (Grossman, 2016). By October 2021, the WTO had grown to include 164 members, and about 350 regional trade agreements (RTAs) covering goods, services and intellectual property were in

force.¹ However, despite signing trade agreements, there still occurred numerous trade disputes among countries over whether specific measures are used for protectionism. Recent affairs such as the ongoing US-China trade conflict, which was started in 2018, have brought the analysis of trade wars and trade agreements a topical issue.

International trade agreements are usually limited to lowering the trade barriers and achieving a principle of free trade. Under the regulation of trade treaties from the WTO, sovereign countries might consider the environmental impacts of different products, however, the production processes which could cause environmental externalities are neglected. Environmental externalities both local and transnational, are common and important. International Environmental Agreements (IEAs) addresses the specific transboundary or global environmental issue, and European Union is an example of a free-trade area that includes institutions for environmental standards enforcement. Since the early 1900s, countries have negotiated and signed hundreds of international legal agreements to address environmental problem that cannot be solved by an individual country. The first international environmental treaty perhaps goes to the International Convention for the Regulation of Whaling in 1946, which aimed at the "proper conservation of whale stocks and thus make possible the orderly development of the whaling industry". By January 2021, there are 88 parties to the convention. IEAs were seriously and frequently used and took effect in the post-World War II period (Barrett, 2003). By 2017, there were over 1,300 multilateral environmental agreements (MEAs) and over 2,200 bilateral environmental agreements (BEAs) dealing with various environmental problems.² As a result of global warming, which was driven by human-mand CO₂, the Kyoto Protocol entered into force in 2005, and implemented the objective of the 1992 United Nations Framework Convention on Climate Change (UNFCCC) to reduce greenhouse gas emission. There were 192 members to the Protocol in 2020. Since carbon emission reduction, including the reduction of "exported emissions" by both developing and developed countries has become a major challenge for the future, the analysis of IEAs in international trade has also become a focused area.

¹ Current members are listed at https://www.wto.org/english/thewto_e/whatis_e/tif_e/org6_e.htm. Information about RTAs can be found at https://www.wto.org/english/tratop_e/region_e/region_e.htm.

² See the IEA Database Project for a list of IEAs at <https://iea.uoregon.edu/>.

This thesis analyses trade wars and the sustainability of international agreements including trade agreements and environmental agreements between governments using a repeated game framework. As countries' decision in setting tariffs are strategically interacted, game theory can be used to analyse a trade policy game. This approach was firstly adopted by Johnson (1953) who considered the case of two large countries each producing two goods under perfect competition.³ With the use of this method, trade war is modelled as a non-cooperative Nash equilibrium in an trade policy game. Countries could cooperate by sign and abide by the trade agreements, which is the cooperative equilibrium. Since most of trade agreements are aiming at eliminating trade barriers, a cooperation in trade policy in this analysis refers to a multilateral free trade agreement. There are numerous reasons why governments sign trade agreements. And as pointed out by Maggi (2014), a trade agreement provides governments with an escape from Prisoners' Dilemma where all the countries receive a lower welfare in the non-cooperative Nash equilibrium than in the cooperative equilibrium. It may also provide government advantage in affecting industrial and individual decisions. This thesis focuses on the first reason and discusses the conditions to win a tariff war. Despite the interior Nash equilibrium, Dixit (1987) showed that both countries minimax each other by setting prohibitive tariffs, resulting in autarky, is another Nash equilibrium known as the "Minimax Nash equilibrium". In the case of environmental damage under oligopoly in chapter four, there exist two externalities, and countries cooperate in the global market by using an environmental policy to counteract the environmental externalities and a production policy to deal with oligopolistic externality. There are no taxes implemented for the purpose of intervening in trade, both countries use free trade policy when cooperating. An environmental policy is adopted by using an tax that equals marginal environmental damage on imports only in the form of an import tariff, and a production policy is implemented through a tax/subsidy on domestic production that maximises the world joint welfare. A country can improve its welfare by unilaterally intervening in trade and using individual welfare maximising production, environmental, and trade policies, however, at the expense of the other country, who is likely to retaliate, thus leaving both worse off. A policy war is modelled as an interior Nash equilibrium in an

³ See the literature survey in chapter two and chapter three for a detailed presentation of research using the game theory approach in analysing trade policies and trigger strategies in a repeated game.

environmental and trade policy game. If the cheating country uses a set of prohibitive policies to improve its welfare, there will be no trade, and both countries receive welfare in autarky, which is another Nash equilibrium of the environmental and trade policy game. It is worth mentioning that since transboundary environmental damage is allowed, each country does not minimise its competitor's maximum welfare by using a set of prohibitive policies. Therefore, the autarky equilibrium is not a minimax Nash equilibrium as it was in the previous two chapters.

Follow the idea of the Folk theorem that cooperation can be achieved in a repeated game with sufficiently patient players, a repeated version of a constituent policy game is analysed to discuss whether cooperation can be self-enforced and sustained in all chapters. It is assumed that all the parties adopt a trigger strategy that any defection would trigger a punishment to all countries. As there are two Nash equilibria, two trigger strategies are studied in this thesis: Nash reversion trigger strategies and minimax reversion (autarky reversion) trigger strategies as in Collie (2019). The case of cooperation is extended to an agreement in dealing with international environmental issues in chapter four as environmental policy can be treated as a substitute to trade policy. In this case, the sustainability of an IEA with no government intervention in trade policy is discussed using the same approach as in chapter two and chapter three.

The organisation of this study is as follows.

Chapter two analyses trade wars between two countries under perfect competition. Trade policy is analysed in a repeated game where the stage game is the well-known model of Kennan and Riezman (1988). In their constituent two-country model, trade policy is analysed in a pure exchange model with Cobb-Douglas preferences and exogenous endowments. It will be shown that trade policy is a Prisoners' Dilemma when the two countries are similar in terms of their endowments. In this case, both countries will be worse off in a tariff war than under free trade. A repeated version of the constituent two-country model is discussed with the use of the Folk theorem and trigger strategies.

Chapter three extends chapter two's results by analysing trade wars in a multi-country setting under perfect competition. The constituent game in chapter three

follows the idea of Bond and Syropoulos (1996) with adjustments over preferences and assumption of numeraire good. A symmetric structure with Cobb-Douglas preferences and exogenous endowments is used to analyse the implications of world size and the degree of comparative advantage on welfare. Nash reversion trigger strategies and minimax trigger strategies are used in an infinitely repeated game and a finitely repeated game to draw conclusions on the sustainability of free trade among numerous countries.

Chapter four analyses environmental externality in international trade under oligopoly with differentiated products. It is assumed that the process of production generates pollution which reduces welfare. The welfare effect of pollution linkage in terms of local, transboundary, and global externalities, environmental damage and the degree of product differentiation is studied both in a constituent and a repeated policy game. Different from chapter two and chapter three that governments do not intervene in the cooperative equilibrium, in chapter four with environmental externalities, it is assumed that government intervene in controlling pollution with the use of a border tax at Pigouvian level when countries cooperate. Policy war causes welfare reduction, thus is analysed as a threat to sustain cooperation. It will be shown that there is a unique Nash equilibrium that leads to autarky in the case of environmental externality under certain parameter values. The sustainability of IEA with free trade is then analysed in a repeated game using the same approach as in chapter two and chapter three.

The literature survey relates to international trade agreement, IEAs and general game theory approach in analysing policy games under perfect and imperfect competition will be in individual chapters.

Chapter 2 : Trade Wars and the Sustainability of Free Trade

2.1 Introduction

The World Trade Organisation (WTO), founded in 1995, is viewed as a negotiating platform for trade partners to achieve a trade agreement and implement the prescribed punishment. The purpose of the WTO is to encourage globalisation and ensure international trade proceeds smoothly in a predictable global environment. However, there has been an increase in trade conflicts among various countries in recent years. For example, in early 2018, the Trump administration triggered a tariff war against China to make changes to “unfair trade practices” and intellectual property rights, which started with tariffs on solar panels and washing machines. China then announced a plan for additional tariffs of 25% on 106 products, including automobiles, aeroplanes, and soybeans, to retaliate against the US. This trade war between China and the US is still an ongoing conflict in 2021. A trade dispute also happened between Japan and South Korea in 2019 when Japan imposed new trade controls on exports of hi-tech materials to South Korea and then removed South Korea from the “white-list” for preferential trading. This conflict arose because a South Korean court ordered Japanese firms to compensate the victims of forced labour during Japan’s colonisation of the Korean Peninsula. In the same year, India announced retaliatory trade tariffs, some as high as 70%, against the US due to the US’s withdrawal of India’s preferential trade treatment and Washington’s refusal to exempt Delhi from higher taxes on steel and aluminium imports. Most trade conflicts result from the increased taxes levied by the United States across various industries.¹ The WTO s intervenes in trade disputes

¹ For more information about trade conflicts around the world, see various articles from the *Financial Times*, *BBC News*, *PIIT*, the *New York Times* and the *Wall Street Journal*, for example: [What you need to know about the Trump steel tariffs](#), [China Retaliates Against Trump Tariffs With Duties on American Meat and Fruit](#), [Trump's Mini-Trade War with India](#), [India announces retaliatory trade tariffs against the US](#), [South Korea files WTO complaint over Japan trade restrictions](#), and [Inside the lose-lose trade fight between Japan and South Korea](#).

as an arbitrator and sets guidelines for the cases by allowing countries to respond. In October 2019, Washington was granted the ability to impose punitive tariffs on the European Union, putting an end to a 15-year dispute over aerospace subsidies between the US and Europe.² In November 2019, China was authorised by the WTO to take retaliatory actions in levies on US goods, whereas this action was already done before the authorisation due to the trade war. Even though the WTO offers a system for international commerce, cooperation among countries is still tricky since it lacks the power to enforce trade agreements. All the agreements are between sovereign nations, and the WTO is not a supranational institution at the global level, thus having no enforcement power. Therefore, once an agreement has been signed, whether the countries themselves could conduct such a treaty becomes an issue. Such an issue arises because large countries can manipulate the terms of trade and will be tempted to use a trade policy to improve their welfare unilaterally.

A tariff imposed by a large country results in non-negative terms of trade effect and deadweight welfare losses. With tariffs not exceeding some definite high value, gains by the terms of trade effect always dominate the deadweight losses from distortion of domestic production and consumption. As a result, a large country gains from using tariffs. Such an argument that a country may benefit from trade taxes was formalised by Bickerdike (1906), who argued that when tax rates are far below the prohibitive level, a country obtains advantages from imposing taxes. However, when a large country improves its welfare by using tariffs to manipulate the terms of trade, the other country would be penalised by the trade tax inefficiency. The inefficiency arose since the other country's terms of trade would worsen, which made the country worse off. An import tariff imposed by a large country increases the domestic relative price of imported goods. Consequently, the demand for imports goes down, and the supply for exports goes up. It causes an increase in excess supply, which leads to a reduction in the relative price of imported goods in the world market. Therefore, a tariff improves a country's terms of trade, whereas it hurts the trade partner.

² See articles from *The European Parliament*, *The European Commission*, and *The Economist* for more recent information and the story of the EU-US debate over aerospace subsidies. For example: [EU-US Dispute Over Civil Aircraft Subsidies](#), [EU and US Take Decisive Step to End Aircraft Dispute](#) and [Is the trade dispute between America and Europe over Airbus and Boeing over?](#)

Unilaterally using an import tariff or an export tax to improve the terms of trade is a beggar-my-neighbour policy.

When a country could use a non-negative trade policy to improve its welfare, there exists an optimum tariff level such that it maximises a country's welfare, the so-called optimum tariff. It can be shown that such an optimum tariff equals the inverse of import supply elasticity (foreign export supply elasticity), as in Corden (1997), and it was derived by maximising welfare to tariffs, see, for example, Feenstra (2015). The value of such a tariff also depends on whether a country can affect world prices or not, i.e., whether the country in interest is a large country or a small country. Theoretically, a small country faces a perfectly elastic export supply and cannot pass the effect of a tariff to foreign producers. Hence the optimum tariff is zero. Broda et al. (2008) provided strong evidence that tariffs vary inversely with foreign export supply elasticities. They argued that countries set higher tariffs on products where they have more market power (when foreign supply is less elastic). If a country is small, it does not have market power by definition. However, evidence by Broda et al. (2008) supports that some seemingly small countries have market power (or term of trade gains) in setting trade policy.³

While tariffs may boost one country's welfare and reducing the welfare of another, the danger of retaliation by the country whose welfare is reduced cannot be neglected. If the country's trade partner retaliates by imposing a tariff and triggering a tariff war, it was the consensus that both countries would potentially be worse off in early trade literature. However, Kaldor (1940) showed the possibility that a country may gain by using tariffs even with retaliation, provided that the elasticity of the country's demand for foreign goods is sufficiently larger than the elasticity of foreign demand for its own goods. The possibility that a country would win in a tariff war was formally discussed by Johnson in 1953, who considered a two-country two-commodity exchange model where both countries have monopoly power in world

³ Amiti et al. (2019) estimated the effects of tariffs using the US's monthly trading data in 2018 and found no terms of trade effects. This preliminary result contradicts Broda et al. (2018) by asserting that the US faced a perfect elastic foreign export supply in 2018. Possible reasons for the contradiction include the stickiness of export prices in the short run and the high uncertainty of the US 2018 trade policy.

trade and can use trade restrictions to improve their welfare. Johnson (1953) was the first to analyse trade wars in a game theory setting and showed that a country might gain by using tariffs even in the presence of retaliation. He pointed out that the tariff-setting decisions made by the two countries strategically interact. A trade policy made by a country affects the decision of its trade partner, which influences its own decision in turn. A tariff war can then be analysed as a non-cooperative Nash equilibrium in a constituent trade policy game. It was shown that such a Nash equilibrium does not always result in a Prisoner's Dilemma, where both countries are worse off in a tariff war than under free trade. By assuming constant elasticity of import demand, he showed that a country could potentially win a tariff war if its import demand elasticity is sufficiently larger than its trade partner's, regardless of retaliation. Therefore, a country may prefer a non-cooperative Nash equilibrium if its relative market power is large enough. Since determinations of the elasticity were not discussed in Johnson's paper, Kennan and Riezman (1988) filled in this research gap by developing a pure exchange model where market power is determined by relative endowment size. However, they remained silent on how endowment size affects elasticity and market power. Different from Johnson (1953), where asymmetries refer to differences in import demand elasticity, Kennan and Riezman identified asymmetries as differences in endowment sizes and considered a model in which two countries are endowed with two goods. They explicitly worked out both countries' optimum import tariffs (a tariff that maximises the country's welfare) as functions of endowments, in the case of identical Cobb-Douglas preferences, and demonstrated that in a constituent game, a country can gain from implementing optimum trade policy only if it has a sufficiently big endowment size by comparing the welfare of two countries under free trade and the optimum trade policy. It was stated in their paper that "... if one country is substantially bigger than the other, then a big country can expect to gain by starting a tariff war". When countries were endowed with similar sizes of goods, both parties necessarily lost. Kilolo (2018) re-examined the model with Stone-Geary preferences and showed that besides endowment patterns, consumption requirements also affect the outcome of a trade war. In the presence of asymmetries, both countries would lose a tariff war if the subsistence level of consumption in the large country is sufficiently higher than in the small country. The idea that large countries win tariff conflicts has been accepted as an article of faith, according to Syropoulos (2002), despite the fact that its generality has remained unquestioned. When discussing the interaction with a

small country, large countries are typically depicted as having an infinitely elastic offer curve, as most textbooks indicate. However, Syropoulos (2002) showed that if a country is infinitely large, its welfare levels under tariff retaliation, free trade, and autarky do not differ, raising questions about why such a government would intervene in trade in the first place. To demonstrate the generality of Kennan and Riezman (1988)'s result, he used a neoclassical trade model with constant return to scale (CRS) technologies and identical and homothetic preferences to formulate the analysis in per capita terms without loss of generality. Country size was defined as the relative number of workers provided that the per capita endowment in both countries was fixed. Therefore, a country's relative size increases when its factor supplies increase by the same proportion. With this so-called “analytically powerful and appealing” definition of size, he also proved that a sufficient condition to generate a winner in a tariff war is that the country's relative size is large enough.

Some countries may find trade battles alluring, but the result of a trade war is not efficient, as in Johnson (1953). Trade negotiations have the potential to boost both countries' welfare by achieving a trade agreement. Such an agreement is Pareto efficient when both countries are better off than under trade wars. This concept is widely acknowledged as the driving force behind the founding of the GATT and its successor, the WTO. Any efficient outcome that dominates Nash equilibrium can be supported in a repeated game, as in the Folk Theorem, by Friedman (1971). Dixit (1987) applied the Folk Theorem in a trade policy game and showed that while free trade is Pareto efficient and non-cooperative Nash equilibrium is not, a trade agreement is sustainable in an infinitely repeated game.⁴ He also pointed out the existence of another NE in which both countries minimise their competitor's maximum welfare by raising the tariff to a prohibitive level (i.e., Minimax strategy ⁵). In this equilibrium, trade restrictions are so tight that no trade occurs, and thus both countries receive welfare under autarky. Once both countries had locked themselves

⁴ Mayer (1981), Bagwell and Staiger (1990), McLaren (1997), Bond and Park (2002) and many others also used retaliatory equilibrium as a threat point in analysing trade agreements. For recent surveys on trade agreements, see Maggi (2014), Grossman (2016) and Bagwell and Staiger (2016).

⁵ For details about minimax strategies, see Fudenberg and Maskin (2009).

into autarky, there was no motivation for either country to cut its tariffs from prohibitive level to a level that would allow trade to take place, as doing so had no effect and would make no difference to the autarky situation. With two Nash equilibria, cooperation (in terms of acting up to free trade deal) can also be sustained in a finitely repeated game, as in Benoit and Krishna (1985). If there is a unique Nash equilibrium in a finitely repeated game, the unique stage game Nash equilibrium must be played in the last round regardless of what happened in earlier rounds. In this case, the outcome of a finitely repeated game would be to play the NE in each round of the game. Collie (2019) used a game theoretical framework to investigate trade wars and the sustainability of free trade in imperfect competition. In particular, he studied a trade policy game in a Cournot duopoly and a Bertrand duopoly. Using the Folk theorem and trigger strategies, he showed that free trade is sustainable in both an infinitely repeated and a finitely repeated game with the competitiveness of each country having an impact on sustainability through cost asymmetries.

Most of the contributors to the literature on trade agreements consider the Nash tariff as a unique threat point for sustaining cooperation in an infinitely repeated game. The contribution of this paper will be to analyse the sustainability of a trade agreement (free trade deal) using both Nash reversion and Minimax reversion in a perfectly competitive market, with the comparisons between these two strategies. Besides asymmetries in endowment size, as shown by Kennan and Riezman (1988) in their constituent trade game, trade volume under free trade between two countries is also considered a significant factor affecting the enforceability of multilateral trade agreements. In the context of a finitely repeated game where countries may deviate from free trade and use optimum trade policy, most of the literature implicitly assumes that countries always desire to deviate in the last round before free trade is no longer sustainable. This research, however, demonstrates the importance of considering incentives to use optimum trade policy at each round of the game. It shows that countries may face powerful incentives to depart from free trade agreements at an early stage of a finitely repeated game. The innovations to Kennan and Riezman (1988)'s work include the definition of trade instruments and a repeated version of their constituent game. Unlike Collie (2019), this chapter looked at the sustainability of free trade in perfect competition rather than imperfect competition, and so can support Collie's findings.

The organisation of this paper is as follows. Section 2.2 describes the theoretical framework based on Kennan and Riezman (1988)'s exchange model and defines trade instruments in a constituent trade game. To analyse the result of a trade war, explicit solutions for Nash equilibrium tariff and welfare are derived under all feasible trade policies. Section 2.3 examines the sustainability of trade agreement and is divided into two subsections where the constituent trade game is finitely or infinitely repeated. All the results are discussed in section 2.4. The appendix contains details and proofs of results.

2.2 The Static Model

This is a static model which will be a stage game. In this stage game, there are two players and each player receives the payoff of a trade game, which is a function of welfare action for the game. Specifically, the trade game is between two welfare-maximising countries, labelled 1 and 2, that trade two goods, also labelled 1 and 2. In a perfectly competitive market, price-taking consumers in the two countries are assumed to be identical with Cobb-Douglas preferences, and receive payoffs from consuming the two goods:

$$U_i = C_{1i}C_{2i}, \quad i=1,2 \quad (2.2.1)$$

U_i is the utility level of country i , C_{1i} and C_{2i} are consumption of good 1 and good 2 owned by the i^{th} country. Following Kennan and Riezman (1988), the world endowment of each good is fixed to one and allocated between two countries. Country i is endowed with e_{1i} good 1 and e_{2i} good 2. The total world endowment of each good is normalised at one, and the initial endowment is defined as $e = (e_{11}, e_{21}, e_{12}, e_{22})$, with $e_{11} = \gamma$, $e_{21} = 1 - \mu$, $e_{12} = 1 - \gamma$ and $e_{22} = \mu$, where $\gamma < 1$, $\mu < 1$. The comparative advantage in endowment determines the flow of trade between the two countries. If country 1 has a comparative advantage in good 1, i.e., its relative endowment of good 1 is greater than country 2's relative endowment of good 1, then it exports good 1, and imports good 2. Trade policy is defined as the difference between domestic and world prices, which is the imposition of positive or negative trade taxes. Each country could impose an *ad valorem* import tariff/export tax on the corresponding imports/exports. In the context of this paper, it is assumed that each country i uses a trade policy on good j , and this study focuses on the use of import tariffs.⁶ Although, the analysis also covers the possibility that country i imports good i , in which case there will be an export tax on good j . The world price of good i is denoted by P_i , $i=1,2$. Trade instrument is defined as $\tau = (t_1, t_2)$, and the effect of such

⁶ The Lerner Symmetry Theorem indicates that an *ad valorem* import tariff will have the same effects as an export tax. Hence, even though this paper focuses on import tariffs, it includes the case of using export taxes implied by the Lerner Symmetry where an import tariff t would be equivalent to an export tax $t/(1+t)$.

a trade instrument is to make the domestic price of good j in country i be $P_j(1+t_i)$, $i=1,2$. This implicitly suggests that t is an import tariff if the product is imported, or an export subsidy if it is exported. Analogously, if t is negative, it is an import subsidy or an export tax.⁷ There are assumed to be no trade costs such as transport costs in this paper.

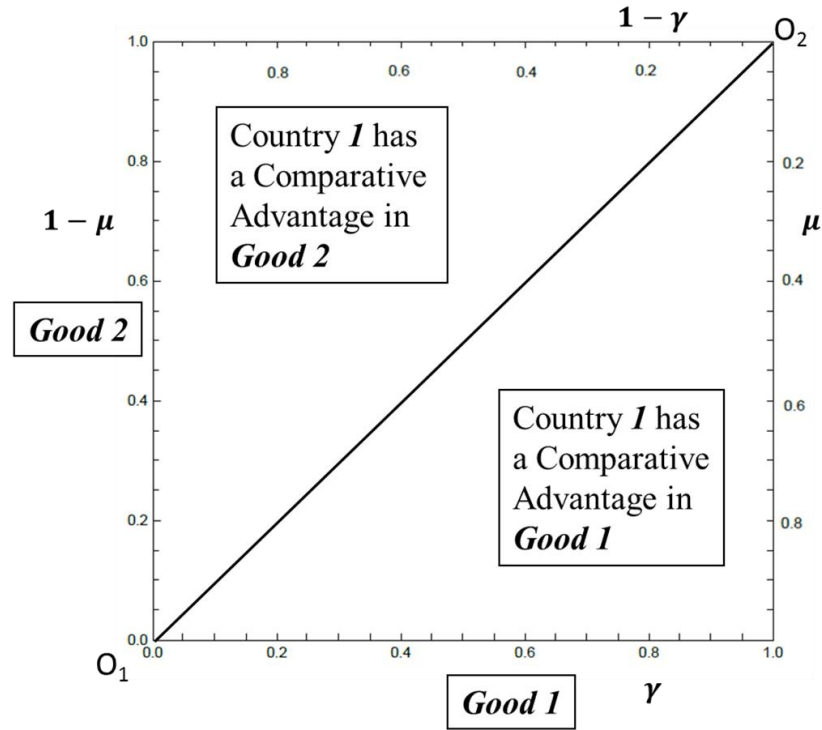


Figure 2.1 Trade Flows between Two Countries ⁸

Each country's consumer wealth is made up of two parts: the income from selling its own endowments and tariff revenue from imports. Domestic prices for good 1 and

⁷ See Dixit and Norman (1980, p.151)

⁸ The trade flow between the two countries is represented by a parameter space that similar to an Edgeworth box. The endowment located to the southeast of the diagonal provides nation 1 with a competitive advantage in good 1, therefore country 1 exports good 1 while importing good 2 with a tariff. If the endowment set is in the other region, country 1 imports good 1 and uses an export tax on good 2. Endowment sets on the diagonal result in identical autarky price in both countries, therefore no country has a comparative advantage, and no trade takes place. Kennan and Reizman (1988) only considered the situation with an import tariff, that is, only the endowment sets to the southeast of the Edgeworth box where country 1 has a comparative advantage in good 1 was analysed. They implicitly assumed the result to be symmetric in the other side of the Edgeworth box.

good 2 are P_1 and $P_2(1+t_1)$ in country 1, $P_1(1+t_2)$ and P_2 in country 2. Consumers in two countries maximise utilities subject to the budget constraints:

$$\begin{aligned} P_1 C_{11} + P_2(1+t_1) C_{21} &= P_1 \gamma + P_2(1+t_1)(1-\mu) + P_2 t_1 im_{21} \\ P_1(1+t_2) C_{12} + P_2 C_{22} &= P_2 \mu + P_1(1+t_2)(1-\gamma) + P_1 t_2 im_{12} \end{aligned} \quad (2.2.2)$$

where im_{ij} shows the trade flow from country i to country j , which represents the country j 's imports. Utility maximisation yields the equilibrium conditions:

$$\begin{aligned} C_{11} P_1 &= C_{21} P_2(1+t_1) \\ C_{22} P_2 &= C_{12} P_1(1+t_2) \end{aligned} \quad (2.2.3)$$

Given $C_{11} = \gamma - im_{12}$, $C_{21} = 1 - \mu + im_{21}$, $C_{12} = 1 - \gamma + im_{12}$ and $C_{22} = \mu - im_{21}$, the budget constraints in equation (2.2.2) indicate a balanced trade $P_1 im_{12} = P_2 im_{21}$. Equilibrium conditions can then be expressed as:

$$\begin{aligned} \frac{\gamma}{im_{12}} &= \frac{(1-\mu)(1+t_1)}{im_{21}} + t_1 + 2 \\ \frac{\mu}{im_{21}} &= \frac{(1-\gamma)(1+t_2)}{im_{12}} + t_2 + 2 \end{aligned} \quad (2.2.4)$$

It gives rise to the equilibrium level of imports:

$$im_{12} = \frac{\Phi}{A_1}, \quad im_{21} = \frac{\Phi}{A_2} \quad (2.2.5)$$

where $\Phi = 1 - \gamma + (\gamma - 1)(\mu - 1)(t_2 + t_1 + t_1 t_2) - \mu$,

$A_i = -(1+t_i)(2+t_j) + (t_i + t_j + t_i t_j)X$, $i=1,2$ $j=1,2$ $i \neq j$ and

$$X = \begin{cases} \mu, & \text{if } i=1 \\ \gamma, & \text{if } i=2 \end{cases}$$

Such imports imply equilibrium consumption levels:

$$C_{11} = \gamma - im_{12} = \frac{-(1+t_1)B_1}{A_1}, \quad C_{21} = 1 - \mu + im_{21} = \frac{-B_1}{A_2} \quad (2.2.6)$$

$$C_{22} = \mu - im_{21} = \frac{-(1+t_2)B_2}{A_2}, \quad C_{12} = 1 - \gamma + im_{12} = \frac{-B_2}{A_1}$$

where $B_1 = (1+t_2)(\mu-1) - \gamma$ and $B_2 = (1+t_1)(\gamma-1) - \mu$. Plugging equation (2.2.6) into utility function (2.2.1), the welfare in each country can then be written as a quadratic function of tariffs as follows:

$$U_1(t_1, t_2) = C_{11}C_{21} = \frac{(1+t_1)B_1^2}{A_1A_2} \quad (2.2.7)$$

$$U_2(t_1, t_2) = C_{12}C_{22} = \frac{(1+t_2)B_2^2}{A_1A_2} \quad (2.2.8)$$

The welfare of each country $U_i(t_1, t_2)$ depends on the trade instrument $\tau = (t_1, t_2)$, which specifies the tariffs imposed by the country itself and its trading partner.

The welfare under multilateral free trade where both countries impose zero import tariffs can be obtained by substituting $\tau = 0$ into equation (2.2.7) and equation (2.2.8):

$$U_1^F = \frac{1}{4}(1 + \gamma - \mu)^2 \quad (2.2.9)$$

$$U_2^F = \frac{1}{4}(1 - \gamma + \mu)^2$$

If no trade occurs, both countries only consume their own resources and receive welfare under autarky:

$$U_1^A = e_{11}e_{21} = \gamma(1 - \mu) \quad (2.2.10)$$

$$U_2^A = e_{12}e_{22} = \mu(1 - \gamma)$$

Subtracting both U_1^A and U_2^A in equation (2.2.10) from U_1^F and U_2^F in equation (2.2.9) yields the same result $(\gamma + \mu - 1)^2 / 4 > 0$. It shows that both countries benefit from multilateral free trade. Although, a large country has the power to use tariffs to improve the terms of trade.

Trade policy is expressed as $\tau = (t_1, 0)$ when country 1 unilaterally imposes an import tariff. Such a tariff is set to maximise its welfare (2.2.7). The first-order condition is obtained:

$$\left. \frac{\partial U_1}{\partial t_1} \right|_{t_2=0} = - \frac{(1 + \gamma - \mu)^2 (t_1 (t_1 + 2) (\gamma - 1) (\mu - 2) - 2(\gamma + \mu - 1))}{(t_1 - t_1 \gamma + 2)^2 (t_1 (\mu - 2) - 2)^2} = 0 \quad (2.2.11)$$

which gives rises to the optimum tariff rate:

$$t_1|_{t_2=0} = \frac{\mu(1 + \gamma)}{\Omega_1} - 1 \quad (2.2.12)$$

where $\Omega_1 = \sqrt{(\gamma^2 - 1)(\mu - 2)\mu}$.⁹ The optimum tariff rate is positive when $\gamma > 1 - \mu$, in which case the endowment is at the southeast of the diagonal in Figure 2.1, and county 1 has a comparative advantage in good 1 thus exports good 1 and imports good 2 with an import tariff t_1 . If $\gamma < 1 - \mu$, the optimum tariff t_1 is negative.

The welfare is then obtained by substituting (2.2.12) and $t_2 = 0$ into (2.2.7), which yields:

$$U_1^D = \frac{1}{2} (1 + U_1^A - \Omega_1) \quad (2.2.13)$$

In the meantime, if country 2 passively pursue free trade, it obtains welfare:

⁹ Another solution to the quadratic is $t_1 = -1 - \mu(1 + \gamma)/\Omega_1$, which is always negative. In the case of country 1 imports good 2, a negative t_1 indicates an import subsidy, which worsens the country's terms of trade, and therefore is not considered as an optimum trade policy.

$$U_2^C = \frac{1}{2} \left(U_2^A + \frac{(-1 + \gamma - \gamma\mu)\Omega_1}{(-2 + \mu)(1 + \gamma)} \right)$$

If country 2 is the one that unilaterally deviates from free trade, the tariff it imposes can be derived from its welfare maximisation problem with the condition $t_1 = 0$.

$$\left. \frac{\partial U_2}{\partial t_2} \right|_{t_1=0} = - \frac{(1 - \gamma + \mu)^2 (t_2 (2 + t_2) (-2 + \gamma) (-1 + \mu) - 2(-1 + \gamma + \mu))}{(-2 + t_2 (-2 + \gamma))^2 (2 + t_2 - t_2 \mu)^2} = 0$$

$$t_2|_{t_1=0} = \frac{\gamma(1 + \mu)}{\Omega_2} - 1$$

where $\Omega_2 = \sqrt{(\mu^2 - 1)(\gamma - 2)\gamma}$.¹⁰ It is positive when $\mu > 1 - \gamma$, in which case country 2 exports good 2 and imports good 1 with an import tariff t_2 . In the other case when $\mu < 1 - \gamma$, t_2 is negative.

The welfare for each country, in this case, obtain as:

$$U_1^C = \frac{1}{2} \left(U_1^A + \frac{(-1 + \mu - \gamma\mu)\Omega_2}{(-2 + \gamma)(1 + \mu)} \right) \quad (2.2.14)$$

$$U_2^D = \frac{1}{2} (1 + U_2^A - \Omega_2)$$

The figure below compares welfare levels for the two countries based on their respective trade policies.

¹⁰ Another root is $t_2 = -1 - \gamma(1 + \mu)/\Omega_2 < 0$, and it is dropped from the solution of optimum trade policy for the same reason as in footnote 8.

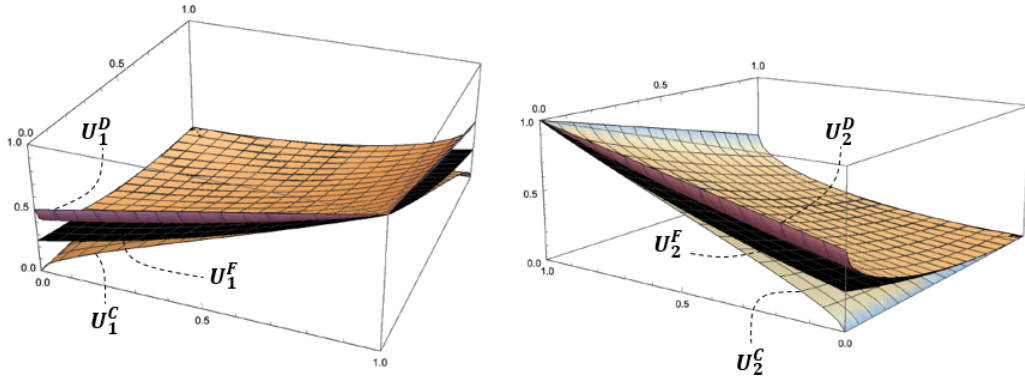


Figure 2.2 Welfare Comparisons

Since welfare is determined by the endowment size of two goods, it is displayed in a three dimensional graph. The three planes, from the top to bottom, depict the welfare of deviation, free trade and being cheated in both countries. It appears to show that unilaterally departing from a free trade agreement benefits a country since welfare is higher under unilateral deviation than under multilateral free trade. As a result, there are incentives for a country to implement tariffs to improve its welfare. However, the welfare of the country being cheated is lower than it would be under free trade, and therefore, it is likely that the cheated country will retaliate with a tariff in turn. It is worth noting that there is no trade when a country is endowed with identical amount of good 1 and good 2 since it is assumed that the relative endowment size determines comparative advantage, thus trade. Retaliation triggers a tariff war, which is the non-cooperative Nash Equilibrium in this model. In this NE, two countries both charge an optimum import tariff to maximise their own welfare.

Taking the other country's trade policy as given, the tariff rate chosen by each country is aimed at maximising welfare (2.2.7) and (2.2.8). Both U_1 and U_2 are functions of t_1 and t_2 . Therefore in the Nash equilibrium, which determines the optimal solution in a non-cooperative game, each country maximises its individual payoff assuming the other country keeps its strategy unchanged. The Nash equilibrium trade policies for two countries are obtained by solving $\partial U_1 / \partial t_1 = 0$ and $\partial U_2 / \partial t_2 = 0$ as simultaneous equations.

$$t_1^N = \frac{\gamma - 1 + \sqrt{\mu - \gamma\mu}}{1 - \gamma}, \quad t_2^N = \frac{\mu - 1 + \sqrt{\gamma - \gamma\mu}}{1 - \mu} \quad (2.2.15)$$

Both t_1^N and t_2^N are positive when the endowment sets satisfy $\gamma > 1 - \mu$, in which case country 1 imports good 2 using an import tariff t_1^N and country 2 imports good 1 with an import tariff t_2^N . When $\gamma < 1 - \mu$, country 1 exports good 2, country 2 exports good 1 and the both the tariffs are negative. Such optimum tariff rates vary inversely with foreign export supply elasticity as shown in Corden (1997) and validated by Broda et al. (2008). Welfare under a tariff war (interior NE) for each country are obtained by substituting the (2.2.15) into the (2.2.7) and (2.2.8), respectively:

$$U_1^N = -\frac{(-1 + \mu)\sqrt{U_2^A}(\gamma + \sqrt{U_1^A})^2}{\Phi_i\Phi_j}, \quad U_2^N = -\frac{(-1 + \gamma)\sqrt{U_1^A}(\mu + \sqrt{U_2^A})^2}{\Phi_i\Phi_j} \quad (2.2.16)$$

where $\Phi_i = U_i^A + \sqrt{U_i^A U_j^A} + \sqrt{U_j^A}$, $i = 1, 2$ and $i \neq j$.

A country wins a tariff war if it receives higher welfare in a tariff war than under free trade. The trade game ends up in a ‘Prisoners’ Dilemma’ if both countries lose in a tariff war, i.e., $U_i^F > U_i^N$, $i = 1, 2$. A big country with a sufficiently large endowment size always wins a tariff war, according to Kennan and Riezman (1988), whose argument is shown by the following figure.

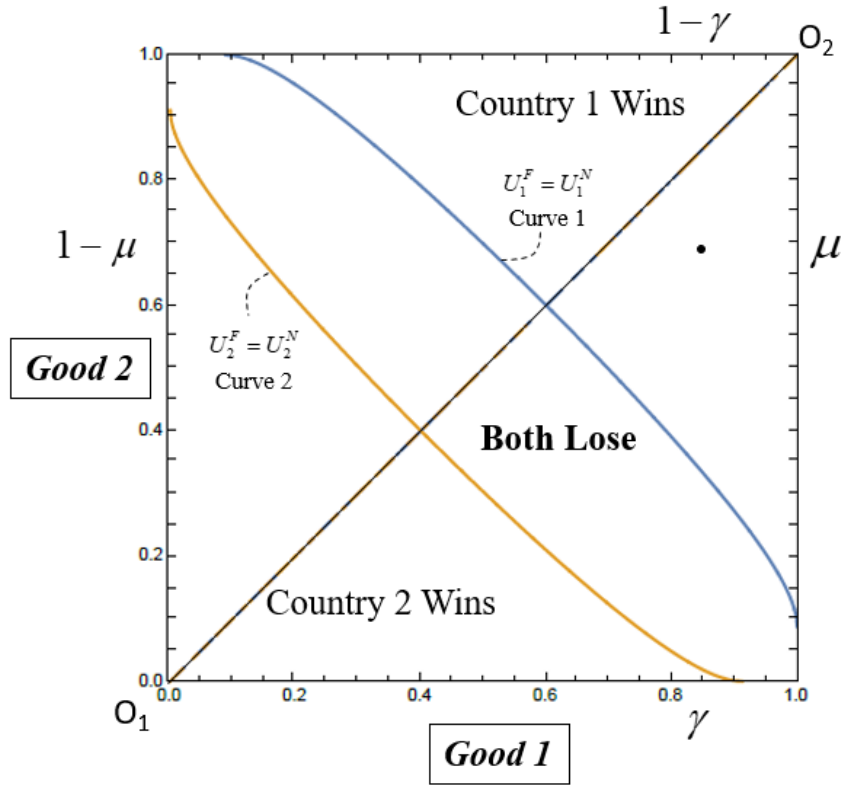


Figure 2.3 Winner and Loser in a Trade War

Curve 1 and 2 in Figure 2.3 show the sets of endowment combinations when a corresponding country is indifferent between using free trade policy and imposing tariffs. Curve 1 depicts the endowment set that allows Country 1 to receive the same amount of welfare in the interior Nash equilibrium and under free trade agreement, and curve 2 is for country 2. Any endowment sets at the northeast corner of curve 1 gives $U_1^N > U_1^F$, that is, country 1 wins the tariff war. The region to the southwest of curve 2 indicates country 2's gains from imposing tariffs. Both countries may lose the trade war if the endowment set is within the cigar-shaped area, where two countries are endowed with approximately similar relative sizes of two goods, i.e., $U_i^N < U_i^F, i=1,2$. It also implies that the two countries never gain from a trade war at the same time. It must be the case that one wins, one loses, or both lose. Imposing tariffs is a beggar-thy-neighbour policy, and a multilateral free trade policy is Pareto efficient.

2.3 Sustaining Free Trade

Since countries have incentives to impose tariffs to increase welfare unilaterally, there exist possibilities of a country triggering a tariff war. Such possibilities arise from the reality that the country being cheated can retaliate with a tariff, lowering both countries' welfare. Trade game is never a static game, and it is more realistic to have a repeated trade game. In the repeated trade game, stage game is the non-cooperative static game described in section 2.2, in which there are two players each receives payoff U_i from consumption actions. When two countries are with similar size, the outcome of the stage game is the Nash equilibrium where both players maximises their own individual payoff assuming the other player's strategy unchanged. Given the possibility that both countries may suffer as a result of a tariff war, a country that is afraid of retaliation may be willing to cooperate and continue to use free trade policy to avoid a trade war, in which case cooperation could be supported as a subgame perfect Nash equilibrium. Free trade, in this case, can possibly be self-enforced and sustained under the threat of retaliation in a repeated game. In this section, the static game in section 2.2 is played infinitely and finitely to discuss the possibility of sustaining cooperation as a subgame perfect Nash equilibrium.

2.3.1 Sustaining Free Trade in an Infinitely Repeated Game

In an infinitely repeated game, the sustainability of free trade can be examined by considering free trade policy as a form of cooperation and unilaterally implementing tariffs as a form of deviation. The Folk Theorem by Friedman (1971) states that any outcome that Pareto dominates a Nash equilibrium can be sustained as a subgame perfect equilibrium in a repeated game with sufficiently patient players. With the use of Nash reversion trigger strategies, it implies that multilateral free trade, which is efficient in a perfect competitive market, can be sustained. The sustainability will also be analysed where countries use Minimax reversion trigger strategies to minimax each other's welfare. There is a common discount factor and countries are again setting trade policies in each round of the repeated game. Players' patience is represented by the same discount factor $\delta \in (0,1)$. Each country determines its own trade policy, which may include a zero tariff and a prohibitive level that prevents trade.

In an infinitely repeated game, now consider the case when each country's strategy is to cooperate by playing free trade. Once a country deviates by unilaterally imposing an import tariff, then both countries play their interior Nash equilibrium trade policy and receive the interior Nash equilibrium welfare forever. The interior Nash equilibrium is defined as the state when both countries use their non-zero welfare maximising import tariffs. In the case of an infinitely repeated game, free trade is sustainable depending upon the discount factor when both countries use the same infinite Nash reversion trigger strategies.

A country stays free trading only if cooperation brings benefits. Using infinite Nash-reversion trigger strategies, a country receives free trade welfare U_i^F for infinite rounds if no country deviates. However, once a country deviates and uses its optimum trade policies by imposing a tariff, both countries play interior Nash policy forever. The cheating country receives welfare U_i^D in the current deviation round, which is larger than free trade welfare U_i^F and Nash tariff welfare U_i^N afterwards forever. All future welfare is discounted by the same discount factor δ . Multilateral free trade can be sustained only when the total welfare without any deviations exceeds the one with deviation for both countries, that is, when $U_i^F / (1 - \delta) > U_i^D + \delta U_i^N / (1 - \delta)$ holds for each of the two countries. It implies the lowest level of discount factors to sustain free trade: $\delta > (U_i^D - U_i^F) / (U_i^D - U_i^N)$. The critical value of discount factors for the two countries labelled as $\delta_i^{N\infty}$ is obtained as:

$$\delta_i^{N\infty} = \frac{U_i^D - U_i^F}{U_i^D - U_i^N}, \quad i = 1, 2 \quad (2.3.1)$$

which can be solved explicitly by replacing U_i^D , U_i^F and U_i^N with their solutions in section 2.

$$\delta_i^{N\infty} = \frac{1 - \phi_1^2 - 2\theta_1 + (2 - \phi_2)\phi_2}{2(1 + \phi_1 - 2\theta_2 / (\theta_3\theta_4) - \theta_1 - \phi_1\phi_2)}$$

where

$\theta_1 = \sqrt{(1-\phi_1^2)(2-\phi_2)}\phi_2$	$\theta_3 = \left(1 + \sqrt{(1-\phi_1)\phi_2}\right)\sqrt{1-\phi_2} + \sqrt{\phi_1}(1-\phi_2)$
$\theta_2 = \sqrt{(1-\phi_1)\phi_1}\left(1 + \sqrt{\phi_1(1-\phi_2)} - \phi_2\right)^2$	$\theta_4 = \sqrt{1-\phi_1}\left(1 + \sqrt{\phi_1(1-\phi_2)} + \sqrt{\phi_2}(1-\phi_1)\right)$

and $\phi_1 = \gamma$, $\phi_2 = \mu$ when $i=1$ for country 1, $\phi_1 = \mu$, $\phi_2 = \gamma$ when $i=2$ for country 2.

Only when the discount factor δ exceeds both $\delta_1^{N\infty}$ and $\delta_2^{N\infty}$, will the two countries co-operate.¹¹ A country will benefit for one round from implementing optimal trade policy, but will be penalised in subsequent rounds. Free trade is therefore sustained by the danger of reverting to interior Nash equilibrium endlessly. It is worth mentioning that the critical discount factor is less than 1 when free trade is sustained. That is, to sustain free trade, $U_i^N < U_i^F$ must hold, and both countries are worse off in the interior Nash equilibrium. If a country's critical discount factor is greater than one, i.e., $U_i^N > U_i^F$, the country gains from the tariff war and will never agree with free trade policy. Multilateral free trade can never be achieved in this case. For simplicity, I first considered the case when the endowment of good 2 for both countries is fixed, e.g. $\mu = 1 - \mu = 1/2$ and endowment set is $e = (e_{11}, e_{21}, e_{12}, e_{22}) = (\gamma, 1/2, 1 - \gamma, 1/2)$.

¹¹ If the two countries have different discount factors, both countries' discount factors are required to exceed their own critical value in order to sustain free trade, i.e., $\delta_1 > \delta_1^{N\infty}$ and $\delta_2 > \delta_2^{N\infty}$.

Figure 2.4 shows the critical discount factors for the two countries with $\gamma \in (0,1)$.

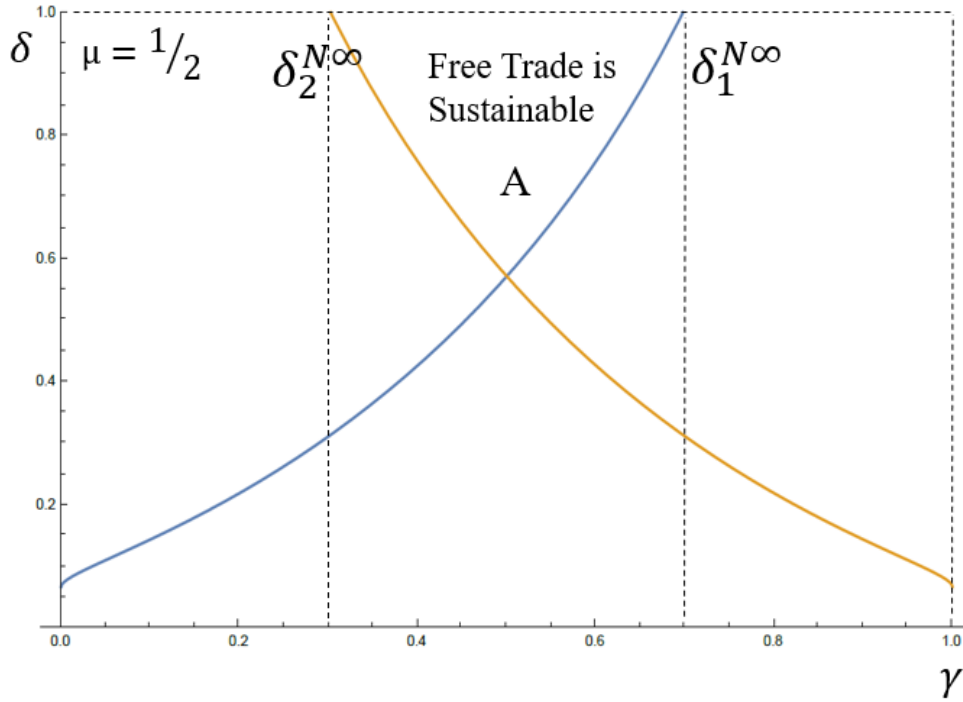


Figure 2.4 Critical Discount Factors with Infinite Nash-Reversion

It shows that both countries' critical discount factors are increasing in their own endowment of good 1 (γ for country 1 and $1-\gamma$ for country 2). Free trade is sustainable in region A when both countries' endowment sizes are similar, and when discount factors are large enough. When countries have a sufficiently big size of good 1, as seen in the left and right zones separated by dashed lines, multilateral free trade is unsustainable. If γ lies outside region A but above the two critical discount curves, only one of the two countries will choose free trade policy. This is because the country can potentially win a tariff war in the presence of retaliation due to a larger endowment size as shown in Figure 2.3. In the 'endowment egworthbox' in Figure 2.3, endowment allocations to the northeast indicates a larger endowment size of both good 1 and good 2 for country 1, in which case country 1 has a welfare gain comparing to the welfare under free trade. Hence, country 1 would never agreed to proceed cooperation. This result can be seen from the above Figure 2.4 in the region where γ is so large such that δ_1^N exceeds 1. When γ is small, country 2 has a larger endowment size in good 1 (note that country 2's endowment allocation of good 1 is represented by $1-\gamma$) and

thus country 2 would not cooperate, δ_2^N exceeds 1. Figure 2.5 shows the critical discount factors when $\mu = 1/4$ and the consulsion remains the same.

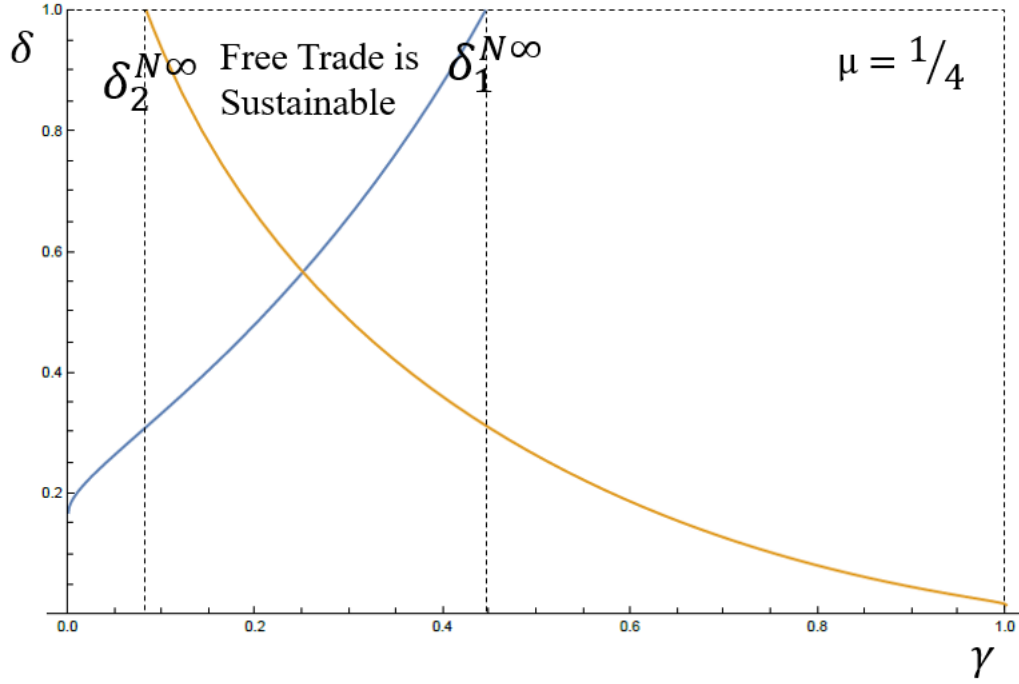


Figure 2.5 Critical Discount Factors when $\mu = 1/4$

In a constituent trade game, Dixit (1987) demonstrated that the circumstance in which two countries both implement their optimal trade policies, resulting in a tariff war, is not the only Nash equilibrium. Another Nash equilibrium occurs when both countries reduce each other's maximum welfare by applying a prohibitive tariff. In the Minimax Nash equilibrium, each country's tariff is so high that there are no gains from trade, and thus no trade occurs. Both countries receive welfare under autarky, which gives each country the lowest welfare among all trade policies. Free trade, in this case, can also be sustained by the threat of infinite reversion to the minimax Nash equilibrium that leads to autarky. If both countries use the infinite Minimax-reversion trigger strategy, each country plays free trade until the other country deviates by a prohibitive tariff. Then both countries use prohibitive tariffs and reverse into autarky afterwards forever. A country will keep cooperation only if the discounted present value of welfare under free trade exceeds the welfare from unilaterally deviating for one round followed by the welfare in the minimax Nash equilibrium forever:

$$U_i^F / (1 - \delta) > U_i^D + \delta U_i^A / (1 - \delta) \quad . \quad \text{Re-arranging the inequality yields}$$

$\delta > (U_i^D - U_i^F) / (U_i^D - U_i^A)$, which gives the critical discount factor under infinite minimax reversion:

$$\delta_i^{M\infty} = \frac{U_i^D - U_i^F}{U_i^D - U_i^A}, \quad i = 1, 2 \quad (2.3.2)$$

The explicit solutions can again be obtained by plugging the value of U_i^D, U_i^F and U_i^A in section 2 into (2.3.2).

$$\delta_1^{M\infty} = \frac{1}{2} \left(1 + \gamma - \sqrt{(1 - \gamma^2)(2 - \mu)\mu - \gamma\mu} \right)$$

$$\delta_2^{M\infty} = \frac{1}{2} \left(1 + \gamma - \sqrt{(1 - \mu^2)(2 - \gamma)\gamma - \gamma\mu} \right)$$

Each of the country's discount factor must be greater than its critical value for free trade to be sustainable. Assuming the endowment of good 2 is fixed at 1/2, Figure 2.6 shows how critical discount factors are affected by the endowment size of good 1.

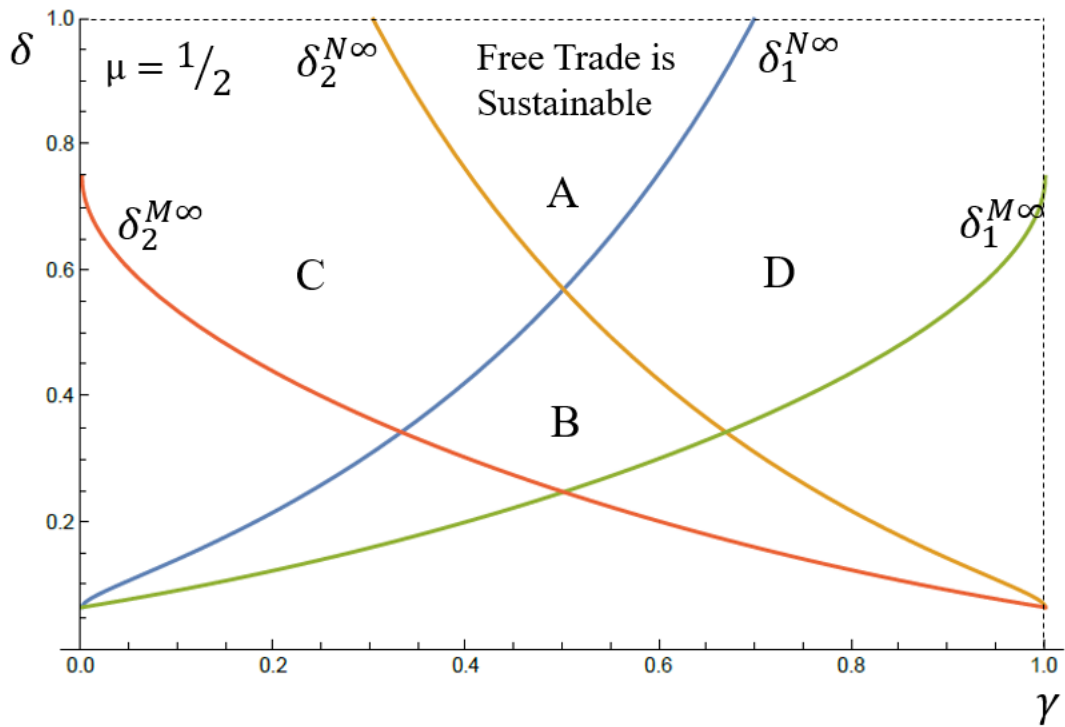


Figure 2.6 Comparison of Critical Discount Factors

Free trade is sustainable given any $\gamma \in (0,1)$, provided that $\delta > \text{Max}\{\delta_1^{M\infty}, \delta_2^{M\infty}\}$. With infinite Minimax-reversion trigger strategies, free trade is sustainable in region A, B, C and D, whereas it can only be sustained in region A with infinite Nash reversion. Since autarky is a more severe threat than the interior Nash equilibrium, cooperation proved to be more sustainable under infinite Minimax-reversion than under infinite Nash-reversion.

Asymmetries in endowment sizes show up when moving γ from the middle point where $\gamma = 1/2$ to both ends in Figure 2.4 and Figure 2.6. Further away from the centre, a larger discount factor is needed to sustain free trade. The reason is explained as a country can benefit from deviating when its endowment size is large enough compared to free trade, making it harder to sustain cooperation. Fixing country 1's endowment of good 2 at $1 - \mu = 3/4$, two countries' endowment sizes are symmetric at $\gamma = 1/4$, as shown in Figure 2.7. The comparison between two strategies and the effect of asymmetries are consistent with the case when $\mu = 1/2$.

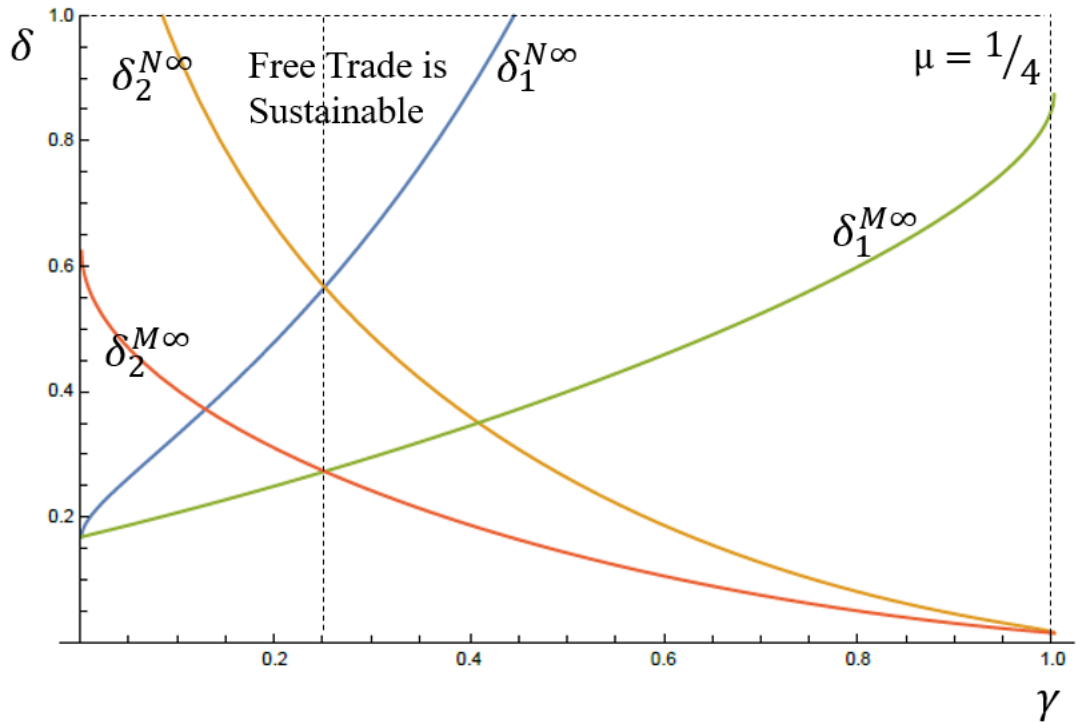


Figure 2.7 Comparison of Critical Discount Factors with $\mu = 1/4$

These results lead to the following result:

Result 2.1: *The critical discount factors δ_1 under both Nash reversion strategy and Minimax reversion strategy are increasing functions of γ , while δ_2 are increasing in $1-\gamma$. A larger discount factor is required to ensure gains when the relative size of endowment gets greater, therefore, asymmetries in endowment size make it more difficult to sustain free trade.*

Releasing the assumption that the endowment of good 2 equals half or quarter, the above results still hold. Figure 2.8 and Figure 2.9 show the sustainability of free trade with two strategies considering all the possible endowment sets.

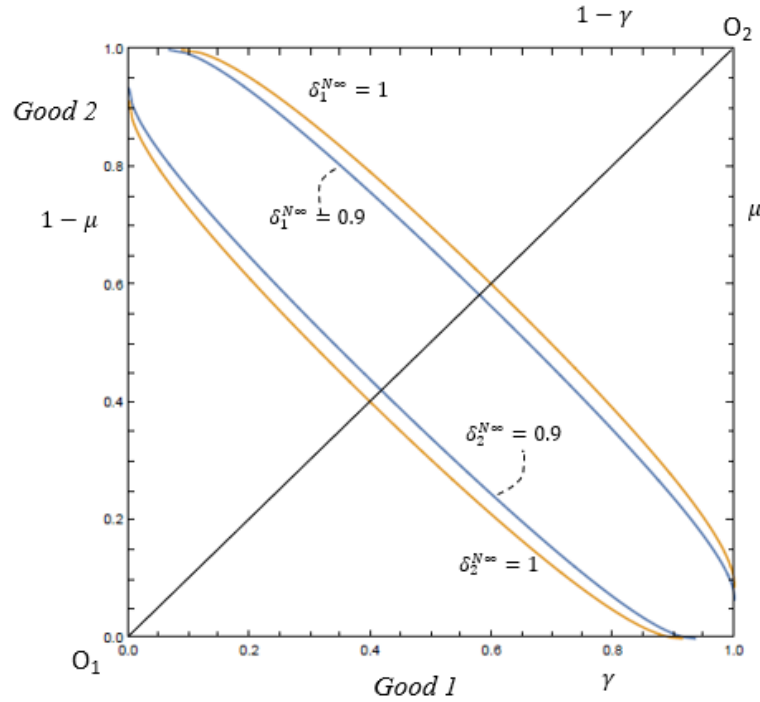


Figure 2.8 Sustainability of Free Trade under Infinite Nash-Reversion

If one of the two countries' critical discount factor exceeds one, which implies a large scale of asymmetries that make a country benefit from trade wars, multilateral free trade would never be sustained. Figure 2.8 shows the contours that countries' critical discount factors equal to 1 (outer curves) and 0.9 (inner curves). Any set of endowment vectors locates within the cigar-shaped area restrained by the outer curves (exclude those on the outer curve, which gives $\delta_i^{N\infty} = 1$) indicates critical discount

factors be smaller than one. As long as the threshold of discount factor does not exceed one, there is always scope for sustaining free trade. The only requirement is that both countries are patient enough with a large discount factor. Therefore, any endowment set inside of the cigar shaped area ensures the possibility of sustaining multilateral free trade.

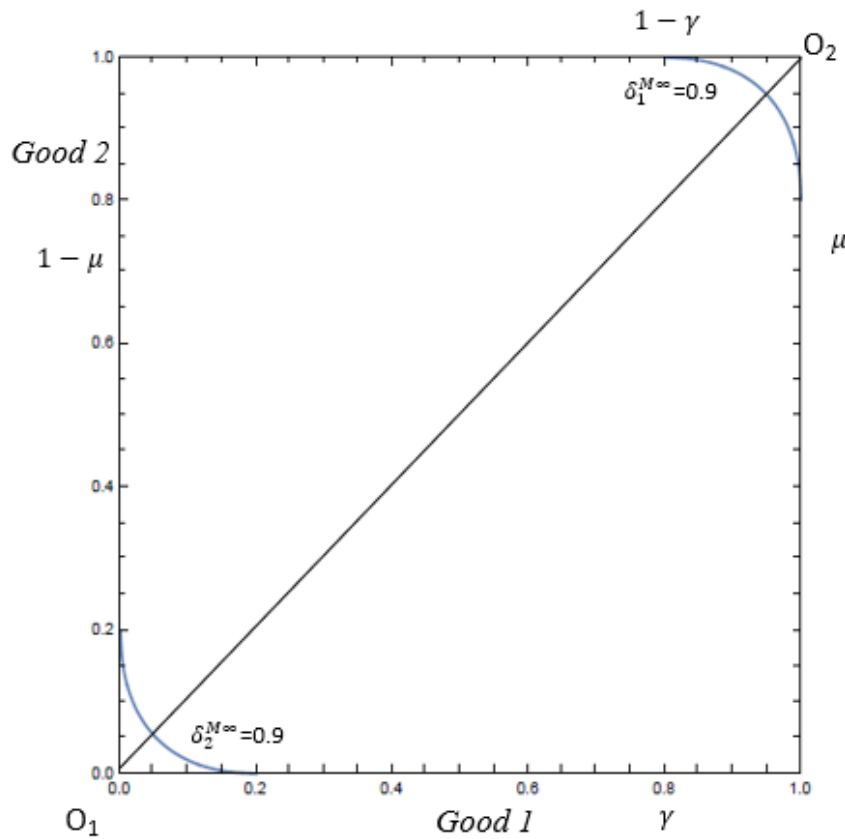


Figure 2.9 Sustainability of Free Trade under Infinite Minimax-Reversion

Figure 2.9 shows the sets of endowments vectors that can help to sustain free trade under infinite Minimax-reversion trigger strategies. As can be seen, any endowment set in the Edgeworth box gives both countries' critical discount factor to be less than a unit and therefore, free trade can possibly be sustained in the whole area of the Edgeworth box. Endowment sets on the diagonal are excluded as they imply no comparative advantage, thus no trade. When the punishment of deviating from free trade is to reverse to minimax Nash equilibrium, any endowment set that supports trade gives countries motivation to stay cooperation, and both countries will keep cooperating if they are with a sufficiently large discount factor.

Comparing Figure 2.8 and Figure 2.9, under infinite Minmax-reversion (the whole Edgeworth box in Figure 2.9), the region of endowment sets that support free trade is larger than under infinite Nash-reversion (the cigar-shaped area outlined by outer curves in Figure 2.8). Autarky turns out to be a more severe threat than the interior Nash equilibrium for both countries.

Result 2.2: *With a given endowment allocation, it is always the case that $\delta_i^{M\infty} > \delta_i^{N\infty}$. The critical discount factor, which is the highest discount factor of two individual countries required to sustain cooperation appears to be smaller with infinite Minimax reversion trigger strategies. Therefore, it is easier to sustain free trade with infinite Minimax-reversion than with infinite Nash-reversion.*

Moving along the diagonal, as shown in Figure 2.10, each country has different levels of comparative advantage, which results in differences in the volume of imports under free trade. It is worth noting that two countries are symmetric in terms of endowment size if endowments lie on the diagonal in Figure 2.10, and free trade is sustainable for a sufficiently large discount factor. This is because in a trade war, both countries suffer, and the crucial discount factors in a symmetric structure are always smaller than one. Trade volume in this paper is defined as import volume under free trade, and with symmetries, country 1's imports of good 2 equals country 2's import of good 1.

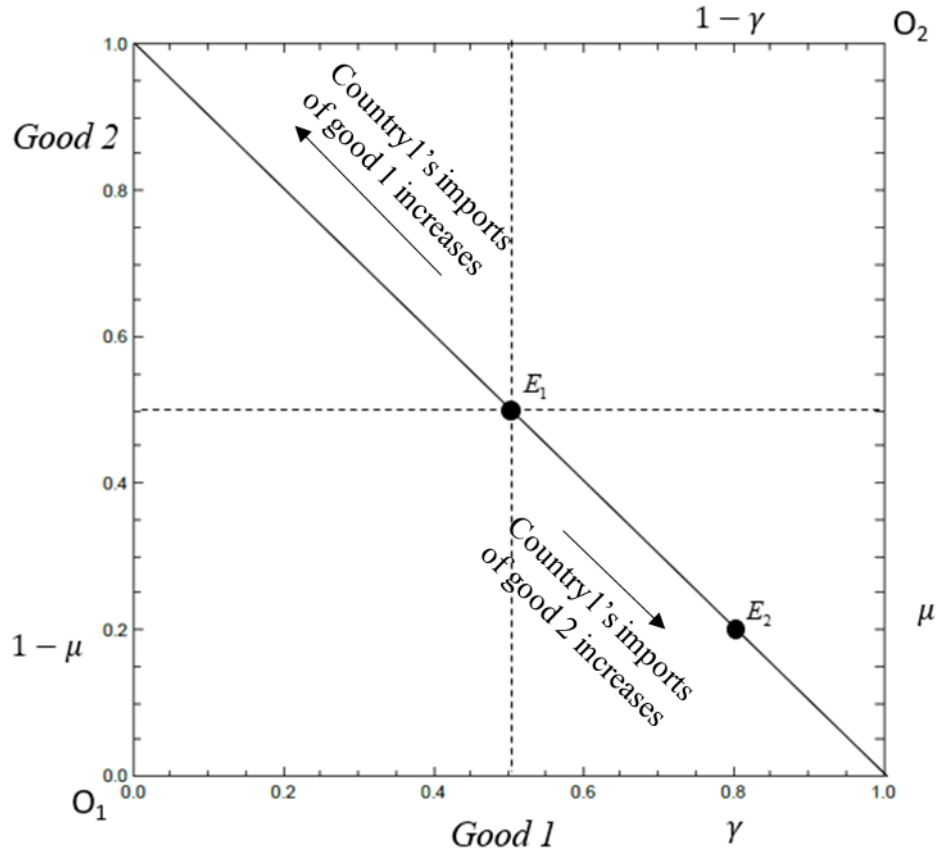


Figure 2.10 Changes in Trade Volume under Free Trade

Both countries have no comparative advantages if the endowment is at E_1 , where the world endowments of two goods are allocated equally, thus no trade occurs. Moving the endowment from E_1 towards E_2 , trade volume increases under free trade due to an increase of country 1's relative endowment of good 1 (and country 2's relative endowment of good 2) and thus country 1's import amount under free trade increases. Moving the endowment from E_1 towards the other direction where $1-\mu$ goes to 1, trade volume also experiences an increase with country 1's relative endowment of good 1 becomes smaller so that imports of good 1 becomes larger.

Assuming countries' endowment sizes are symmetric, as those on the diagonal, i.e., $\gamma/\mu=1$, the effect of trade volume on the sustainability of free trade can be analysed by plotting discount factors δ against $\gamma(\mu)$ in Figure 2.11. It is worth mentioning that critical discount factors for two countries that determined by U_i^F , U_i^A , U_i^D and U_i^N are identical with symmetric endowments. To prove it, substitute

$\gamma = \mu$ into the welfare functions under different trade policies in equation (2.2.9), (2.2.10), (2.2.13), (2.2.14) and (2.2.16), one could get the following solutions:

$$U_1^F = U_2^F = \frac{1}{4}$$

$$U_1^A = U_2^A = (1 - \gamma)\gamma$$

$$U_1^D = U_2^D = \frac{1}{2} \left(1 + \gamma - \gamma^2 - \sqrt{\gamma(\gamma - 2)(\gamma^2 - 1)} \right)$$

$$U_1^N = U_2^N = \frac{(1 - \gamma)\gamma \left(2\gamma(1 - \gamma) + \sqrt{(1 - \gamma)\gamma} \right)}{\left(\gamma - \gamma^2 + \sqrt{(1 - \gamma)\gamma} + \sqrt{(\gamma - 1)^2 \gamma^2} \right)^2}$$

The critical discount factors are then obtained and are showed in the following equation and figure.

$$\delta_1^{N\infty} = \delta_2^{N\infty} = \frac{\theta_1 (2\gamma^2 - 2\gamma - 1 + 2\theta_2)}{-2 + 2\theta_1 (\gamma^2 - \gamma + \theta_2)}$$

$$\delta_1^{M\infty} = \delta_2^{M\infty} = \frac{1}{2} (1 - \gamma - \gamma^2 - \theta_2)$$

where $\theta_1 = 1 + 2\sqrt{(1 - \gamma^2)}$ and $\theta_2 = \sqrt{\gamma(2 - \gamma)(1 - \gamma^2)}$.

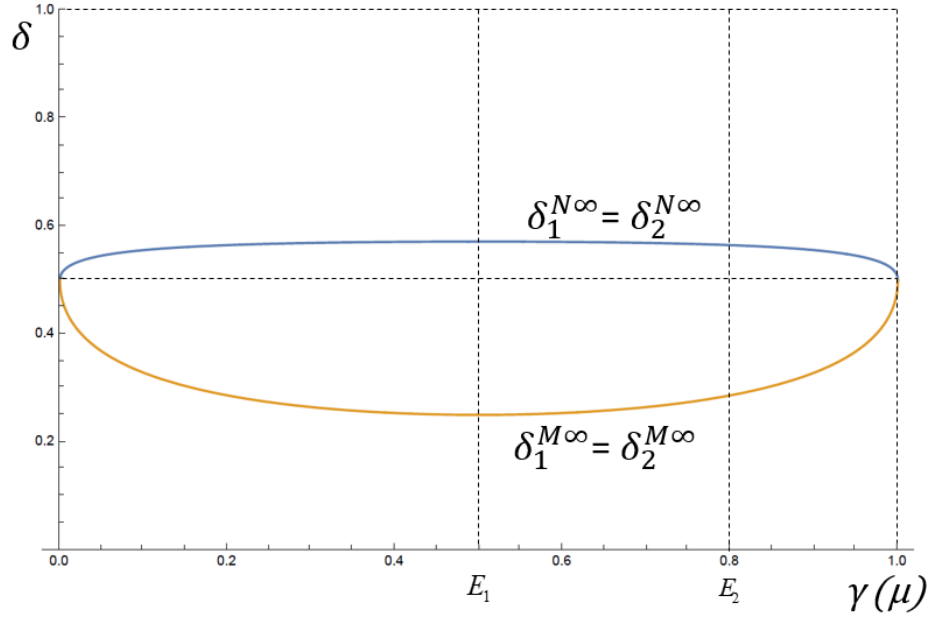


Figure 2.11 Critical Discount Factors with Symmetric Endowments

The highest value of the critical discount factor under infinite Minimax-reversion is $\delta_i^{M\infty} = 1/2$, which appears to be the lowest value under infinite Nash-reversion. With symmetric endowments, free trade is always sustainable with infinite Minimax-reversion, provided that $\delta > 1/2$. However, it is not the case when punishment is to reverse to interior Nash equilibrium. The upper curve experiences a flat trend when γ takes the values close to $1/2$, which indicates a small effect of trade volume on critical discount factors and thus on the sustainability of free trade. This is because welfare under different trade policies does not vary much when the allocation of world endowment is close to half and half. In addition, $\delta_i^{M\infty}$ decreases whereas $\delta_i^{N\infty}$ increases when moving γ from both ends towards the centre. It implies that with less specialisation, free trade is easier to be sustained under infinite Minimax-reversion. However, more difficult under infinite Nash-reversion.

Result 2.3: While $\gamma/(1-\mu)$ is an indicator of trade volume (in terms of import under free trade), the critical discount factor $\delta_i^{N\infty}$ decreases in $\gamma/(1-\mu)$, and $\delta_i^{M\infty}$ increases in $\gamma/(1-\mu)$. Therefore, the possibility that free trade could be sustained is

increasing in trade volume with infinite Nash-reversion, however, is decreasing with infinite Minimax-reversion.

Using infinite Nash-reversion and infinite Minimax-reversion trigger strategies, free trade is sustainable under the threat of being penalised for infinite rounds once a country deviates. However, the punishment that both countries stay in interior Nash equilibrium or minimax Nash equilibrium forever is not a credible and plausible punishment. Since a country is unknown about whether it can win a trade war, it is irrational for the country to deviate, knowing that an infinite punishment phase is followed. It is likely that the two countries might return to cooperation and receive a higher level of welfare under free trade if they can forget about the deviation and negotiate again in the punishment phase, where both countries suffer. In that case, punishment is less influential, provided that the two countries know renegotiation will occur. To avoid the possibility of renegotiation and make punishment effective, an alternative is to penalise countries only for a limited number of rounds. Two countries play free trade policy until one country deviates. Following deviation, two countries engage in a limited number of rounds of interior Nash equilibrium or minimax Nash equilibrium before returning to free trade. If the benefits of cooperation outweighed the benefits of deviation followed by a limited punishment, both countries would be willing to stay free trade. Whether reverse to interior NE or minimax NE depends on the strategies.

First, I consider the case when both countries use a limited number of round of Nash-reversion trigger strategies. Free trade is sustainable when the discounted welfare under free trade exceeds welfare from deviation from free trade, followed by the discounted welfare under a limited number of rounds of punishment. Such a sustainability when punishment last for one round is determined by the critical discount factors obtains from:

$$U_i^F + \delta U_i^F > U_i^D + \delta U_i^N \quad (2.3.3)$$

so that:

$$\delta > \delta_i^{N1} = \frac{U_i^D - U_i^F}{U_i^F - U_i^N}$$

Welfare under free trade must be larger than the interior Nash equilibrium welfare to sustain free trade with a limited number of rounds punishment. Otherwise, countries will prefer to be in an interior Nash equilibrium.

When the punishment phase lasts for two rounds, the welfare a country obtains under deviation must be less than benefit received under free trade for three rounds in order to sustain free trade:

$$U_i^F + \delta U_i^F + \delta^2 U_i^F > U_i^D + \delta U_i^N + \delta^2 U_i^N \quad (2.3.4)$$

The critical discount factors are derived from the above inequality by setting both sides equal:

$$\delta(1 + \delta) = \frac{U_i^D - U_i^F}{U_i^F - U_i^N}$$

Such a δ obtained from (2.3.4) is the critical value δ_i^{N2} , which is always positive when free trade is sustainable, given the gains from deviation and losses from a trade war.

One could also analyse the case when there are three rounds of punishments, when the following inequality must be satisfied:

$$U_i^F + \delta U_i^F + \delta^2 U_i^F + \delta^3 U_i^F > U_i^D + \delta U_i^N + \delta^2 U_i^N + \delta^3 U_i^N \quad (2.3.5)$$

It implies the value of δ_i^{N3} .

The critical discount factors obtained above follow that $\delta_i^{N3} < \delta_i^{N2} < \delta_i^{N1}$. With the punishment phase lasting for a longer period, the critical discount factor becomes smaller and makes it easier to sustain free trade.¹²

Instead of the interior Nash equilibrium, an autarky economy is also considered as a punishment followed by any deviations when both countries use Minimax-reversion trigger strategies for a limited number of rounds. It follows the same logic

¹² See Appendix A.1 for the detailed proof.

as when countries are using Nash-reversion trigger strategies for a limited number of rounds. To sustain free trade under one, two and three rounds of punishments, the following inequalities must be satisfied respectively:

$$U_i^F + \delta U_i^F > U_i^D + \delta U_i^A \quad (2.3.6)$$

$$U_i^F + \delta U_i^F + \delta^2 U_i^F > U_i^D + \delta U_i^A + \delta^2 U_i^A \quad (2.3.7)$$

$$U_i^F + \delta U_i^F + \delta^2 U_i^F + \delta^3 U_i^F > U_i^D + \delta U_i^A + \delta^2 U_i^A + \delta^3 U_i^A \quad (2.3.8)$$

The critical discount factors are obtained by setting both sides equal and are denoted by δ_i^{M1} , δ_i^{M2} and δ_i^{M3} . It is not difficult to prove that $\delta_i^{M1} > \delta_i^{M2} > \delta_i^{M3}$ since there are always gains from multilateral free trade. U_i^F is always greater than U_i^A . A δ that satisfy (2.3.6) surely support (2.3.7) and (2.3.8). It further proved that it is always easier to sustain free trade with a longer period of the punishment phase.

Assuming the endowment of good 2 for each country is fixed at $\mu = 1/2$. Figure 2.12 shows the critical discount factors under Nash-reversion and Minimax reversion for up to two rounds. They are also plotted in Figure 2.13 when $\mu = 1/4$.

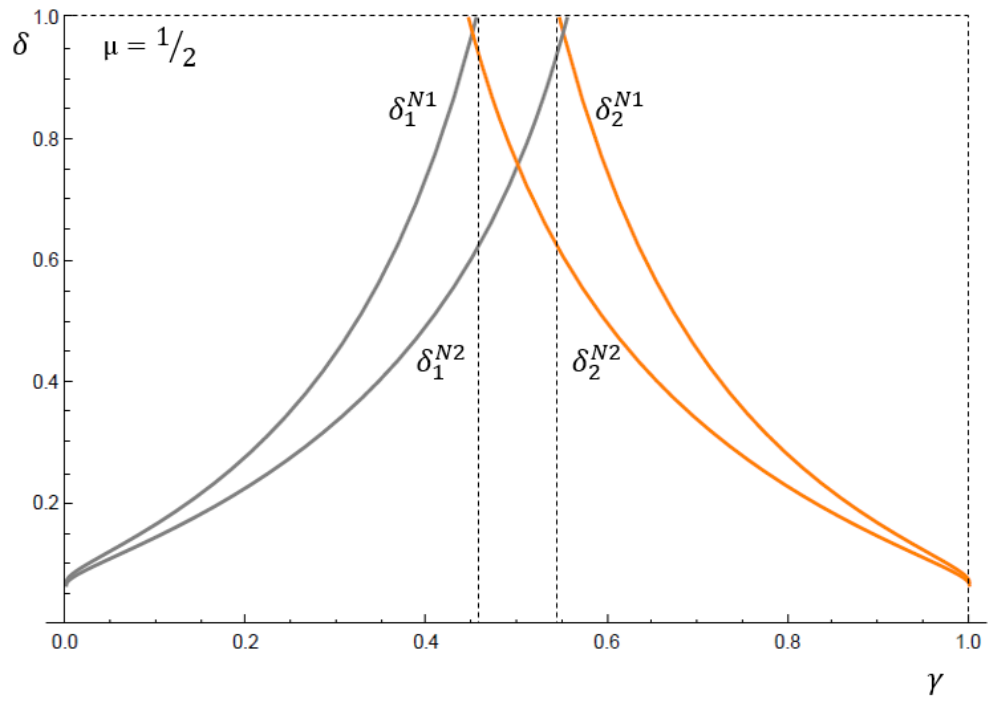


Figure 2.12 Critical Discount Factors with Nash Reversion for 1 and 2 Rounds

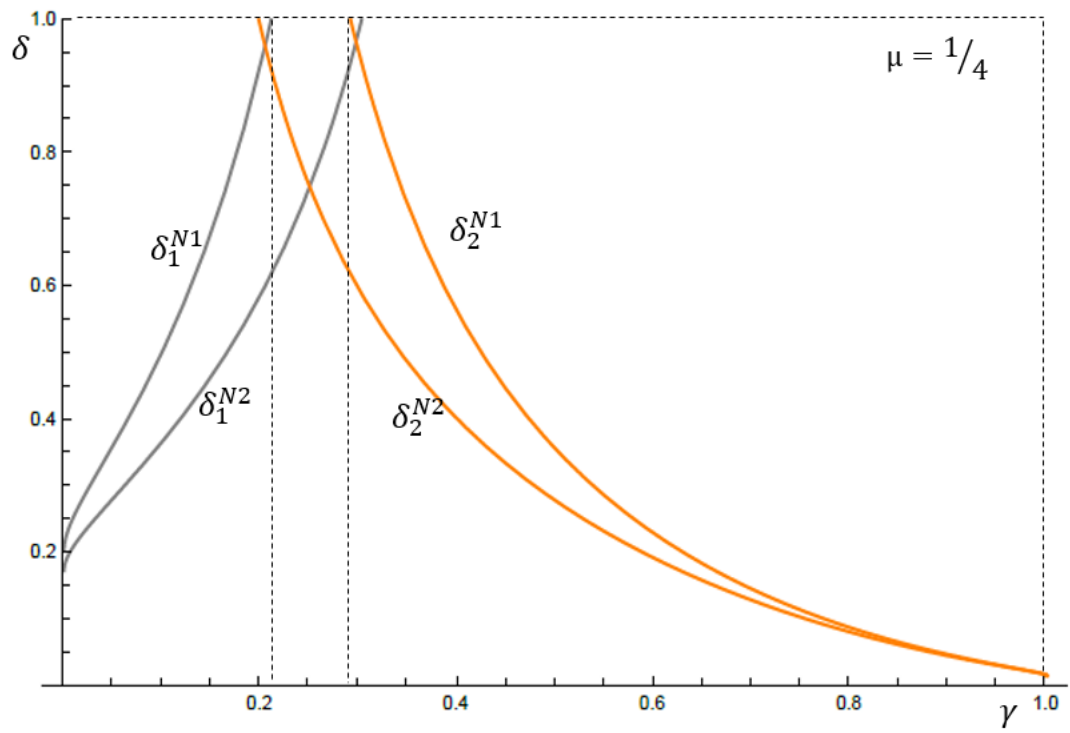


Figure 2.13 Critical Discount Factors with Nash Reversion for 1 and 2 Rounds with $\mu = 1/4$

Only when the discount factor exceeds the maximum of two countries' critical value, will free trade be sustained. As can be seen from both Figure 2.12 and Figure 2.13, there are no discount factors $\delta \in (0,1)$ satisfy the condition that $\delta > \text{Max}\{\delta_1^{N1}, \delta_2^{N1}\}$ when countries being penalised by reversing to interior Nash equilibrium for only one round. Hence, free trade is unsustainable using one round Nash reversion. Only when punishment lasts for more than two rounds, can free trade possibly be sustained, as shown in Figure 2.14 and Figure 2.15.

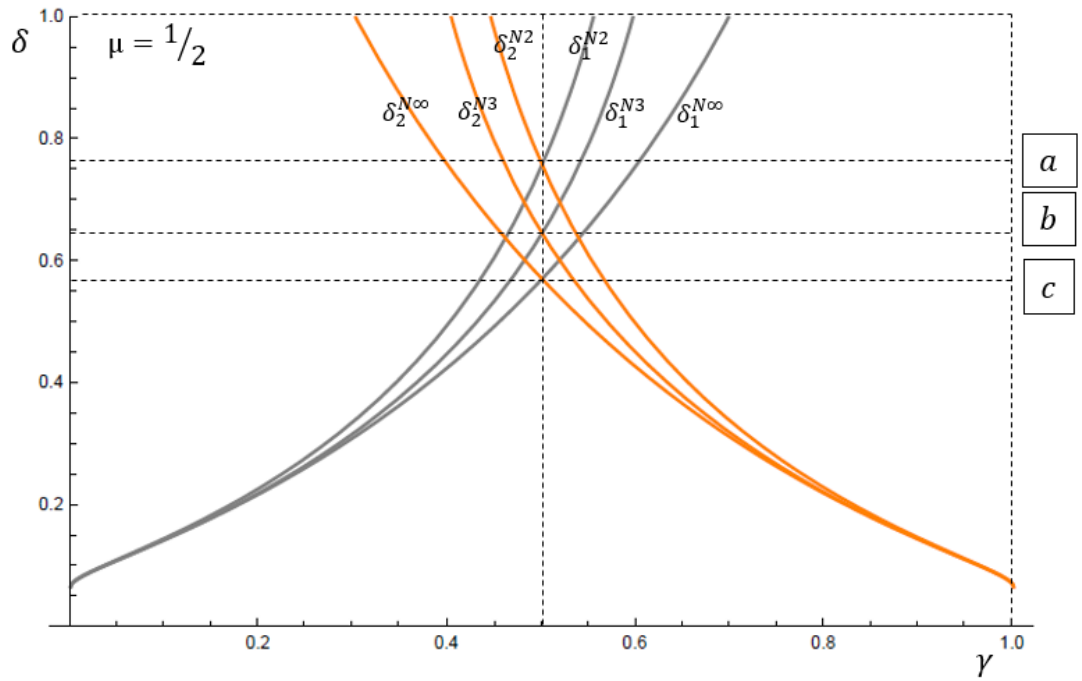


Figure 2.14 Critical Discount Factors with Limited Round of Nash Reversion

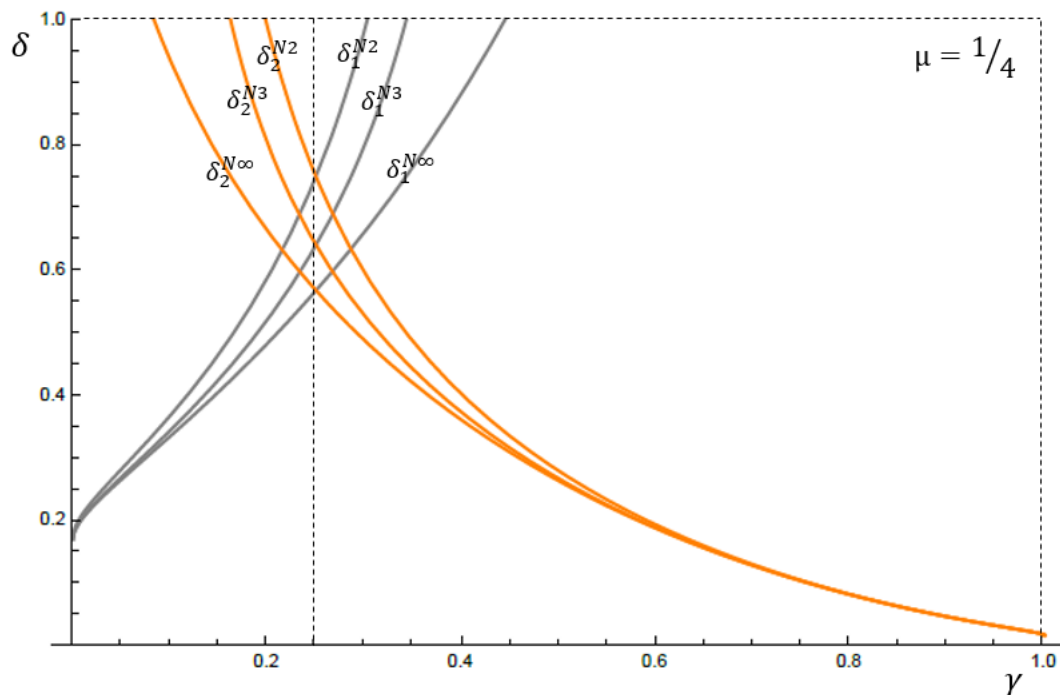


Figure 2.15 Critical Discount Factors with Limited Round of Nash reversion when $\mu = 1/4$

Whether free trade is sustainable relies on two variables: the relative endowment size and discount factors. With the same endowment allocation, the discount factors required to sustained free trade become smaller when the punishment phase lasts longer. When the strategy it to use Nash reversion for two rounds, free trade can be sustained if $\delta > a$ and endowment allocation are quite similar in Figure 2.14. $\delta > b$ is needed to sustain free trade with three rounds of punishment and $\delta > c$ when there is an infinite Nash-reversion. It is clear that $c < b < a$. Therefore, with punishment lasting longer, free trade becomes more possible to be sustained. There is a larger endowment sets that could make free trade be self-enforced.

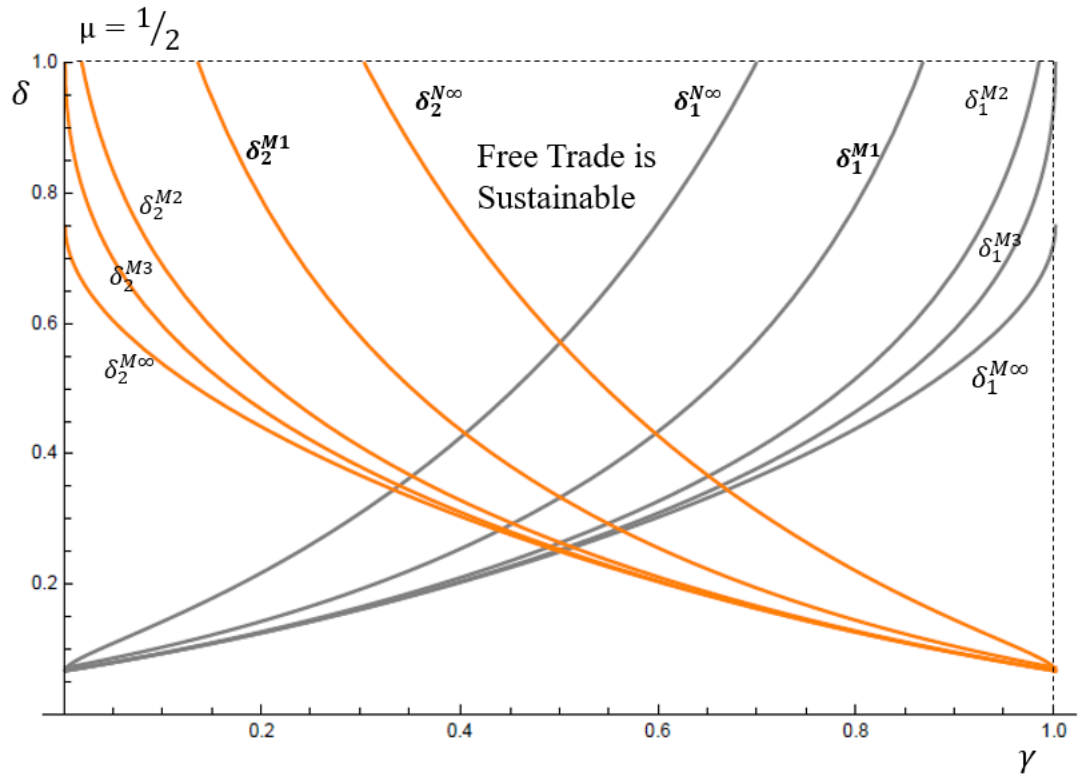


Figure 2.16 Comparisons of Critical Discount Factors

Figure 2.16 shows the region that free trade can be sustained under a limited round of Minimax-reversion. Conclusions remain the same as using Nash reversion. In addition, the area that free trade is sustainable under infinite Nash reversion is smaller than the area using minimax reversion for only one round, which demonstrates that reverting to minimax equilibrium for only one round is a heavier penalty than unlimited Nash reversion. This suggests that sustaining free trade by the threat of the minimax reversion for a limited number of rounds (presumably one round) followed by a return to free trade might be the best solution. Results remain the same when μ is fixed at $1/4$ as shown in Figure 2.17.

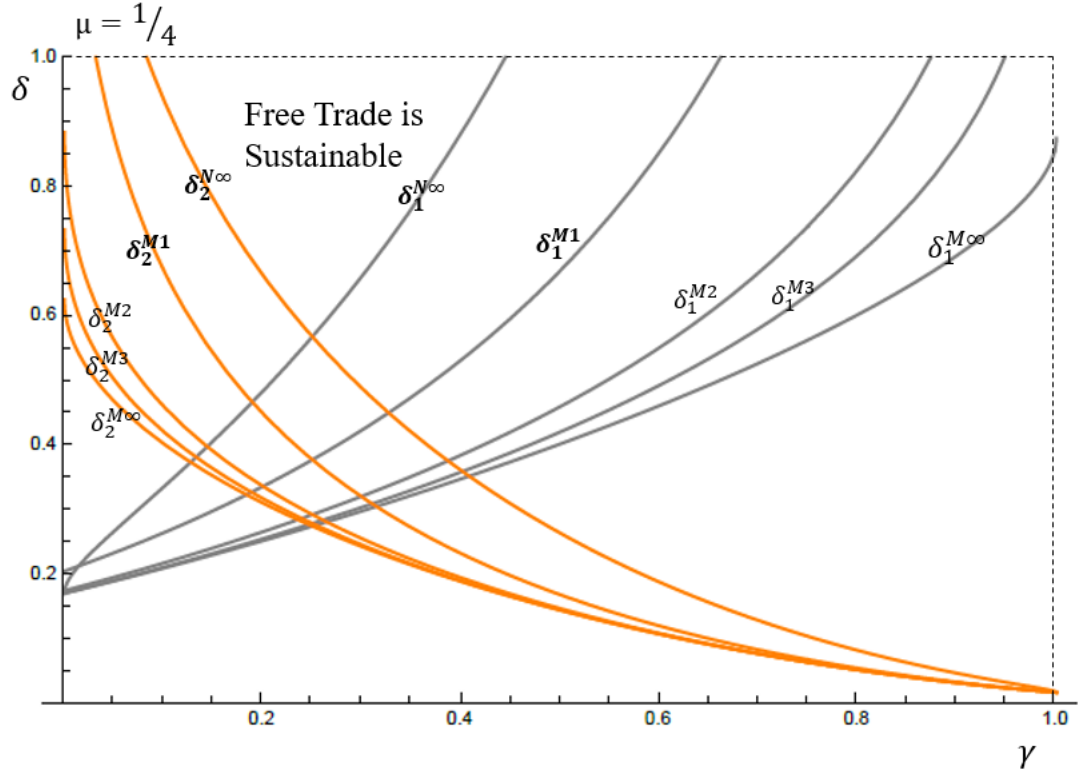


Figure 2.17 Comparisons of Critical Discount Factors when $\mu = 1/4$

Results mentioned above lead to the following result:

Result 2.4: For any endowment allocation, there is $\delta_i^{M1} > \delta_i^{N\infty}$. One round Minimax-reversion is a more severe threat than infinite Nash-reversion, and one round Nash-reversion is not severe enough to persuade countries to stay free trade.

The result can be verified with a larger endowment vectors as follow. Figure 2.18 shows the sustainability of free trade after releasing the fix endowment assumption, and results are consistent.

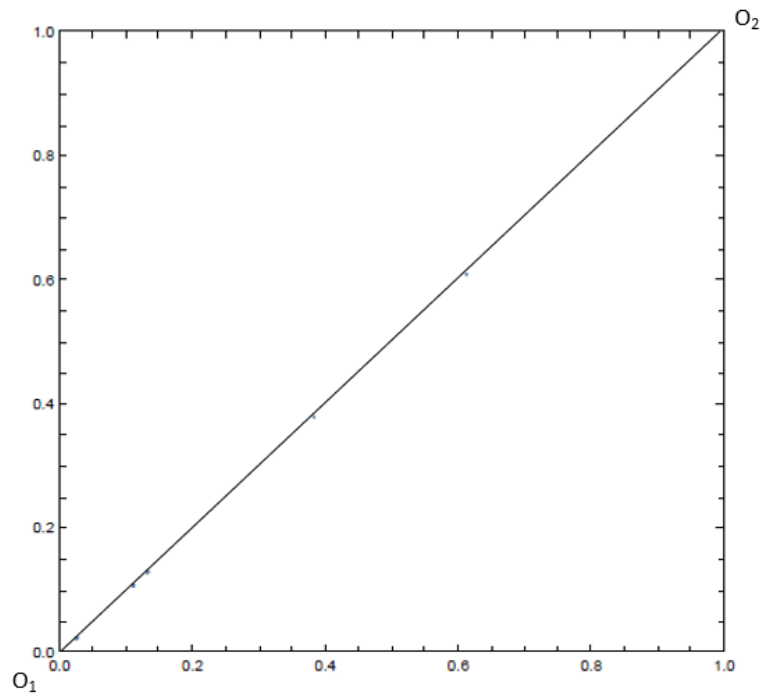


Figure 2.18(a) Sustainability of Free Trade Using Nash Reversion for One Round

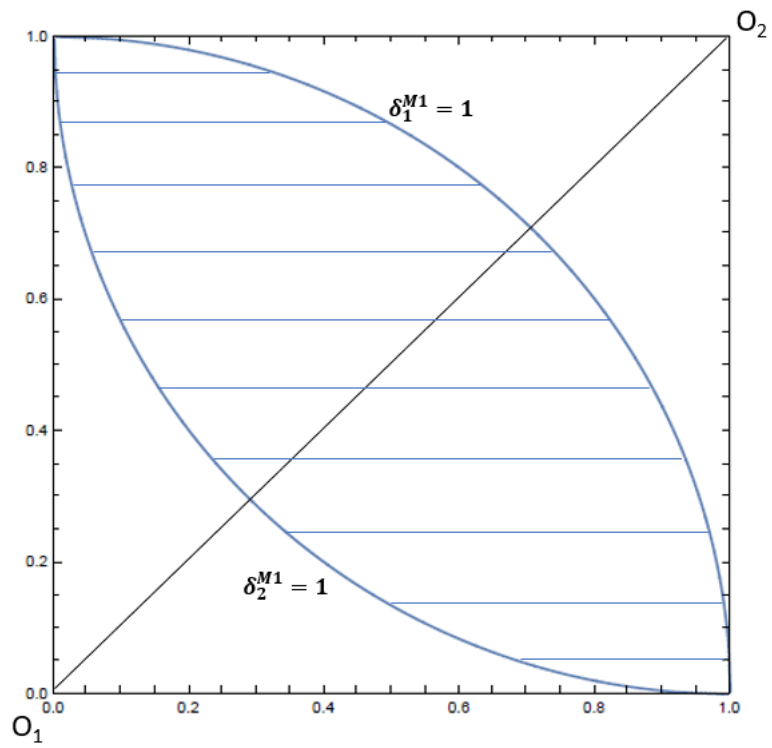


Figure 2.18(b) Sustainability of Free Trade using Minimax Reversion for One Round

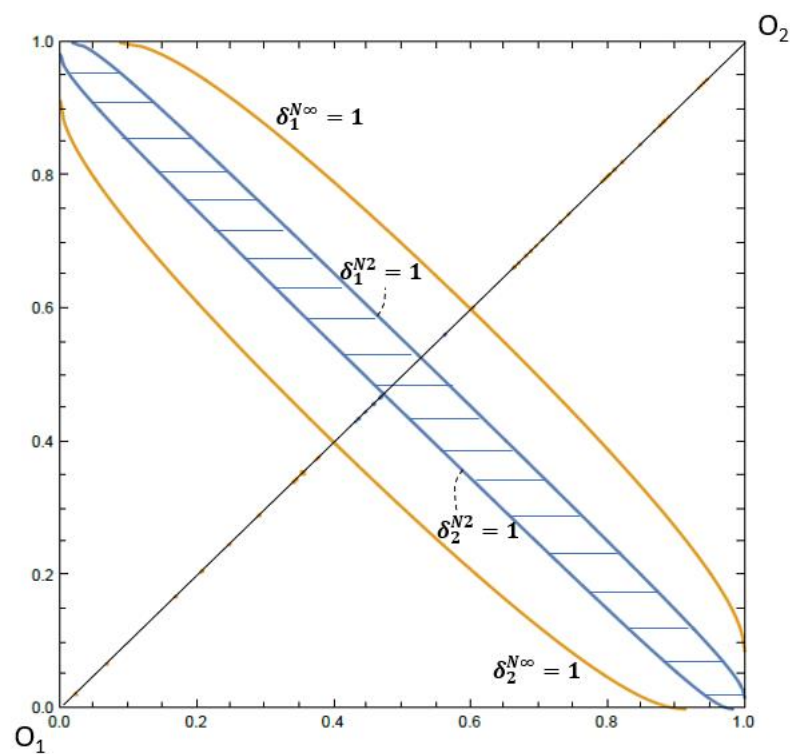


Figure 2.18(c) Sustainability of Free Trade using Nash Reversion for Two Round

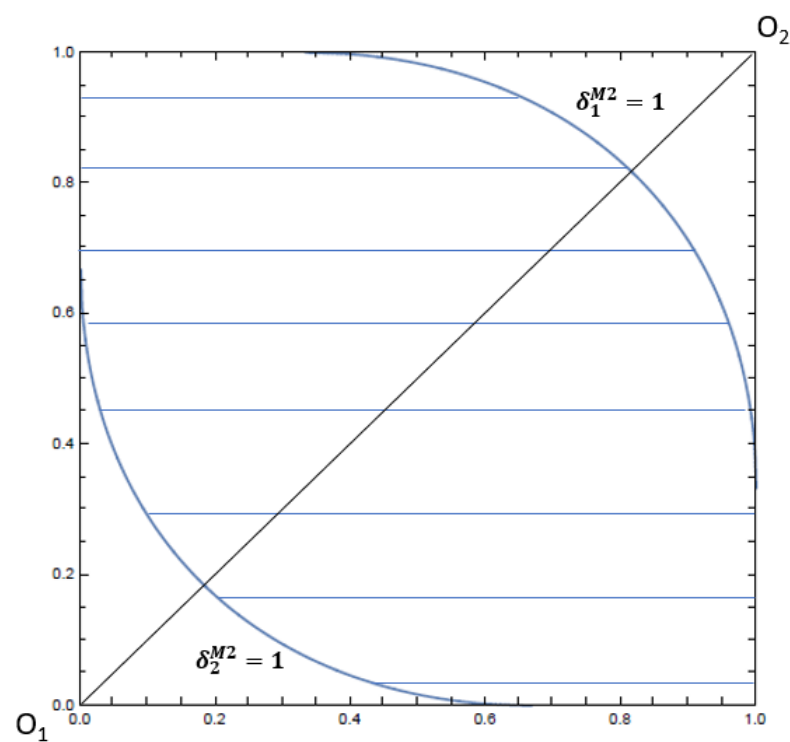


Figure 2.18(d) Sustainability of Free Trade using Minimax Reversion for Two Round

The necessary condition for sustaining multilateral free trade is that the critical discount factor be smaller than 1. With Nash-reversion for one round as shown in (a), no endowment vectors support free trade, whereas any endowments within the shaded area in (c) do. Free trade is therefore sustainable with Nash reversion for two or more rounds. The shaded area in (c) is smaller than the cigar-shaped area outlined by outer curves, which indicates that Nash reversion for a limited number of rounds is a milder punishment than an infinite Nash reversion. What's more, endowments in the shaded area in (b) and (d) help to support free trade under one and two rounds Minimax reversion. Compared to infinite Minimax-reversion in Figure 2.9 where any endowments allocation in the Edgeworth box makes free trade possible with a sufficient large discount factor, it is harder to sustain free trade with fewer rounds of punishment. In addition, the cigar-shaped area restrained by outer curves in (c) is smaller than the shaded area in (b), which implies that reverse to autarky for one round is more severe than reverse to the interior Nash equilibrium forever.

With limited rounds of punishment, effect of trade volumes on the sustainability is analysed by assuming symmetric endowment vectors ($\gamma = \mu$). Figure 2.19 illustrates how trade volume affects critical discount factors using Nash-reversion for one, two, three, and infinite rounds. In the case of one round Nash-reversion, free trade can never be sustained as shown in **Result 2.4**. δ_i^{N1} is always greater than one, hence not showing up in Figure 2.19, where δ is restricted to up to one. The critical value of discount factor is decreasing in the number of punishment rounds. Moving γ from $\gamma = 1/2$ to both $\gamma = 0$ and $\gamma = 1$, which indicates an increase in trade volume, the critical discount factor decreases. It further demonstrates **Result 2.3** that the sustainability of free trade is increasing in trade volumes with Nash-reversion, even though in this case is with Nash-reversion for a limited number of rounds.

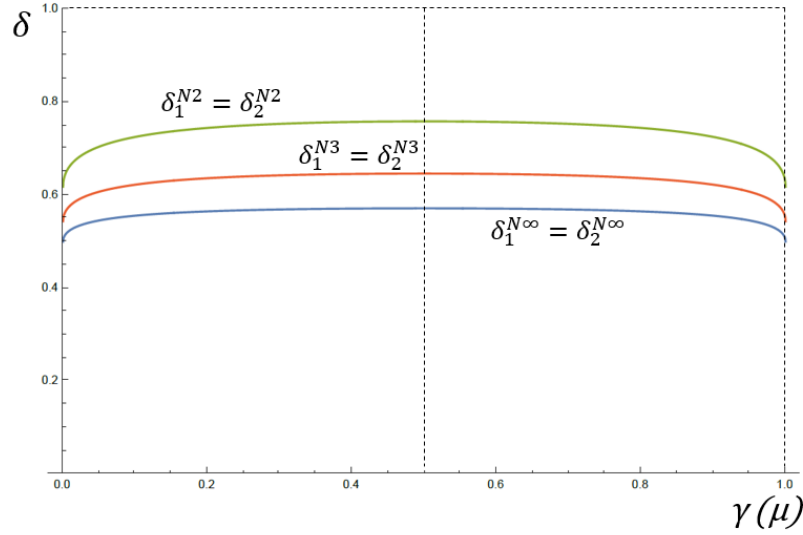


Figure 2.19 The Effect of Trade Volume under Nash-Reversion

Figure 2.20 compares critical discount factors with Minimax-reversion for a different number of rounds. When punishment lasts for only one round, it is more difficult to achieve and sustain multilateral free trade if the endowment goes to either one of the two extremes ($\gamma = 0$ or $\gamma = 1$). It appears to show that with Minimax-reversion, no matter for infinite rounds or a limited number of rounds, the sustainability of free trade is always decreasing in trade volume, which strengthened **Result 2.3**.

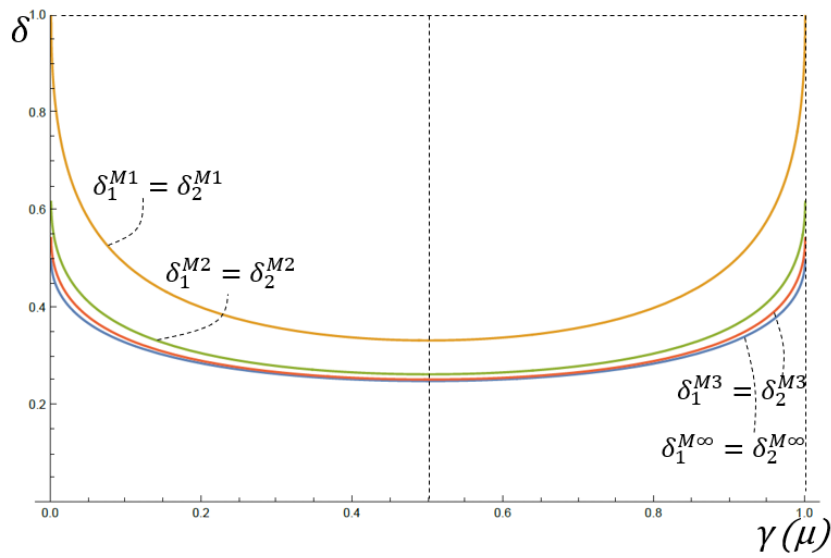


Figure 2.20 The Effect of Trade Volume under Minimax-Reversion

2.3.2 Sustaining Free Trade in a Finitely Repeated Game

In a finitely repeated game with T rounds, both countries cooperate by playing free trade policy for $T-z$ rounds and then interior Nash equilibrium for the remaining z rounds, where $z \in (1, T)$.¹³ If deviation occurs, both countries play Minimax trade policies by using prohibitive import tariffs until the end of the game. Free trade is sustainable for $T-z$ round if there are no incentives for either country to deviate at any time from the first round of the game to the $(T-z)$ th round. The incentives to deviate at each round, however, decide whether a country will diverge in the first round or in the middle of the game. The majority of the research only considers deviating at the $(T-z)$ th round, implicitly assuming that the incentives to depart increase as the game progresses. However, countries may deviate at the beginning of the game. It follows that a country has the strongest incentive to deviate from free trade at the $(T-z)$ th round only under a certain condition. The detailed proof can be seen in Appendix A.2 and A3.

Result 2.5: *In a finitely repeated game with T rounds, country i 's incentives to deviate from free trade are increasing over time, provided that $U_i^N - U_i^F < \delta^z (U_i^N - U_i^A)$. Free trade is then sustained for $T-z$ round if the country has no incentive to deviate at $T-z$ round. Otherwise, if $U_i^N - U_i^F > \delta^z (U_i^N - U_i^A) > 0$, country i has the strongest incentive to deviate at the first round of the game. Consequently, a country is more likely to deviate at the first round when z becomes larger.*

With a fixed endowment size, the following figures illustrate the significance of considering countries to deviate at the first round of the game when $T = 5$.

¹³ In this paper, z is determined exogenously. Future research could endogenize z and discuss the corresponding welfare effect.

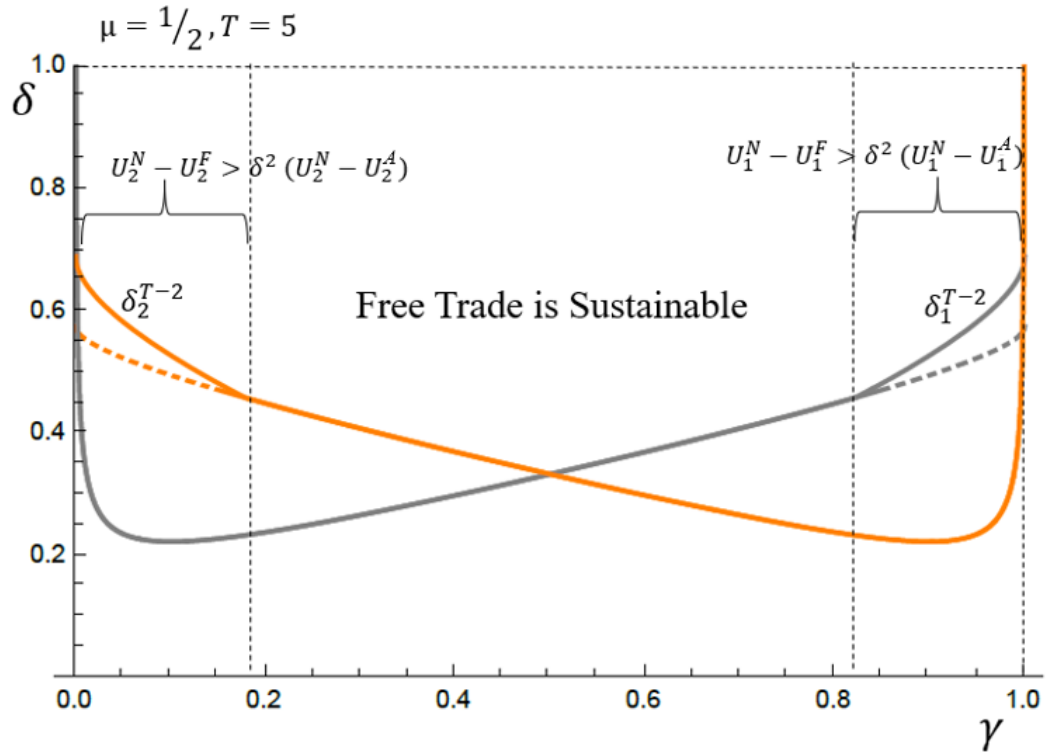


Figure 2.21 Critical Discount Factors to Sustain Free Trade for 3 Rounds

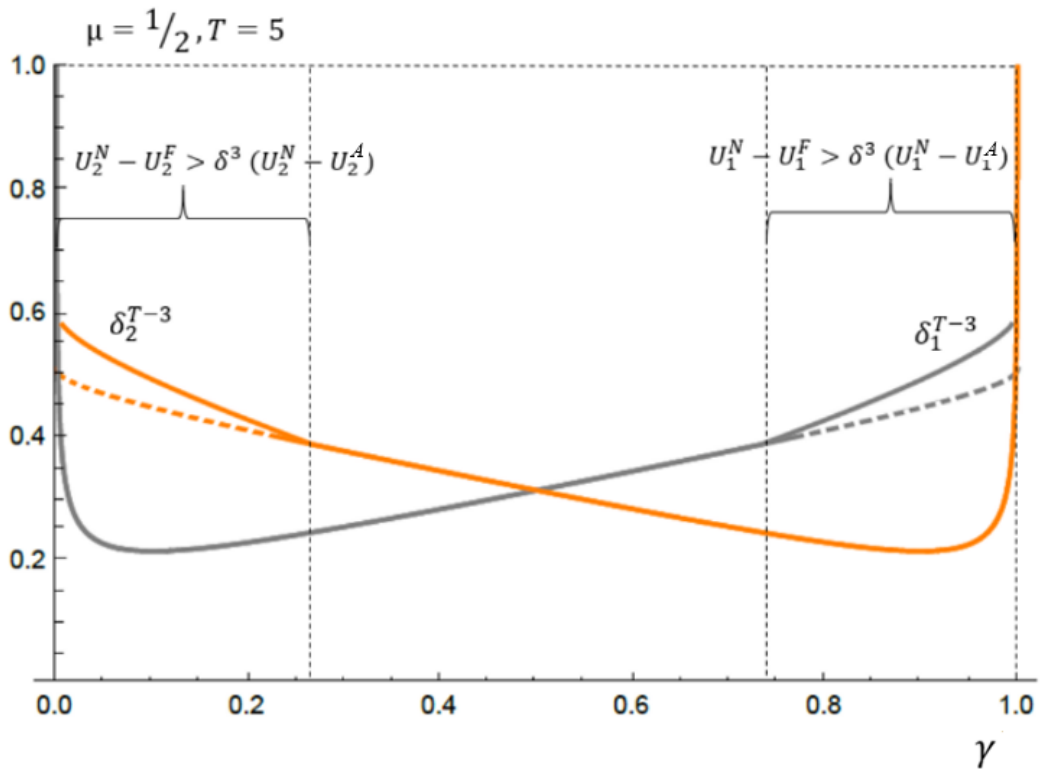


Figure 2.22 Critical Discount Factors to Sustain Free Trade for 2 Rounds

Figure 2.21 and Figure 2.22 shows the critical discount factors when free trade can be sustained for $T-2$ and $T-3$ round. In the middle region in Figure 2.21, where $U_i^N - U_i^F < \delta^2 (U_i^N - U_i^A)$ $i = 1, 2$, both countries will deviate at the $(T-2)$ th round since the incentives to deviate at that round appears to be the largest one throughout the entire game. However, such incentives to deviate at the $(T-2)$ th round, illustrated by the orange dash line and grey dash line in Figure 2.21, are lower than the incentives to deviate at first round, as shown by the solid lines, provided that $U_i^N - U_i^F > \delta^2 (U_i^N - U_i^A)$.¹⁴ The difference is significant. A country always deviates as soon as possible when the welfare under interior Nash equilibrium is sufficiently larger than the welfare under free trade policy. It is also more likely that a country will deviate at round one when free trade is sustainable for $T-3$ round than when free trade is sustainable for $T-2$ round.

To analyse the sustainability, first consider the situation that countries have incentives to deviate at the $(T-z)$ th round. To sustain free trade for the $(T-1)$ th round, each country should have no incentive to deviate at that round, which will be the case if:

$$U_i^F + \delta U_i^N > U_i^D + \delta U_i^A \quad (2.3.9)$$

The critical discount factor required to sustain free trade is:

$$\delta_i^{T-1} = \frac{U_i^D - U_i^F}{U_i^N - U_i^A} \quad (2.3.10)$$

To sustain free trade for $T-2$ round, discount factors are required to satisfy the following condition:

$$U_i^F + \delta U_i^N + \delta^2 U_i^N > U_i^D + \delta U_i^A + \delta^2 U_i^A \quad (2.3.11)$$

¹⁴ Conditions stated in result 2.5 only apply for one of the two countries. If country 1 has the strongest incentive to deviate at $T-z$ round such that $U_1^N - U_1^F < \delta^z (U_1^N - U_1^A)$, then country 2 must have $U_2^N - U_2^F > \delta^z (U_2^N - U_2^A)$. That is, it will consider deviating as early as possible.

where the critical discount factor δ_i^{T-2} is given by the solution of δ in $\delta + \delta^2 = (U_i^D - U_i^F) / (U_i^N - U_i^A)$. Similarly, free trade is sustainable for $T-3$ round if there is no incentive for either country to deviate at round $T-3$.

$$U_i^F + \delta U_i^N + \delta^2 U_i^N + \delta^3 U_i^N > U_i^D + \delta U_i^A + \delta^2 U_i^A + \delta^3 U_i^A \quad (2.3.12)$$

Setting both sides equal, the critical value of discount factor δ_i^{T-3} is obtained from $\delta + \delta^2 + \delta^3 = (U_i^D - U_i^F) / (U_i^N - U_i^A)$.

If a country has the strongest incentive to deviate at the first round, free trade can be sustained for $T-z$ round when there is no incentive for either country to deviate in the first round.

Free trade is sustainable for $T-1$ round if

$$U_i^F + \delta U_i^F + \dots + \delta^{T-2} U_i^F + \delta^{T-1} U_i^N > U_i^D + \delta U_i^A + \dots + \delta^{T-1} U_i^A \quad (2.3.13)$$

Free trade is sustainable for $T-2$ round if

$$U_i^F + \delta U_i^F + \dots + \delta^{T-3} U_i^F + \delta^{T-2} U_i^N + \delta^{T-1} U_i^N > U_i^D + \delta U_i^A + \dots + \delta^{T-1} U_i^A \quad (2.3.14)$$

Free trade is sustainable for $T-3$ round if

$$U_i^F + \delta U_i^F + \dots + \delta^{T-4} U_i^F + \delta^{T-3} U_i^N + \dots + \delta^{T-1} U_i^N > U_i^D + \delta U_i^A + \dots + \delta^{T-1} U_i^A \quad (2.3.15)$$

Critical discount factors are obtained by setting both sides equal in the above three inequalities.¹⁵ The larger critical value between the one when deviate at first

¹⁵ Critical discount factor is denoted by δ_i^{T-z} , $i=1,2$ when free trade is sustainable for $T-z$ round. If there is no subscript i on δ as shown in (2.3.13), (2.3.14) and (2.3.15), the superscript represents power.

round and when deviate at the $(T - z)$ th round will be taken as the final threshold value to sustain free trade.

Assuming $\mu = 1/2$ and $T = 5$, it is possible to solve $\delta_i^{T-1}, \delta_i^{T-2}$ and δ_i^{T-3} explicitly, which are plotted against γ in Figure 2.23.

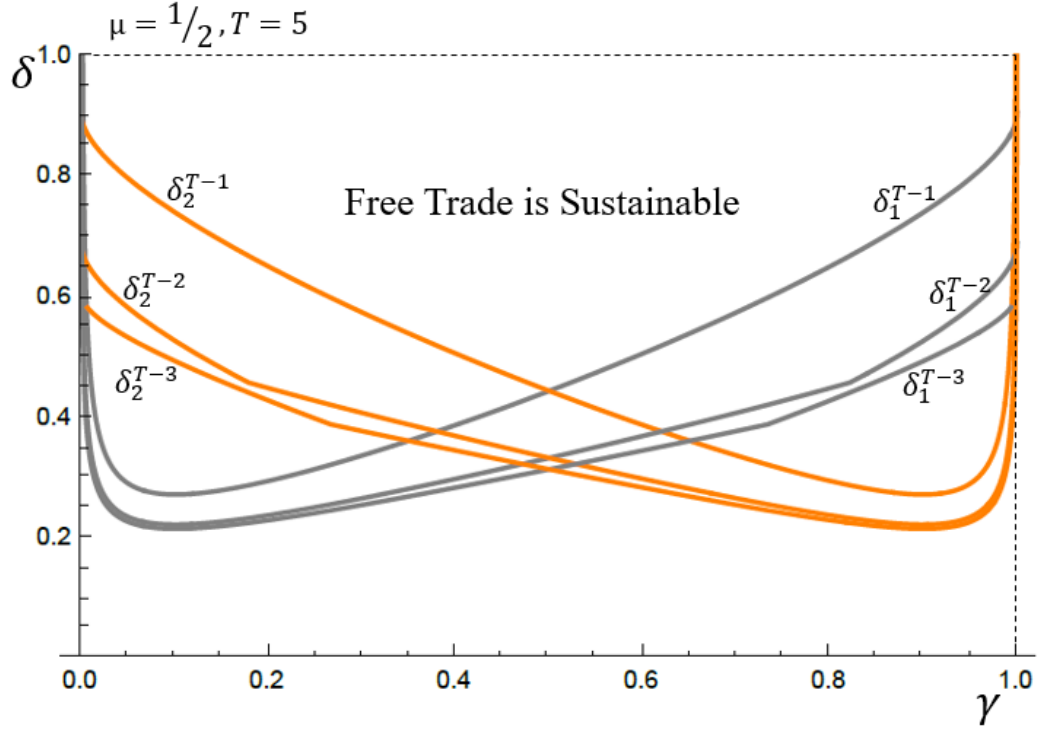


Figure 2.23 Critical Discount Factors in a Finitely Repeated Game

Any discount factor δ that is greater than $\text{Max}\{\delta_1^{T-z}, \delta_2^{T-z}\}$ support sustain free trade for $T - z$ rounds. Figure 2.23 suggests that the critical discount factor is decreasing in z .¹⁶

Result 2.6: *In a finitely repeated game when free trade is sustainable for $T - z$ rounds, the critical discount factor δ_i^{T-z} is decreasing in z . It is always easier to sustain free trade with a longer punishment duration.*

¹⁶ See Appendix A.4 for analytical proof.

When considering the effect of z and T on sustainability when a country deviates at the $(T - z)$ th rounds, it is worth mentioning that only the welfare received in the last z rounds affects critical discount factors. T , which is the length for the game, is not influential. The middle region in Figure 2.24, where there is only one trend for discount factors given different T s, represents the case when countries have incentives to deviate at the $(T - z)$ th rounds. However, if a country has powerful incentives to deviate at the first round, both T and z matter in determining the critical discount factor. Given $z = 2$ and $z = 3$ while $T = 5$, δ_i^{T-2} is greater than δ_i^{T-3} for both countries with any γ in Figure 2.23. The effect of z is showed in **Result 2.6** . Figure 2.25 and Figure 2.26 show the effect of the total game length on critical discount factors when a country deviates in the first round. Assuming free trade is sustainable for $T - 2$ rounds, it is easier for each country to co-operate given a “shorter” game, i.e., a smaller T .

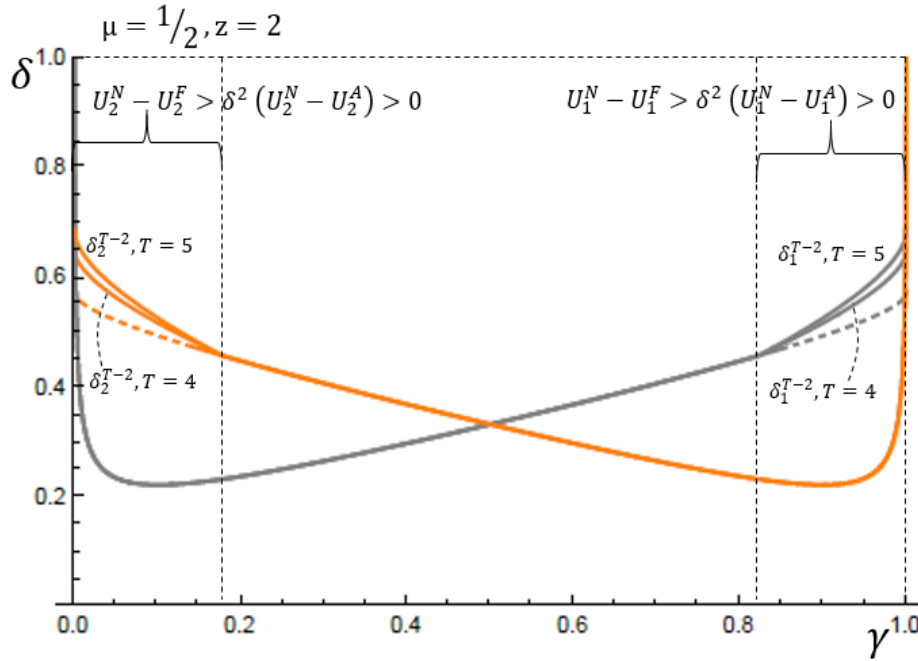


Figure 2.24 Critical Discount Factors when $z = 2$

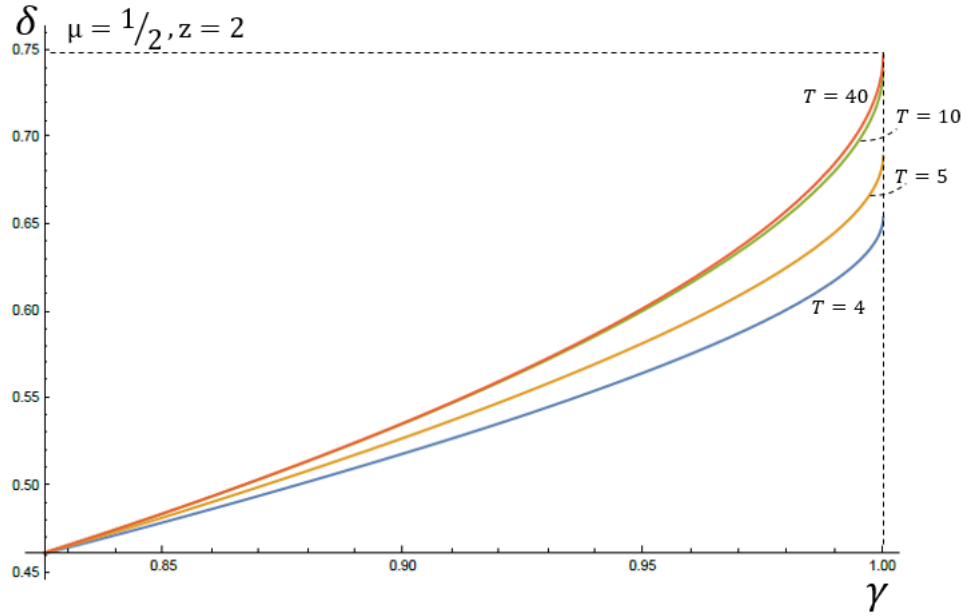


Figure 2.25 Effect of Game Length in Country 1

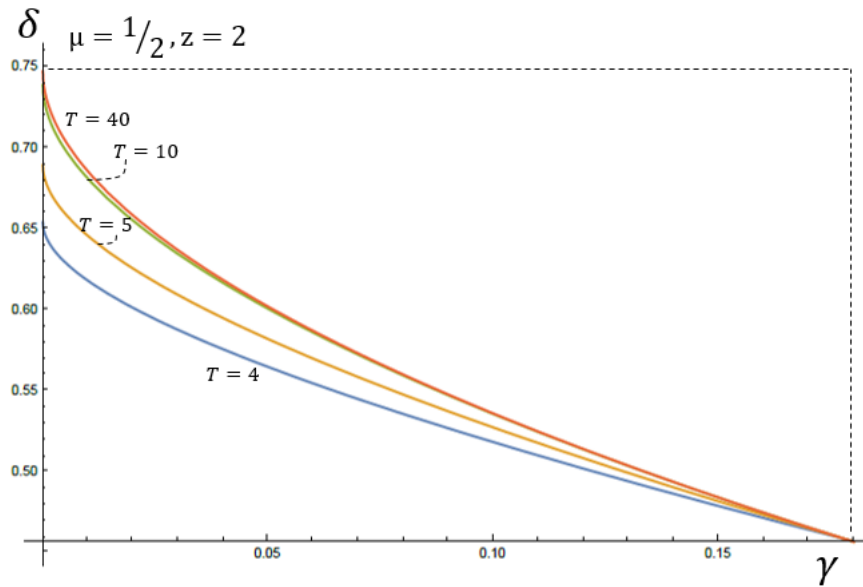


Figure 2.26 Effect of Game Length in Country 2

These results lead to the final result:

Result 2.7: In a finitely repeated game when a country considers deviating in the $T - z$ rounds, only z affects the sustainability of free trade. If a country has the strongest incentive to deviate at the first round of the game, then both T and z matter.

2.4 Conclusions

By looking at a repeated version of Kennan and Riezman (1988)'s constituent game, this paper has analysed the enforceability of a free trade agreement between two countries, where each country used either an import tariff or an export tax.

The sustainability was firstly considered in an infinitely repeated game. Free trade was sustainable with either infinite Nash reversion trigger strategies (that leads to the interior Nash equilibrium) or infinite Minimax reversion trigger strategies (which results in autarky for both countries). An infinite Minimax reversion turned out to be a more severe threat than an infinite Nash reversion. When countries were asymmetric in endowment size, free trade became more difficult to sustain than when there were no asymmetries. Using infinite Nash reversion, Cooperation was unsustainable when asymmetries were at a high level. However, it was not a problem when using infinite Minimax reversion. Free trade can always be sustained given sufficiently large discount factors. It was shown that trade volume in terms of import amount under free trade also affects sustainability when countries are symmetric. Trading amount was more effective with infinite Nash reversion than with infinite Minimax reversion, and such impacts using different strategies were opposite. Larger trade volume made free trade easier to be sustained using infinite Nash reversion, whereas using infinite Minimax reversion made it more difficult. While it was impossible for both countries to be panelised forever, infinite reversion was not a plausible strategy. In this case, reversion for a limited number of rounds was discussed. Both countries' critical discount factors gradually converge to the critical value under an infinite reversion as the punishment period increases. Although, Nash reversion was still a less severe punishment than Minimax reversion. To be more specific, it was easier to sustain free trade using one round Minimax reversion than using an infinite Nash reversion. Multilateral free trade could never be achieved and sustained if the punishment is to revert to the interior Nash equilibrium for only one round.

The enforceability of free trade was also considered in a finitely repeated game with T rounds, given that cooperation is sustainable with two Nash equilibria. It was easier to sustain free trade with a longer punishment phase. Furthermore, it was demonstrated that it would not always be the case that free trade can be sustainable for

$T - z$ round if countries are not motivated to depart during that round. Countries wanted to deviate from free trade as soon as possible when welfare in the interior Nash equilibrium was much larger than the welfare under free trade. As a result, if the welfare in interior NE was large enough, free trade was sustainable for $T - z$ round when either country has no incentive to deviate at the first round. Differences between incentives to deviate at round one and round $T - z$ was significant. When a country has the strongest incentive to deviate at the $(T - z)$ th round, only the length of the game affects sustainability, whereas both the length of the game and the length of the punishment phase matter when a country deviates at the beginning of the trade game.

This chapter did the same analyses as Collie (2019) except for the assumption over market structure and the definition of asymmetry. Asymmetry is featured as the differences in marginal cost, therefore the competitiveness of each country. In his paper under oligopoly, both countries are worse off in a trade war than under free trade when two countries are similar in terms of competitiveness, but the country with uncompetitive firm may win the trade war when the cost asymmetries are sufficiently great. Combining the results from Collie and from this paper, it shows that asymmetries play a significant role in analysing trade wars and the sustainability of trade agreements in both imperfect and perfect competition. Results from the two papers, especially those in the infinitely-repeated game, were similar, and therefore showed the robustness of the findings.

The analysis of this chapter could be extended in several directions. For example, a trade model where countries use both import tariff and export tax could be re-examined. Tariff wars could be analysed in a multi-country setting, and trade blocks could be considered. Besides Cobb-Douglas preference, consumers taste with constant elasticity of substitution are also a possible extension of this paper. With many countries, one can show the effect of the world size in terms of the number of countries on sustainability. This problem will be addressed in chapter three with an n -country n -commodity trade model.

2.5 Appendix A

2.5.1 Appendix A.1

To show that it is easier to sustain free trade with more rounds of punishment:

$$\delta_i^{N3} < \delta_i^{N2} < \delta_i^{N1}.$$

Re-arranging (2.3.3) and (2.3.4) gives rise to:

$$(U_i^F - U_i^D) + \delta(U_i^F - U_i^N) > 0 \rightarrow \delta > \delta_i^{N1} \quad (2.5.1)$$

$$(U_i^F - U_i^D) + \delta(U_i^F - U_i^N) + \delta^2(U_i^F - U_i^N) > 0 \rightarrow \delta > \delta_i^{N2} \quad (2.5.2)$$

The left side of (2.5.2) is the summation of the left side of (2.5.1) and $\delta^2(U_i^F - U_i^N)$. If free trade can be sustained with one round punishment, that is, (2.5.1) holds, then (2.5.2) must hold since $\delta^2(U_i^F - U_i^N) > 0$ for both countries. Welfare under free trade must be greater than welfare under interior NE, otherwise multilateral free trade can never be achieved. Therefore, the critical discount factor obtained from (2.5.2) is smaller than the one obtained from (2.5.1), i.e., $\delta_i^{N2} < \delta_i^{N1}$. Free trade is more sustainable when punishment phase lasts for two rounds than when it lasts for only one round.

Re-writing (2.3.5) as:

$$\begin{aligned} (U_i^F - U_i^D) + \delta(U_i^F - U_i^N) + \delta^2(U_i^F - U_i^N) + \delta^3(U_i^F - U_i^N) &> 0 \\ \rightarrow \delta &> \delta_i^{N2} \end{aligned} \quad (2.5.3)$$

Any δ satisfies the (2.5.2) can be a solution for (2.5.3), hence $\delta_i^{N3} < \delta_i^{N2}$. Critical discount factors become smaller with more rounds of punishment. Results also hold when the punishment is Minimax-reversion. Replacing all the U_i^N by U_i^A , one can prove that $\delta_i^{A3} < \delta_i^{A2} < \delta_i^{A1}$ because there are always gains from trade, i.e., $U_i^F - U_i^A > 0$.

2.5.2 Appendix A.2

To check at which round will countries deviate, we consider the situation when free trade is sustainable for $T - z$ round. To sustain co-operation for $T - z$ rounds, there should be no incentives for either countries to deviate from first round till $T - z$ round. At each round of the game, there is a critical discount factor. If both countries' discount factor δ is greater than the particular critical value, then countries have no incentive to deviate at that particular round. For countries have no incentive to deviate, discount factors are required to satisfy the following inequalities:

No incentive to deviate at $T - z$ round:

$$\begin{aligned} U_i^F + \delta U_i^N + \dots + \delta^z U_i^N &> U_i^D + \delta U_i^A + \dots + \delta^z U_i^A \\ \rightarrow \delta &> \delta_i^{t-z} \end{aligned} \quad (2.5.4)$$

No incentive to deviate at $T - z - 1$ round:

$$\begin{aligned} U_i^F + \delta U_i^F + \delta^2 U_i^N + \dots + \delta^{z+1} U_i^N &> U_i^D + \delta U_i^A + \dots + \delta^{z+1} U_i^A \\ \rightarrow \delta &> \delta_i^{t-z-1} \end{aligned} \quad (2.5.5)$$

No incentive to deviate at $T - z - 2$ round:

$$\begin{aligned} U_i^F + \delta U_i^F + \delta^2 U_i^F + \delta^3 U_i^N + \dots + \delta^{z+2} U_i^N &> U_i^D + \delta U_i^A + \dots + \delta^{z+2} U_i^A \\ \rightarrow \delta &> \delta_i^{t-z-2} \end{aligned} \quad (2.5.6)$$

...

No incentive to deviate at 2nd round:

$$\begin{aligned}
U_i^F + \delta U_i^F + \dots + \delta^{T-z-2} U_i^F + \delta^{T-z-1} U_i^N + \dots + \delta^{T-2} U_i^N &> U_i^D + \delta U_i^A + \dots + \delta^{T-2} U_i^A \\
\rightarrow \delta &> \delta_i^{t-2}
\end{aligned} \tag{2.5.7}$$

No incentive to deviate at 1st round:

$$\begin{aligned}
U_i^F + \delta U_i^F + \dots + \delta^{T-z-1} U_i^F + \delta^{T-z} U_i^N + \dots + \delta^{T-1} U_i^N &> U_i^D + \delta U_i^A + \dots + \delta^{T-1} U_i^A \\
\rightarrow \delta &> \delta_i^{t-1}
\end{aligned} \tag{2.5.8}$$

Denoting $\delta_i^{T-z} = \text{Max}\{\delta_i^{t-z}, \delta_i^{t-z-1}, \delta_i^{t-z-2}, \dots, \delta_i^2, \delta_i^1\}$, free trade is sustainable for $T-z$ round iff $\delta > \delta_i^{T-z}$. It can be proved that the above critical discount factors follow a monotone trend. Re-arranging equation (2.5.4) to equation (2.5.8):

$$U_i^F + \delta U_i^N + \dots + \delta^z U_i^N - U_i^D - \delta U_i^A - \dots - \delta^z U_i^A > 0 \tag{2.5.9}$$

$$\begin{aligned}
&(U_i^F + \delta U_i^N + \dots + \delta^z U_i^N - U_i^D - \delta U_i^A - \dots - \delta^z U_i^A) \\
&+ (\delta(U_i^F - U_i^N) + \delta^{z+1}(U_i^N - U_i^A)) > 0
\end{aligned} \tag{2.5.10}$$

$$\begin{aligned}
&(U_i^F + \delta U_i^F + \delta^2 U_i^N + \dots + \delta^{z+1} U_i^N - U_i^D - \delta U_i^A - \dots - \delta^{z+1} U_i^A) \\
&+ (\delta^2(U_i^F - U_i^N) + \delta^{z+2}(U_i^N - U_i^A)) > 0
\end{aligned} \tag{2.5.11}$$

$$\begin{aligned}
&(U_i^F + \delta U_i^F + \dots + \delta^{T-z-2} U_i^F + \delta^{T-z-1} U_i^N + \dots + \delta^{T-2} U_i^N - U_i^D - \delta U_i^A - \dots - \delta^{T-2} U_i^A) \\
&+ (\delta^{T-z-2}(U_i^F - U_i^N) + \delta^{T-2}(U_i^N - U_i^A)) > 0
\end{aligned} \tag{2.5.12}$$

$$\begin{aligned}
&(U_i^F + \delta U_i^F + \dots + \delta^{T-z-2} U_i^F + \delta^{T-z-1} U_i^N + \dots + \delta^{T-2} U_i^N - U_i^D - \delta U_i^A - \dots - \delta^{T-2} U_i^A) \\
&+ (\delta^{T-z-1}(U_i^F - U_i^N) + \delta^{T-1}(U_i^N - U_i^A)) > 0
\end{aligned} \tag{2.5.13}$$

Looking at the left side of the above inequalities, the first term of (2.5.10), (2.5.11), (2.5.12), (2.5.13) is (2.5.9), (2.5.10), (2.5.11), (2.5.12), respectively. (2.5.10)

implies (2.5.11) if the second term of (2.5.11) is positive, i.e., $(U_i^F - U_i^N) + \delta^z (U_i^N - U_i^A) > 0$. Any δ that satisfies the inequality (2.5.11) can be an answer for (2.5.12). The critical discount factor obtained from (2.5.10) is then greater than the one from (2.5.11), i.e., $\delta_i^{T-z} > \delta_i^{T-z-1}$. Otherwise, if $(U_i^F - U_i^N) + \delta^z (U_i^N - U_i^A) < 0$, then $\delta_i^{T-z} < \delta_i^{T-z-1}$. By comparing (2.5.11) with (2.5.10), (2.5.13) with (2.5.12), it can also be concluded that when $(U_i^F - U_i^N) + \delta^z (U_i^N - U_i^A) > 0$, (2.5.11) implies (2.5.10) and (2.5.13) implies (2.5.12), so that $\delta_i^{T-z-1} > \delta_i^{T-z-2}$ and $\delta_i^2 > \delta_i^1$. The critical discount factors are always monotone. The direction of the monotonicity depends on the sign of $(U_i^F - U_i^N) + \delta^z (U_i^N - U_i^A)$.

Since there are always gains from trade, welfare under interior NE is always higher than autarkic welfare. However, the comparison between welfare under free trade and in the interior Nash equilibrium is undefined. Therefore, the sign of $(U_i^F - U_i^N) + \delta^z (U_i^N - U_i^A)$ is ambiguous when $U_i^F > U_i^N$. Two cases are considered as follow:

Case 1. $U_i^F > U_i^N > U_i^A$

In this case, both $U_i^F - U_i^N$ and $U_i^N - U_i^A$ are positive. $(U_i^F - U_i^N) + \delta^z (U_i^N - U_i^A)$ is then always positive. It indicates that $\delta_i^{t-z} > \delta_i^{t-z-1} > \dots > \delta_i^2 > \delta_i^1$ and $\delta_i^{T-z} = \delta_i^{t-z}$. If welfare under free trade is greater than under interior NE, then countries have the strongest incentive to deviate at $T - z$ round.

Case 2. $U_i^N > U_i^F > U_i^A$

When welfare in the interior Nash equilibrium is higher than in free trade, $U_i^N - U_i^A$ is positive whereas $U_i^F - U_i^N$ is negative. If $U_i^N - U_i^F < \delta^z (U_i^N - U_i^A)$, we still have $(U_i^F - U_i^N) + \delta^z (U_i^N - U_i^A) > 0$, any δ that satisfy (2.5.9) can be a solution of (2.5.10) and can further be a solution of (2.5.11), (2.5.12) and (2.5.13). $\delta_i^{t-z} > \delta_i^{t-z-1} > \dots > \delta_i^2 > \delta_i^1$ still holds. Otherwise, if $U_i^N - U_i^F > \delta^z (U_i^N - U_i^A)$, critical

discount factors follow an opposite trend where δ_i^1 is the largest critical value, $\delta_i^{t-z} < \delta_i^{t-z-1} < \dots < \delta_i^2 < \delta_i^1$. Countries will always consider deviating at the first round of game, $\delta_i^{T-z} = \delta_i^1$.

2.5.3 Appendix A.3

To show that countries' incentive to deviate at the first round of the game is increasing in the length of punishment phase.

δ^z is decreasing in z since δ is always smaller than 1. When z becomes larger, i.e., punishment phase lasts longer, $\delta^z(U_i^N - U_i^A)$ goes smaller. The probability that $U_i^N - U_i^F$ is greater than $\delta^z(U_i^N - U_i^A)$ becomes larger. According to Appendix A.2, when $U_i^N - U_i^F > \delta^z(U_i^N - U_i^A)$, countries will deviate at round one. When z increases, countries are more likely to deviate as early as possible.

2.5.4 Appendix A.4

To show that the critical discount factor is decreasing in t .

Case 1. $U_i^N - U_i^F < \delta^z (U_i^N - U_i^A)$, country deviates at $T - z$ round.

Re-writing (2.3.9), (2.3.11), (2.3.12) as:

$$U_i^F - U_i^D + \delta(U_i^N + U_i^A) > 0 \rightarrow \delta > \delta_i^{T-1} \quad (2.5.14)$$

$$U_i^F - U_i^D + \delta(U_i^N - U_i^A) + \delta^2(U_i^N - U_i^A) > 0 \rightarrow \delta > \delta_i^{T-2} \quad (2.5.15)$$

$$U_i^F - U_i^D + \delta(U_i^N - U_i^A) + \delta^2(U_i^N - U_i^A) + \delta^3(U_i^N - U_i^A) > 0 \rightarrow \delta > \delta_i^{T-3} \quad (2.5.16)$$

It follows that $\delta^z (U_i^N - U_i^A)$, $z \in (1, T)$ is always positive, hence (2.5.14) implies (2.5.15) and (2.5.16), which leads to the result that $\delta_i^{T-1} > \delta_i^{T-2} > \delta_i^{T-3}$. As z increases, the critical discount factor δ_i^{T-z} decreases.

Case 2. $U_i^N - U_i^F > \delta^z (U_i^N - U_i^A)$, country deviates at round one.

Re-arranging (2.3.13), (2.3.14), (2.3.15) as:

$$\begin{aligned} U_i^F - U_i^D + \delta(U_i^F - U_i^A) + \dots + \delta^{T-2}(U_i^F - U_i^A) + \delta^{T-1}(U_i^N - U_i^A) &> 0 \\ \rightarrow \delta &> \delta_i^{T-1} \end{aligned} \quad (2.5.17)$$

$$\begin{aligned} U_i^F - U_i^D + \delta(U_i^F - U_i^A) + \dots + \delta^{T-2}(U_i^F - U_i^A) + \delta^{T-1}(U_i^N - U_i^A) \\ + \delta^{T-2}(U_i^N - U_i^F) &> 0 \rightarrow \delta > \delta_i^{T-2} \end{aligned} \quad (2.5.18)$$

$$\begin{aligned} (U_i^F - U_i^D) + \delta(U_i^F - U_i^A) + \dots + \delta^{T-2}(U_i^F - U_i^A) + \delta^{T-1}(U_i^N - U_i^A) \\ + \delta^{T-2}(U_i^N - U_i^F) + \delta^{T-3}(U_i^N - U_i^F) &> 0 \rightarrow \delta > \delta_i^{T-3} \end{aligned} \quad (2.5.19)$$

The difference between (2.5.17) and (2.5.18) is that there is an extra term $\delta^{T-2}(U_i^N - U_i^F)$ in (2.5.18). Country will only consider deviating at first round of the

game if $U_i^N - U_i^F > \delta^z (U_i^N - U_i^A)$, which implies $U_i^N - U_i^F > 0$. Hence, (2.5.18) can be implied by (2.5.17). Similarly, (2.5.19) can be implied by (2.5.18). Again, when county has strongest incentive to deviate at round 1, critical discount factors δ_i^{T-z} are still decreasing in z .

Chapter 3 : World Size, Comparative Advantage, and The Sustainability of Free Trade

3.1 Introduction

Since Johnson's pioneering work in 1953, in which he demonstrated that, despite the threat of foreign retaliation, bilateral tariff conflicts may not always result in Prisoner's Dilemma scenarios, and policymakers may face tremendous incentives to deviate from free trade on national welfare grounds, trade policy research has begun to include game-theoretical analyses in using tariffs to intervene in international trade. A government's most prevalent tactic for influencing foreign trade is imposing tariffs. Recent trade conflicts, such as the well-known US-China trade war, have re-ignited interest in international trade policy studies, which began over half a century ago. Under the assumption of perfect competition, Johnson (1953) studied trade wars in a two-country two-good exchange model. A pair of welfare-maximizing governments chose their trade policies by setting import tariffs. A large country would be willing to implement a trade tax provided there is no retaliation, as it is generally recognised that a country with market power could improve its welfare by improving its terms of trade. The improvement of one country's terms of trade, on the other side, implies a worsening of the other country's terms of trade, which is detrimental to its trading partners. As a result, the possibility of retaliation must be considered. Since both countries' trade policy decisions were affected by each other's, trade war, that was brought out by retaliation, was modelled as a Nash equilibrium in a trade policy game in Johnson's work. In such a Nash equilibrium, each country imposed its welfare-maximising tariffs given the tariff rates of the other country. The consensus was that trade wars result in Prisoner's dilemma, in which both players' welfare was worsened as compared to free trade. However, with the use of the special case of constant elasticity offer curves, Johnson (1953) proved that, even in the face of retaliation, a tariff can nevertheless benefit a country with large monopoly/monopsony power. The major characteristic of a constant elasticity form was that the optimum tariffs for each country were independent of the other country's retaliation, hence retaliation had no

effect on the optimum tariff, making Nash equilibrium easy to obtain. He demonstrated that a country is only likely to gain in a tariff war if its import price elasticity is significantly higher than that in the other country.¹ However, Johnson suggested that to satisfy the constant elasticity condition, only one model could be constructed. Gorman (1958) investigated the constant elasticity condition and showed that a wide class of indifference maps can be fitted into the framework with constant elasticity. He started with a "well-behaved" indifference map, which has indifference curves that are strictly convex, and do not cut. Then he showed that any given pair of indifference maps could be reduced to the "well behaved" kind. He also analysed numerically the issue of conditions under which countries gain from a tariff war and obtained the same results as Johnson. In addition, he discovered that trade volume is roughly three times as large under free trade as it is in the tariff equilibrium when neither good is inferior and the demand is elastic. Kennan and Riezman (1988) revisited Johnson's research by relating country welfare levels to differences in commodity endowments between countries. Using a model with identical and symmetric preferences, they analytically proved that big countries, in terms of relative endowment size, win tariff wars, and presented the result in an endowment Edgeworth box. Syropoulos (2002) used a neoclassical trade model with constant return to scale technologies and homothetic preferences to re-examine Kennan and Riezman (1988)'s work. Country size was defined as the relative number of workers provided that the per capita endowment in both countries was fixed. He generalised the result that country size benefits a country in a tariff war by analysing welfare in per capita terms.

Trade wars are also analysed in trade models with more than two countries. Kuga (1973) attempted an extension of the Johnson-Gorman analysis in an M -country, N -good world and dealt with an equilibrium of tariff policies in presence of retaliation. He began by providing a general analysis that shows the existence of a Nash equilibrium supported by retaliatory tariffs. Then he considered a numerical example of a three-country, two-good pure exchange model, in which preferences follow Cobb-Douglas form. A payoff matrix involving 27 pure strategies and a Nash equilibrium

¹ Although, plenty of figures indicate that both the U.S. and China economies suffered recessions during the trade war, and there seems to be more pain than gain for both large countries, as argued by some researchers.

involving mix strategies for at least one country were presented using a particular numerical specification. It was shown that a country might improve its position as compared with the free trade by imposing a tariff on imports, which was at the expense of some other countries. Those who were left worse off would retaliate until no country found it beneficial to change its tariff policy. Kennan and Riezman (1990) also extended the Johnson-Gorman analysis by allowing for customs unions. They considered a three-country three-good model with identical preferences and different endowment specifications, and discussed four different trading states: a multilateral free trade situation where all the three countries set zero tariffs on all imports, the Nash equilibrium when all countries use welfare maximising tariffs, a state with free trade association when two countries trade their export goods with no tariffs but charge a tariff on the third good, and a state with customs union between two of the members. By using a specific functional form for the utility function and numerically working out each country's welfare level under the above four cases, they found that all the countries become better off when moving from Nash equilibrium to a free trade association. Big customs union improves its member's welfare at the expense of the non-member country. They also confirmed that when endowment structure is symmetric, be in a Nash equilibrium always worsen a country's welfare as compared to multilateral free trade.

Bond and Syropoulos (1996) further extended the case to an N -country N -good model with identical *CES* preferences and symmetric endowment structure. This chapter follows the idea of Bond and Syropouls (1996) by using the similar endowment structure but with a Cobb-Douglas preferen. In their study, the N countries were divided into several trading blocs to analyse the connection among the size of trading blocs, market power and the world welfare. It was assumed that all the countries in the same trading bloc are identical and good one is the numéraire good in this multi-country multi-good case. The price of all the other goods was then represented in terms of good one. Each bloc exports the items in which it has a competitive advantage and imports the rest of the goods. The world is at free trade level when there is only one bloc. With the use of the inverse relationship between an optimum tariff and foreign export supply elasticity, they obtained a Nash equilibrium tariff, which is the same across all the trading blocs given the symmetric structure. It was analytically showed that trading bloc does not necessarily lead to a welfare loss.

Also, when the bloc size exceeds some absolute value, expanding bloc improves welfare as compared to the free trade level. Such a result of Nash tariff was challenged by Chang et al. (2016) in terms of the normalisation rule. Chang et al. (2016) studied a three-bloc case and showed that Bond and Syropoulos (1996)'s normalisation rule causes asymmetries in a symmetric model. When only one good is used as a numéraire, the resulting Nash tariffs in each of the three blocs differ, resulting in asymmetries. They argued that under a symmetric specification, Bond and Syropoulos (1996)'s normalisation rule only works in the model with two blocs. This result motivates this chapter to investigate the impact of world size on welfare using Bond and Syropoulos (1996)'s model structure, however a different normalisation rule that each country treats their export good as the numéraire good. This rule ensures the symmetry of the model and will be discussed in the next section.

Since most of the literature took the size of the economy in interest as given without investigating the implication of an endogenous world size on the outcome of a tariff war, Gros (1987) analysed trade policy in a monopolistic competition with identical countries and discussed the effect of the size of the economy on the optimal tariff. In an intra-industry trade model where there was only one industry producing a differentiated good with increasing returns to scale, and consumers were with *CES* preferences, he worked out the optimal tariff explicitly and showed that such an optimum tariff can be positive even with large number of small countries. The optimal tariff rate for a small country was determined by the proportional mark-up applied by monopolistically competitive manufacturers. Broda et al. (2008) showed empirical evidence that import tariff is inversely related to export supply elasticity in perfect competition, and even small countries have the market power to impose tariffs.² Broda et al. (2008) estimated elasticities of export supply faced by 15 small importer countries and used these elasticities to show that these countries set higher tariffs on products where they have more market power. To ensure the countries set tariffs in a unilateral and noncooperative way, the data of tariffs they obtained were prior to the WTO membership. It was stated in their paper that:

² Amiti et al. (2019)'s finding that there is no terms of trade effect for the US in 2018 contradicts Broda et al.(2008). Possible reasons for the contradiction include the stickiness of export prices in the short-run and the high uncertainty of the US 2018 trade policy.

‘...many economists simply assumed that most countries are small, i.e., do not have market power in trade. One of the contributions of this work is to demonstrate that this assumption is not correct...when countries are not subject to constraints such as those imposed in the WTO, they set higher tariffs on goods with lower export supply elasticities...’ (Broda et al., 2008)

Zissimos (2009) investigated the connection between the number of countries and the outcome of a tariff war in a perfectly competitive market. By introducing a North-South model of international trade, in which the number of countries varies in each region, he showed that with an increase in the number of countries, competition over trade becomes more aggressively, and countries’ terms of trade and welfare are worsened. In his paper, a world economy with N countries, that were divided into two subsets: the North and the South was considered. Each of the country produces two homogenous goods using two factors. With the use of comparative statics, he demonstrated that each government would lower its tariff to attract imports from the other region when the number of countries in its region increases. There existed a negative terms of trade externality for all countries in the expanded region, which undermined their welfare level and motivated free trade policy. However, Zissimos (2009) only discussed a static trade game, which is considered as a stage game of a repeated game in this chapter. Instead of dividing N countries to finite subsets or trade bloc, this chapter instead focuses on each individual country, and can also be seen as a special case of Zissimos (2009) game where N countries are divided into N subsets. Also, there are only 2 goods and both the South and North are exporting the same good in Zissimos (2009) while in this chapter, there exist symmetries that n countries exporting n goods with each exporting its main good.

When studying the relationship between global size and international trade, researchers look at how the number of countries affects tariff decisions and welfare, with some allowing for trade blocs and customs unions. When it comes to the sustainability of trade agreements, however, most of literature focuses on the case of only two countries. Since there are 164 countries in the WTO, analysing the effect of the number of countries on the sustainability of free trade is important. Therefore, the significance of this chapter will be to analyse tariff wars in a multi-country setting, and to explore the effect of world economy in terms of the number of countries and

the degree of comparative advantage on the sustainability of cooperation (multilateral free trade).³

Collie (2019, ETSG) analysed the sustainability of free trade in a symmetric Cournot oligopoly model with many countries and differentiated products. In his paper, countries use both import tariffs and export taxes and welfare is measured as the sum of consumer surplus, profits and government revenue. He showed that the number of countries plays an important role in affecting the sustainability of trade agreements under different trigger strategies in a repeated game where there is a common discount factor. With infinite Nash-reversion, the required discount factor to sustain trade agreement increases as the number of countries increase, whereas with infinite minimax-reversion, it becomes easier to sustain free trade as the number of countries increase. This chapter adopts the method he used in a repeated game and discusses sustaining trade agreement in the case of a perfect competition. Except for the number of countries, this chapter also points out the welfare effect of the degree of comparative advantage.

When countries are able to choose their trade policy, including the choice of zero tariffs, it will be shown that whether free trade can successfully be achieved and sustained is affected by the welfare level under different trade policies. In a perfect competition where the world is symmetric, the result of a trade policy game is always a Prisoner's Dilemma, in which countries become worse off in the Nash equilibrium (trade war) compared to free trade. Such a Prisoner's Dilemma situation could be avoided when the constituent trade policy game is infinitely repeated. This argument was demonstrated by Friedman (1971) using the Folk Theorem, which was applied by Dixit (1987). The Folk Theorem suggests that if the players are patient enough and far-sighted, any feasible and strongly individually rational outcome in the constituent game can be supported as an equilibrium outcome. For example, in the constituent Prisoners' Dilemma, there is a Nash equilibrium such that both players cooperate in the infinitely repeated version of the game, if players are sufficiently patient. Therefore, in the case of a symmetric trade policy game, free trade is possible to be sustained using the idea of the Folk Theorem. Apart from the interior Nash equilibrium, Dixit

³ For recent surveys on trade agreements see Maggi (2014), Grossman (2016), and Bagwell and Staiger (2016).

(1987) pointed out that autarky is also a Nash equilibrium in trade policy games, in which each country sets tariffs at prohibitive levels to minimise its competitor's maximum welfare and thus halts trade. In general, a country receives the lowest welfare in the case of autarky, and the minimax Nash equilibrium that leads to autarky can be seen as another threat to deviations in a repeated game. The use of autarky as a threat point was known as minimax reversion trigger strategies, suggested by Fudenberg and Maskin (1986), due to the fact that players are minimaxing each other using this strategy. Based on the fact that there are two Nash equilibria, the sustainability of free trade is further analysed in a finitely repeated game as in Benoit and Krishna (1985). If there is a unique Nash equilibrium in a finitely repeated game, the unique stage game Nash equilibrium must be played in the last round regardless of what happened in earlier rounds. In this case, cooperation is not sustainable as the outcome of the finitely repeated game will be to play the SPNE (Subgame perfect Nash equilibrium) throughout the game.

Most of the results from this chapter are consistent with those in the previous chapter when only two countries and two traded goods are considered. Welfare levels under autarky, free trade, unilateral deviation, and the interior Nash equilibrium were explicitly obtained in a pure exchange trading model when countries' endowment allocation was symmetric in chapter two. If the endowment size of one good is relatively large in a country, the country would have a comparative advantage in that good and therefore export it. Under free trade, if the relative endowment size of one good gets larger, indicating a greater scale of comparative advantage, then the country would export more of this good and the volume of trade would increase. It was shown that the trade volume helps to sustain cooperation with the use of infinite Nash reversion trigger strategies but makes it more difficult when using infinite minimax reversion in an infinitely repeated game. The trade volume in chapter two is an implication of the degree of comparative advantages, which is assumed to be the determinant of trade in this chapter. Under free trade, comparative advantage increases trade volume. When trading countries have a larger scale of comparative advantage, international trade will expand. The consistency will be verified by the finding that under infinite Nash reversion, there is a positive relationship between the sustainability of free trade and the degree of comparative advantages, but a negative relationship

under infinite minimax reversion. Comparisons between these two strategies will also be analysed in terms of the number of countries.

This chapter is organised in the following way. A symmetric multi-country model is built up in section 3.2, and the trade policy game is investigated in a constituent game. World welfare effects are analysed against the degree of comparative advantage and the world size. In section 3.3, the constituent trade policy game is investigated in an infinitely and finitely repeated version to see if cooperation (multilateral free trade) can be sustained. In an infinitely repeated game, two different trigger strategies are considered for comparisons. Conclusions are in section 3.4. Details and proofs of results are shown in the appendix.

3.2 The Model with Symmetric Countries

I consider an exchange model in which there are n countries, indexed by the subscript i , and n goods, indexed by the subscript j . Each country contains a representative consumer, whose tastes are represented by a Cobb-Douglas utility function:

$$U_i = \prod_{j=1}^n (C_{ji})^{\frac{1}{n}}, \quad i = 1, 2, \dots, n \quad (3.2.1)$$

where U_i is the utility level of the representative consumer in country i , and C_{ji} is the consumption of good j in country i . Each country i has an endowment $x(1+z)$ of good i and an endowment x of all other goods $j \neq i$, where $x > 0$, $z > 0$. Hence, the world endowment of each good is $E = x(z+n)$. The parameter z is a measure of the degree of comparative advantage, which determines trade in this model. For any given z , country i has a comparative advantage in good i and thus exports good i , imports all the other goods. The world price of good i is P_i . There are assumed to be no trade costs in the model.

Under autarky, there is no trade, and the country consumes its endowments and receives the welfare U_i^A . The symmetry in preferences and endowments ensures each country's welfare level to be the same under autarky:

$$U_i^A = U^A = x(1+z)^{\frac{1}{n}} \quad (3.2.2)$$

3.2.1 The Model

The world consists of n countries where each country exports the good, in which it has a comparative advantage, to the rest of the world and imports all the other goods. The behaviour of each country in setting tariffs is assumed to be non-cooperative. The i th country imposes a tariff at a rate τ_i on all imports. If an import tariff is negative, i.e., $\tau_i < 0$, it is an import subsidy. Since a country only imports goods in which it has no comparative advantage, the domestic price is P_i for good i , and $P_j(1+\tau_i)$ for

good $j \neq i$ in country i . Each country chooses a tariff rate to maximise its welfare, taking the tariffs from the rest of the world as given. Government revenue collected from such a trade policy is redistributed back to consumers in the form of a lump-sum payment. In this section, I derive the welfare maximising problem by focusing on country i 's behaviour in setting trade policies. Such a welfare maximising problem will be the same across all the countries under a symmetric structure.

Country i maximises its welfare subjects to the budget constraint:

$$P_i C_{ii} + \sum_{\substack{j=1 \\ j \neq i}}^n (P_j (1 + \tau_i) C_{ji}) = M_i$$

where M_i is country i 'th's total wealth. Since tariff revenue is distributed in a lump-sum payment, the wealth is made up of the profit from the sale of its endowment goods as well as tax revenue as follows:

$$M_i = P_i x (1 + z) + \sum_{\substack{j=1 \\ j \neq i}}^n P_j (1 + \tau_i) x + \sum_{\substack{j=1 \\ j \neq i}}^n (P_j \tau_i (C_{ji} - x))$$

Define $m_{ij} = M_i / P_j$ and $p_{ji} = P_j / P_i$, the wealth can be written as:

$$m_{ii} = x(1 + z) + x \sum_{\substack{j=1 \\ j \neq i}}^n p_{ji} + \tau_i \sum_{\substack{j=1 \\ j \neq i}}^n (p_{ji} C_{ji}) \quad (3.2.3)$$

The demands for each good with Cobb-Douglas preferences setting are:

$$C_{ii} = \frac{m_{ii}}{n} \quad (3.2.4)$$

$$C_{ji} = \frac{m_{ij}}{n(1 + \tau_i)} = \frac{m_{ii}}{n(1 + \tau_i) p_{ji}}, \text{ for } j \neq i$$

Substituting the second expression for C_{ji} from (3.2.4) into (3.2.3) gives:

$$m_{ii} = \frac{n(1+\tau_i)x}{n+\tau_i} \left(1+z + \sum_{\substack{j=1 \\ j \neq i}}^n p_{ji} \right) \quad (3.2.5)$$

$$m_{ij} = m_{ii} p_{ij} = \frac{n(1+\tau_i)x}{n+\tau_i} \left(1+(1+z)p_{ij} + \sum_{\substack{k=1 \\ k \neq i, j}}^n p_{kj} \right)$$

and thus, demands are simplified to:

$$C_{ii} = \frac{x(1+\tau_i)}{n+\tau_i} \left(1+z + \sum_{\substack{j=1 \\ j \neq i}}^n P_{ji} \right) \quad (3.2.6)$$

$$C_{ji} = \frac{x}{(n+\tau_i)p_{ji}} \left(1+z + \sum_{\substack{j=1 \\ j \neq i}}^n P_{ji} \right), \text{ for } j \neq i$$

The utility maximisation problem is:

$$\underset{\tau_i, p_{ji}}{\text{Max}} \quad U_i = \prod_{j=1}^n (C_{ji})^{\frac{1}{n}} \quad (3.2.7)$$

Taking logs of the utility, the objective is as follows:

$$\begin{aligned} n \log(U_i) &= \sum_{j=1}^n \log(C_{ji}) \\ &= \log(C_{ii}) + \sum_{\substack{j=1 \\ j \neq i}}^n \log(C_{ji}) \\ &= n \log(x) - n \log(n+\tau_i) + \log(1+\tau_i) + n \log \left(1+z + \sum_{\substack{j=1 \\ j \neq i}}^n p_{ji} \right) + \sum_{\substack{j=1 \\ j \neq i}}^n \log(p_{ji}) \end{aligned}$$

The world market will clear given the resource constraint:

$$C_{ii} + \sum_{\substack{j=1 \\ j \neq i}}^n C_{ij} = x(n+z)$$

Following the first expression for C_{ji} in (3.2.4), one could exchange i and j , and express C_{ij} as $m_{ji}/(n(1+\tau_j))$, where:

$$m_{ji} = \frac{n(1+\tau_j)x}{n+\tau_j} \left(1 + (1+z)p_{ji} + \sum_{\substack{k=1 \\ k \neq i,j}}^n p_{ki} \right)$$

It gives:

$$C_{ij} = \frac{x}{n+\tau_j} \left(1 + (1+z)p_{ji} + \sum_{\substack{k=1 \\ k \neq i,j}}^n p_{ki} \right) \quad (3.2.8)$$

where τ_j is the tariff set by the country j . When analysing the behaviour of country i only, one can consider the behaviour of other countries in setting tariffs as given, that is, treat τ_j as a constant.

Substituting C_{ii} in (3.2.6) and C_{ij} in (3.2.8) into the resource constraint gives

$$\frac{x(1+\tau_i)}{n+\tau_i} \left(1+z + \sum_{\substack{j=1 \\ j \neq i}}^n p_{ji} \right) + \sum_{\substack{j=1 \\ j \neq i}}^n \left(\frac{x}{n+\tau_j} \left(1 + (1+z)p_{ji} + \sum_{\substack{k=1 \\ k \neq i,j}}^n p_{ki} \right) \right) = x(n+z) \quad (3.2.9)$$

Since country i is the country of interest, one could separate it from the other countries and divide the whole world into two groups. Group one contains only country i and group two has all the other countries $j \neq i$. In the light of a symmetric structure, the maximisation problem can be proceeded by imposing symmetry constraints that each country $j \neq i$ in group two chooses the same tariff rate $\tau_{j \neq i} = \tau_{-i}$, and the world prices for the goods that group two countries have a comparative advantage in are the same, that is, $p_{ji} = p_{-i}$. The objective for country i is to choose a

tariff level, which could affect the equilibrium good prices, to maximise its utility when the world market clears. Such a policy is called the “optimum trade policy” which results in an optimum tariff. With symmetry constraints, the utility maximisation problem in (3.2.7) and resource constraint (3.2.9) can, therefore, be simplified to:

$$\begin{aligned}
& \max_{\tau_i, p_{-i}} n \log(U_i) \\
& = n \log(x) - n \log(n + \tau_i) + \log(1 + \tau_i) \\
& \quad + n \log(1 + z + (n-1)p_{-i}) - (n-1) \log(p_{-i}) \\
& s.t. \quad \frac{1 + \tau_i}{n + \tau_i} (1 + z + (n-1)p_{-i}) + \frac{n-1}{n + \tau_{-i}} ((n+z-1)p_{-i} + 1) = n + z
\end{aligned} \tag{3.2.10}$$

In different situations, there will be various constraints on both the tariff of interest τ_i and the tariff τ_{-i} applied by the rest of the world. Countries face different problems and will make different choices.

3.2.2 Trade Policy Game

Consider a constituent trade policy game where each country's tariff decision is made independently and simultaneously. Each country chooses its own import tariff that may equals zero. A country's welfare is at the free trade level U^F when each country in the world uses zero tariffs on all importable goods, i.e., $\tau_i = 0, \tau_{-i} = 0$. Knowing the tariff set by each country, the equilibrium relative price of good i , i.e., p_{-i} , is solely determined by the market-clearing condition, and $p_{-i} = 1$. The world is purely symmetric with identical tariffs and prices across all the countries under multilateral free trade. Plugging $\tau_i = 0$ and $p_{ji} = p_{-i} = 1$ into demand (3.2.6), yields country i 's equilibrium consumptions:

$$C_{ii} = C_{ji} = \frac{x(n+z)}{n}$$

It shows that with no trade barriers, the world can be treated as a single market, where the total endowment of each good $E = x(n+z)$ is equally allocated among all countries. Hence, the utility level for each of the n countries is the same at:

$$U_i^F = U^F = \frac{x(n+z)}{n} \quad (3.2.11)$$

By comparing welfare under free trade (3.2.11) to welfare under autarky (3.2.2), one could show that there are always gains from trade using Bernoulli's inequality as follows:

$$\begin{aligned} U^F - U^A &= \frac{x(n+z)}{n} - x(1+z)^{\frac{1}{n}} \\ &= x \left(1+z \cdot \frac{1}{n} - (1+z)^{\frac{1}{n}} \right) \geq 0 \end{aligned}$$

given that $0 \leq 1/n \leq 1$ and $x \geq 0$.⁴

Another possibility is when the country of interest uses a tariff while the rest of the world countries pursue a policy of free trade. With an import tariff, a country could possibly improve its welfare through the terms of trade effect. In this case when country i unilaterally deviates from free trade policy and imposes a tariff, its optimum import tariff τ^D is obtained by adding a tariff constraint $\tau_{-i} = 0$ into the maximisation problem (3.2.10). The resource constraint in (3.2.10) is simplified:

$$\frac{1+\tau_i}{n+\tau_i} (1+z+(n-1)p_{-i}) + \left(1 - \frac{1}{n}\right) ((n+z-1)p_{-i} + 1) = n+z$$

which implies:

$$p_{-i} = \frac{n(n+z+\tau_i) - \tau_i}{n(n+z) + (2n+z-1)\tau_i}$$

⁴ Bernoulli's inequality states that, $(1+z)^r \leq 1+rz$ for every real number $0 \leq r \leq 1$ and $x \geq -1$. The inequality is binding when $z=0$, in which case, no country has a comparative advantage, and therefore no trade occurs.

Substituting the relative price, which is function of tariff, into the maximisation problem (3.2.10) and the first order condition is obtained:

$$\frac{\partial(n \log(U_i))}{\partial \tau_i} = \frac{1}{1 + \tau_i} - \frac{2n + z - 1}{n(n + z) + (2n + z - 1)\tau_i} - \frac{(n - 1)^2}{n(n + z + \tau_i) - \tau_i} = 0$$

which yields:

$$\tau_i^D = \frac{-n(n - 1)(n + 1 + z) + \Phi}{2(n - 1)(2n - 1 + z)} > 0$$

where $\Phi = \sqrt{n(n - 1)(n - 1 + z)(n(n + 1)^2 + n(n + 7)z + 4z^2)}$.

One can verify the positivity of the resulting tariff by plotting τ_i^D against n and z . Note that $n > 0, z > 0$. The equilibrium relative price of good i is:

$$p_{-i}^D = \frac{2 - 2z - n(5 - 3z + n(n - 4 + z)) + \Phi}{2(n - 1 + z)(2n - 1 + z)}$$

Substituting trade policies τ_i^D and $\tau_{-i} = 0$ together with equilibrium price p_{-i}^D into demand function (3.2.6), it gives country i 's consumption of each good C_{ii}^D and C_{ji}^D . Follow the Cobb-Douglas preference, welfare for country i from unilaterally deviating from free trade is:

$$U_i^D = U^D = (C_{ii}^D)^{\frac{1}{n}} (C_{ji}^D)^{\frac{n-1}{n}} \quad (3.2.12)^5$$

By fixing the value of initial endowment size x , one could compare a country's welfare under different trade policies through plotting utilities against the number of countries n and the index of comparative advantages z . Figure 3.1 shows the comparison when $x = 1$.

⁵ For a complete expression of (3.2.12), please see Appendix B.1.

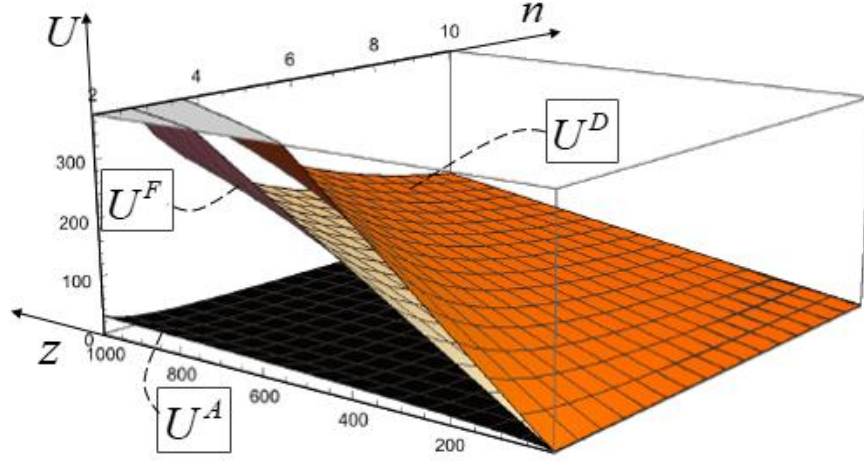


Figure 3.1 Gains from Free Trade

To emphasize the differences, we consider the case when there are up to 10 countries, and the comparative advantage index takes the value from 0 to 1,000. Results remain the same when the number of countries exceeds 10. Gains from trade are also showed as the utility level under autarky U^A appears to be the lowest one among all the utilities under different trade policies, which is also analytically proved using Bernoulli's inequality in previous context. A country's welfare is improved if a country aggressively imposes a tariff while all the other countries stay using free trade policy. Attracted by welfare improvements, a country has incentives to unilaterally increase its tariff to an optimum level. However, those countries who passively pursue free trade policy will then face a welfare loss. Hence, it is likely that those who suffer from a welfare decrease retaliate by imposing a tariff and thus trigger a "trade war". The world is then in a position where each county uses an optimum trade policy with a welfare maximising tariff, which is also called an optimum tariff. Such an optimum tariff is different to the one when a country unilaterally uses a trade tax. The reason is that the world is in a different state where every single country in the world market, instead of only one country, uses a non-zero tariff. This situation can be modelled as an interior Nash equilibrium(NE) in a constituent trade policy game as in Johnson (1953).

Following the symmetric structure of the model, one could conjecture the existence of a NE where all countries levy the same tariff, denoted by τ^N . To solve

the Nash tariff, first solve the first order condition for the welfare maximising problem (3.2.10), which yields:

$$\frac{\partial(n \log(U_i))}{\partial \tau_i} = (n-1) \left(\frac{1+z}{(\lambda_1+1)(\tau_{-i}-\tau_i+(n+\tau_{-i})\lambda_1)} - \frac{1}{\lambda_1+1} + \frac{n+z-1}{(1+\tau_i)\lambda_2} \right) = 0$$

where $\lambda_1 = n+z+\tau_i$, and $\lambda_2 = (n(\lambda_1+\tau_i)+\tau_{-i}+\tau_i(z+\tau_{-i}-1))$.

Then apply the condition of symmetry that $\tau_i = \tau_{-i} = \tau^N$. The above first order condition is simplified to:

$$\frac{1}{1+\tau^N} - \frac{1}{n+\tau^N} - \frac{n-1}{n+z+\tau^N} = 0$$

And the best response of the i th country is obtained:

$$\tau^N = \frac{1}{2}(\sqrt{n^2+4z}-n) \quad (3.2.13)$$

As shown in the tariff function, the NE tariff is affected by the level of comparative advantages z and the total number of countries n .⁶ It shows that such an optimum tariff is always increasing in z for any given n . A larger z provides a country a larger endowment size in terms of the good that it has a comparative advantage. Hence, trade is expanded in the volume, which motivates the country to use a higher tariff to increase its welfare. It can also be explained by an increase in the market share when there is a larger endowment size, and the country is more capable of increasing its tariff.

The Nash equilibrium tariff is also determined by the number of countries in the world. Differentiating the tariff in (3.2.13) with respect to the number of countries, gives:

$$\frac{\partial \tau^N}{\partial n} = \frac{1}{2} \left(\frac{n}{\sqrt{n^2+4z}} - 1 \right) < 0$$

⁶ For a detailed calculation, please see Appendix B.2.

When there exist more sovereign countries, each country is less powerful and thus has less market power to increase its tariffs.⁷ With the number of countries goes infinity, each country can be considered as a country that has less ability to influence world prices, i.e., a small country. In that case, the optimum tariff goes down to zero in theory.

The relative price of good i , p_{-i}^N equals one in the Nash equilibrium, which is the same as the one under multilateral free trade where all the countries use a common tariff rate. This is because world prices of all the goods are the same given the same trade policies in a symmetric model.

Plug the resulting tariff (3.2.13) and the relative price $p_{ji}^N = p_{-i}^N = 1$ into the demand function (3.2.6). The equilibrium demands are obtained:

$$C_{ii}^N = \frac{x(n+z)(2-n+\sqrt{n^2+4z})}{n+\sqrt{n^2+4z}} \quad (3.2.14)$$

$$C_{ji}^N = \frac{2x(n+z)}{n+\sqrt{n^2+4z}}$$

Country i 's welfare then takes the form:

$$U_i^N = U^N = (C_{ii}^N)^{1/n} (C_{ji}^N)^{(n-1)/n} = \frac{2^{\frac{n-1}{n}} x(n+z)(2-n+\sqrt{n^2+4z})^{\frac{1}{n}}}{n+\sqrt{n^2+4z}} \quad (3.2.15)$$

With an endowment size $x=1$, differences in welfare among different trade policies are shown in Figure 3.2. Result remains the same when $n > 10$.

⁷ Broda et al.(2008) have estimated 15 countries' export supply elasticities and showed evidence that before join WTO when countries' behaviour in setting trade policy is non-cooperative, they set higher tariffs on the good in which they have market power. In the case where trade is determined by comparative advantage, the index of comparative advantage z and the country number n can be considered as market power indicators.

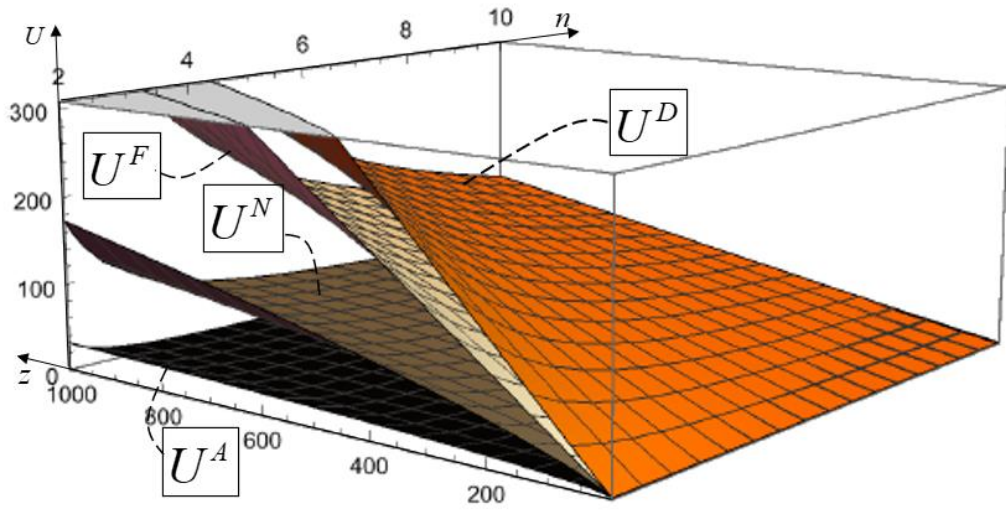


Figure 3.2 Result of a Tariff War

For any given n and z in the diagram, welfare for a representative country in the interior Nash equilibrium U^N is always lower than the welfare under multilateral free trade U^F . Therefore, in a world where all the countries have the same endowment size, all the countries are bound to lose in a “tariff war” as compared to multilateral free trade. To present the comparisons in a clearer way, one of the variables is fixed in the following analysis. Since there are 164 countries in WTO, Figure 3.3 illustrates the welfare for each sovereign country under different trade policies when number of countries is fixed at 164.

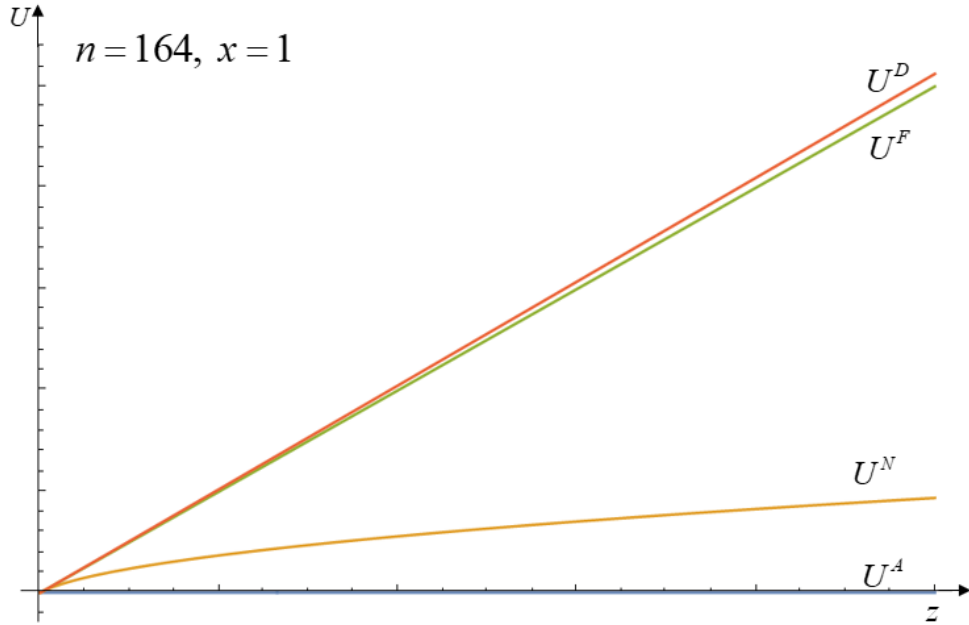


Figure 3.3 Result of a Tariff War with 164 Countries

Clearly, welfare level in the interior Nash equilibrium U^N is much lower than under free trade U^F when the number of countries increases to 164. This situation is known as a Prisoners' Dilemma since the world welfare in the Nash equilibrium is lower as compared to free trade. One could also verify the prisoners' dilemma by plotting utilities against the number of countries with a fixed z as shown below.

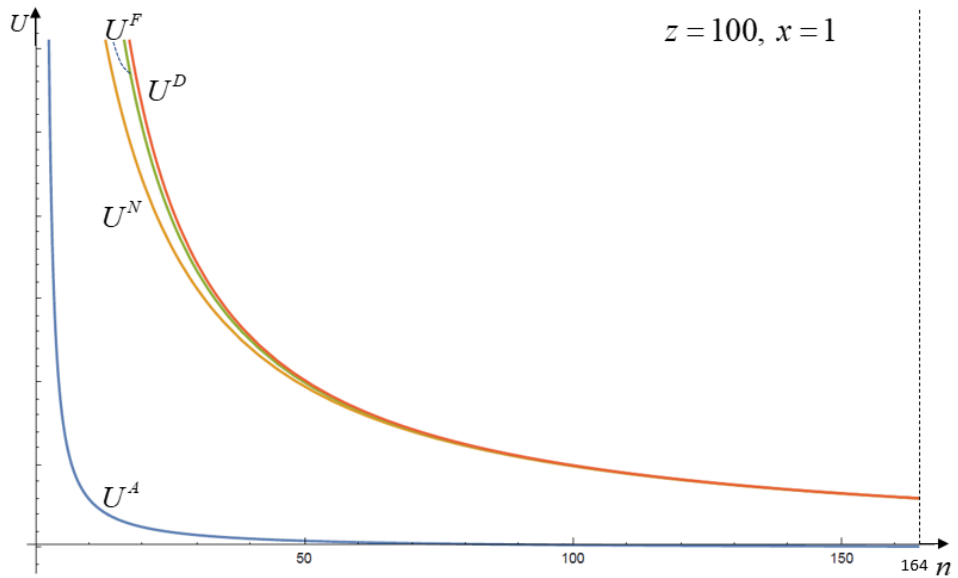


Figure 3.4 Welfare and the Number of Countries

Countries obtain the highest welfare from unilateral deviation, and the lowest from autarky. It is shown that in a constituent trade policy game when there exists comparative advantage and trade occurs, countries always obtain a higher welfare under free trade compared to autarky. When there are numerous countries, as demonstrated previously, the optimum tariff is zero, and all the countries receive welfare under free trade. This argument can be illustrated from the diagram that U^D, U^F, U^N gradually merge when n goes large. Among all the figures, a country's welfare in autarky when there is no trade at all appears to be the lowest one among the welfare levels, which re-enforced the argument that there are always gains from trade.

3.3 Sustaining Free Trade

A trade war, which is modelled as a Nash equilibrium in a static trade policy game, is always a worse outcome in terms of world welfare as compared to multilateral free trade in a symmetric setting. Such a Prisoners' Dilemma outcome is not socially desirable since both the world and any single country in the world market are better off under free trade than in a trade war. However, the Prisoners' Dilemma can successfully be avoided in a repeated game with the use of grim trigger strategies, so that free trade can possibly be sustained. In a repeated game, countries observe the outcome of the previous play and then decide whether to cooperate by playing free trade, or to defect by using an optimum trade policy with a welfare-maximising tariff. Suppose that each country starts with a zero tariff rate. If any country deviates and uses an optimum trade policy, all the rest countries do the same by increasing tariff to an optimum level. Cooperation is then permanently broken down for the remainder of the game, and all the countries in the world defect forever, which results in an infinite tariff war. In the static game, which will be a stage game in this section, there are n countries, each of which receives payoff which is a function of welfare action of a trade policy game. Trade instrument is an import tariff that could possibly be zero. As suggested by various Folk Theorem that cooperation is a possible outcome in a repeated game, the static trade policy game in the previous section will be studied in an infinitely and a finitely repeated game to analyse the sustainability of free trade in this section.

3.3.1 Sustaining Free Trade in an Infinitely Repeated Game

The general Folk Theorem are a class of theorems describing an abundance of Nash equilibrium payoff profile in repeated game. The Folk theorem was formalised by Friedman (1971) that cooperation can be sustained with the use of Nash reversion trigger strategies in an infinitely repeated game. He strengthened the original Folk Theorem by using the concept of subgame perfect Nash equilibrium (SPNE) and argued that if the players are patient enough and far-sighted, any feasible and strongly individually rational outcome in the constituent game can be supported as a SPNE. Therefore, an infinitely repeated version of the constituent trade policy game is firstly considered. The stage game in section 3.2 will be repeated infinitely with discounting in this subsection. It will be show that there is a Nash equilibrium such that all the

countries cooperate on the equilibrium path. All the countries start by choosing a free trade policy. If any country deviates and sets a welfare maximising tariff, all the countries revert to the interior Nash equilibrium forever. With a discount factor $\delta \in [0,1]$, which is a common discount factor for all the countries, free trade is sustainable if a country benefits from not deviating.⁸ In the light of a symmetric structure, all the countries' welfare is the same under the same trade policy. For example, each of the countries obtain the same utility in a multilateral free trade situation as shown in the previous section. When a country unilaterally deviates from free trade, it receives a higher level of welfare, whereas when a country engages in a trade war, it receives a lower level of welfare as compared to free trade. With the use of Nash reversion trigger strategies, the country that deviates receives high welfare for the current deviation period but followed by receiving low welfare in the interior Nash equilibrium forever afterwards. Multilateral free trade can then be sustained if, for any country in the world market, the present discounted value of welfare from free trade is greater than the total discounted welfare from deviation followed by a reversion to the NE forever afterwards:

$$\frac{1}{1-\delta}U^F > U^D + \frac{\delta}{1-\delta}U^N \quad (3.3.1)$$

The critical value of discount factor is obtained by equating the above inequality. Such a critical discount factor is the same for all the n countries in the world due to symmetry. Free trade is sustainable if the discount factor exceeds its critical value, so that all the countries are patient enough and forgo the one period benefit from deviation. A discount factor that below the critical value indicates a less patient country who desires current payoff more than future ones. In this case, free trade is not sustainable since all the countries are attracted by a higher welfare from deviation. The condition for free trade to be sustained is solved as:

$$\delta > \delta^{N\infty} = \frac{U^D - U^F}{U^D - U^N} \quad (3.3.2)$$

⁸ All the countries' level of patience is represented by the same discount factor δ .

where $\delta^{N\infty}$ represents the critical discount factor using infinite Nash reversion trigger strategies. The discount factor takes the range from zero to one due to the fact that the outcome of a constituent trade policy game is a Prisoners' Dilemma in the symmetric case, i.e., $U^F > U^N$. If welfare from the interior Nash equilibrium is high enough, the critical discount factor will be close to one and sustaining free trade becomes less possible.

Using the Nash reversion trigger strategies, all the countries revert to the interior Nash equilibrium. However, it worth noting that the interior Nash equilibrium is not a unique NE. As demonstrated by Dixit (1987), besides the interior Nash equilibrium, there exists another equilibrium when both countries set prohibitive tariffs. A prohibitive tariff is the level of tariff that stops trade. When a country tries to minimise other countries' maximum welfare by setting a prohibitive tariff, all the countries will be locked into autarky. No country could possibly improve its welfare by unilaterally deviate from autarky, which makes minimaxing another Nash equilibrium. The threat of reversion to autarky can be used to sustain free trade. To distinguish the two Nash equilibria, the interior Nash equilibrium refers to the case that both countries use a non-prohibitive optimum tariff, whereas the minimax Nash equilibrium is the one that leads to autarky. Now suppose that each country uses an infinite minimax reversion trigger strategies. Start from a cooperation (multilateral free trade) in an infinitely repeated game, the strategy for each country is to play free trade until a country deviates. Once deviation happens, all the countries minimax each other by using a prohibitive tariff and receive welfare under autarky for the remainder of the game. With minimax trigger strategies, free trade is sustainable as long as:

$$\frac{1}{1-\delta}U^F > U^D + \frac{\delta}{1-\delta}U^A \quad (3.3.3)$$

The only difference between the two types of strategies is the punishment. With infinite Nash reversion trigger strategies, sustaining free trade is threatened by reverting to the interior Nash equilibrium when both country use a non-prohibitive optimum tariff, whereas, with infinite minimax trigger strategies, the threat is to revert to autarky. As shown in the previous section 3.2.2 that there are always gains from trade, reversion to autarky is a more severe threat than reversion to the interior Nash

equilibrium, i.e., $U^N > U^A$. It is always easier to sustain free trade using infinite minimax trigger strategies compared to Nash reversion. The critical discount factor is obtained:

$$\delta^{M\infty} = \frac{U^D - U^F}{U^D - U^A} \quad (3.3.4)$$

Free trade is sustainable if $\delta > \delta^{M\infty}$. Note that both critical discount factors $\{\delta^{N\infty}, \delta^{M\infty}\}$ are irrelevant to the endowment size x , but determined by the number of countries n and the index of comparative advantage z . The parameter x can be factored out from U^A in (3.2.2), U^F in (3.2.11), U^N in (3.2.15) and U^D in Appendix B.1. Therefore, is cancelled out when calculating discount factors.

Figure 3.5 and Figure 3.6 illustrate how comparative advantages and the number of countries could affect the sustainability of free trade. Follow the previous section, n is set at 164 when plotting discount factor against the index of comparative advantage. To see the effect of country numbers, z is fixed at 100.

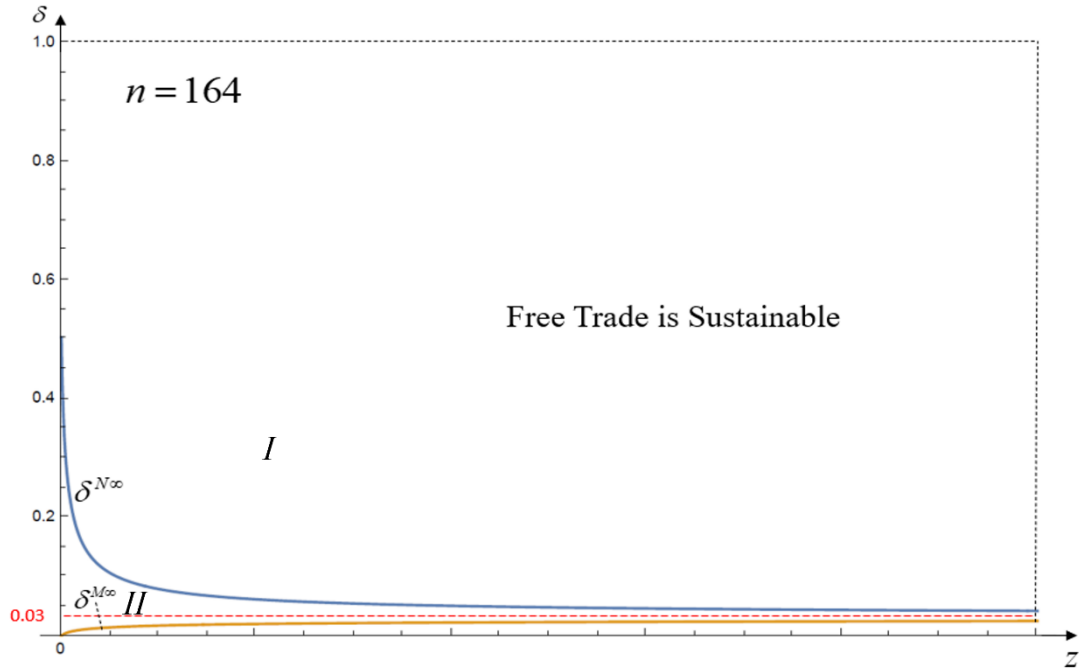


Figure 3.5 Critical Discount Factors and Comparative Advantage

Free trade is sustainable in the region labelled *I* with infinite Nash reversion, whereas it is sustainable in the regions labelled *I* and *II* with infinite minimax reversion.

Clearly, the critical discount factor using infinite Nash reversion exceed the one under infinite minimax reversion for any given z . Reversing to autarky is a more severe threat than reversing to the interior Nash equilibrium. With a larger scale of comparative advantage, the required discount factor decreases using Nash reversion, however, even slightly, but still increases using minimax reversion. When z goes to infinity, the limit of $\delta^{N\infty}$ and $\delta^{M\infty}$ are the same at $1 - 1/(2^{1/82} 4^{1/164})$, which is approximately 0.03 as shown in the above figure.

Result 3.1: *In an infinitely repeated game when countries are symmetric, comparative advantages help to sustain free trade using infinite Nash reversion ($\delta^{N\infty}$ decreases in z), however, it impedes the sustainability using infinite minimax reversion ($\delta^{M\infty}$ increases in z). Although, it is always easier to sustain free trade using infinite minimax reversion than using Nash reversion.*

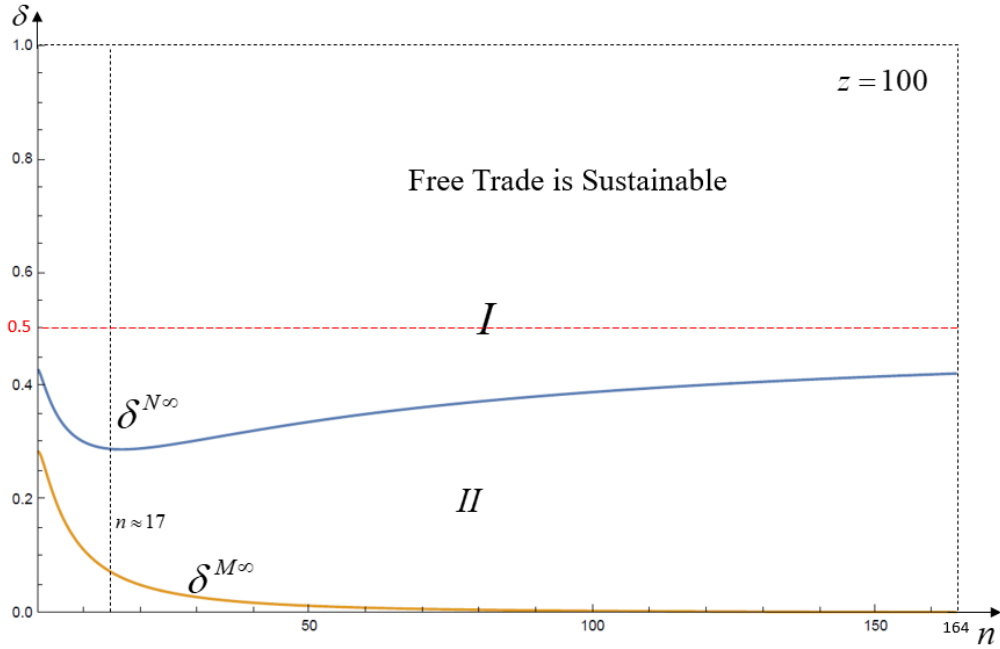


Figure 3.6 Critical Discount Factors and World Size

Free trade is sustainable in the region labelled *I* with infinite Nash reversion, whereas it is sustainable in the regions labelled *I* and *II* with infinite minimax reversion. The effect of world size on critical discount factors is shown above. The number of countries takes the value from 2 to 164. The critical discount factor using infinite Nash reversion is positively related to the number of countries in general, while a negative

relationship is observed under infinite minimax reversion. The limit of $\delta^{N\infty}$ when there is infinite number of countries is 0.5, and the limit of $\delta^{M\infty}$ is zero. When there are more countries, it is easier to sustain free trade with minimax reversion. However, it becomes more difficult using Nash reversion. Such result can be interpreted by looking at the determinant of critical discount factors in (3.3.2) and (3.3.4). With the number of countries n goes up, each country has less market power as each of them would be considered as a small country among numerous countries. As demonstrated in the previous section 3.2.2, each country's optimum tariff rate goes down to 0. Therefore, even a country uses an optimum trade policy that maximises its welfare, the country obtains a utility that closes to the one under free trade, and there could be no gains or loses from unilateral deviating from trade agreements. That is, $U^D \approx U^N \approx U^F$. With infinite Nash reversion, each country receives the welfare U^N which is the same as as the country is in a trade agreement when a country is small. The welfare in autarky, however, is always positive and smaller than under free trade, $U^A < U^F$. Now go back to (3.3.2), which is the function that determines critical discount factor using infinite Nash reversion. When n gradually increases, U^D and U^N get close to U^F . Both the denominator and the numerator go to zero and the critical discount factor goes to 0.5. As for $\delta^{M\infty}$ in (3.3.4), the numerator $U^D - U^F$ goes down to zero when n increases. The denominator $U^D - U^A$ is always positive, which leads to a result that approach zero. Therefore as the number of countries increases, each country has a small market power, there could be no gains from cooperation comparing to the welfare countries could receive from deviation, thus whether countries would sustaining cooperation depends on parameter values. This leads to the following result:

Result 3.2: *In an infinitely repeated game when the number of countries is large enough, an increase in the number of countries makes it easier to sustain free trade using infinite minimax reversion ($\delta^{M\infty}$ decreases in n), but it makes it more difficult using infinite Nash reversion($\delta^{N\infty}$ increases in n),.*

As suggested by previous analyses, cooperation is sustainable with the threat of being punished. No matter the interior Nash equilibrium or an autarky economy, these punishments are often inefficient. Countries can always achieve a mutual

improvement in welfare by choosing a free trade policy. If there exists a chance for players to renegotiate to an efficient equilibrium, any punishment, especially an infinite punishment may no longer be credible, and the original Nash equilibrium (either the interior one or the minimax equilibrium that results in autarky) breaks down. Collie (2019) pointed out that renegotiation-proof strategies can help to avoid this issue by allowing the cheated country to benefit from increased welfare during punishment phases, resulting in the Nash equilibrium punishing only the cheating country. When a country unilaterally deviates from trade agreements, the all the other countries impose tariffs on all imported goods, only the cheating country is punished by receiving a lower welfare while all the other cheated countries become better off. There will be no scope for renegotiation in that circumstance because the cheated country is better off in the Nash equilibrium. The possibility of renegotiation can also be addressed by having the punishment phase lasts for only a few rounds, then allowing countries to return to free trade. Free trade can be sustained as a subgame perfect Nash equilibrium if a limited number of round of punishment is severe enough and players are sufficiently patient. This chapter addresses the possibility of renegotiation by using a limited number of rounds of punishment and compares the result with infinite punishment.

Suppose there is only one round of punishment. With one round Nash reversion, free trade is sustainable if $U^F + \delta U^F > U^D + \delta U^N$, which yields a critical discount factor:

$$\delta^{N1} = \frac{U^D - U^F}{U^F - U^N} \quad (3.3.5)$$

As long all the countries' discount factors are greater than the critical value, free trade is sustainable with only one round punishment. Such a critical discount factor with one round of punishment is greater than an infinite punishment since welfare from deviation always exceeds welfare under free trade, and the denominator in (3.3.5) is smaller than the denominator in (3.3.2), which is the equation that gives the threshold of discount factors using infinite Nash reversion. When there are two rounds of punishment, free trade is sustainable if $U^F + \delta U^F + \delta^2 U^F > U^D + \delta U^N + \delta^2 U^N$. The critical value is obtained by setting both sides equal:

$$\delta^{N_2}(1 + \delta^{N_2}) = \frac{U^D - U^F}{U^F - U^N} \quad (3.3.6)$$

With a limited number of rounds of punishments q , that is, using q round Nash reversion strategies, free trade can be sustained when $\delta > \delta^{N_q}$, and δ^{N_q} is derived from:

$$\delta^{N_q} \left(1 + \delta^{N_q} + (\delta^{N_q})^2 + (\delta^{N_q})^3 + \dots + (\delta^{N_q})^{q-1} \right) = \frac{U^D - U^F}{U^F - U^N} \quad (3.3.7)$$

Replacing U^N by U^A gives critical discount factors under a limited number of rounds of minimax reversion.

With a fixed level of comparative advantage, Figure 3.7 and Figure 3.8 show how sustainable free trade is using a different length of punishment phase, up to three rounds, using Nash reversion and minimax reversion.

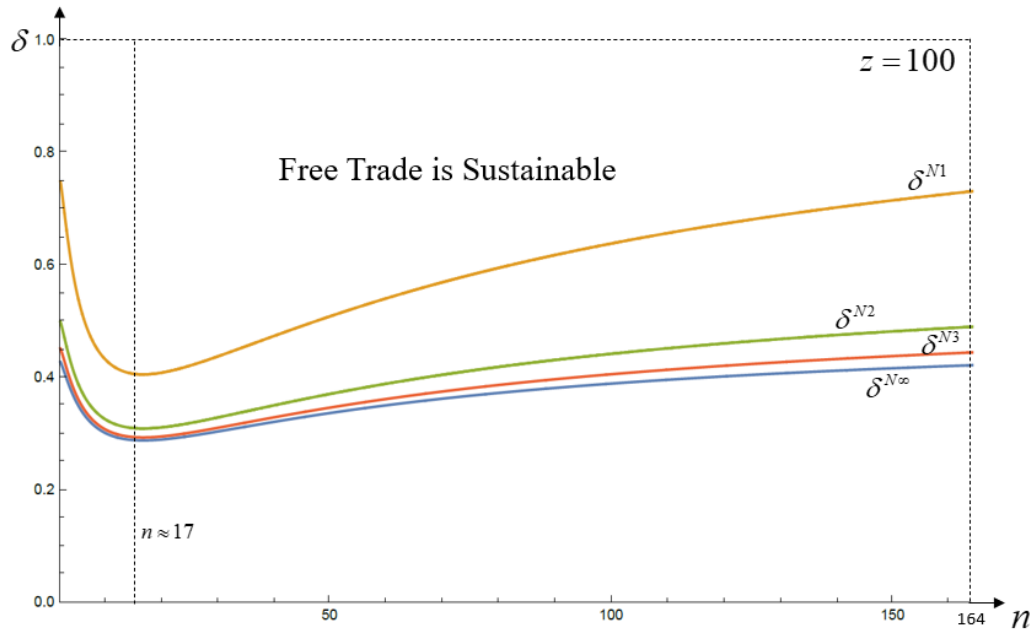


Figure 3.7 Nash Reversion for a Limited Number of Rounds



Figure 3.8 Minimax Reversion for a Limited Number of Rounds

As can be seen from the two figures that critical discount factors are always less than one. Free trade is sustainable with the use of a few rounds of punishment, even only one round, provided that players are patient enough. A fewer round of reversion indicates a lighter sanction for defection, thus makes free trade more difficult to be sustained. The following figure shows critical discount factors using minimax reversion for a limited number of rounds when there are up to 10 countries.

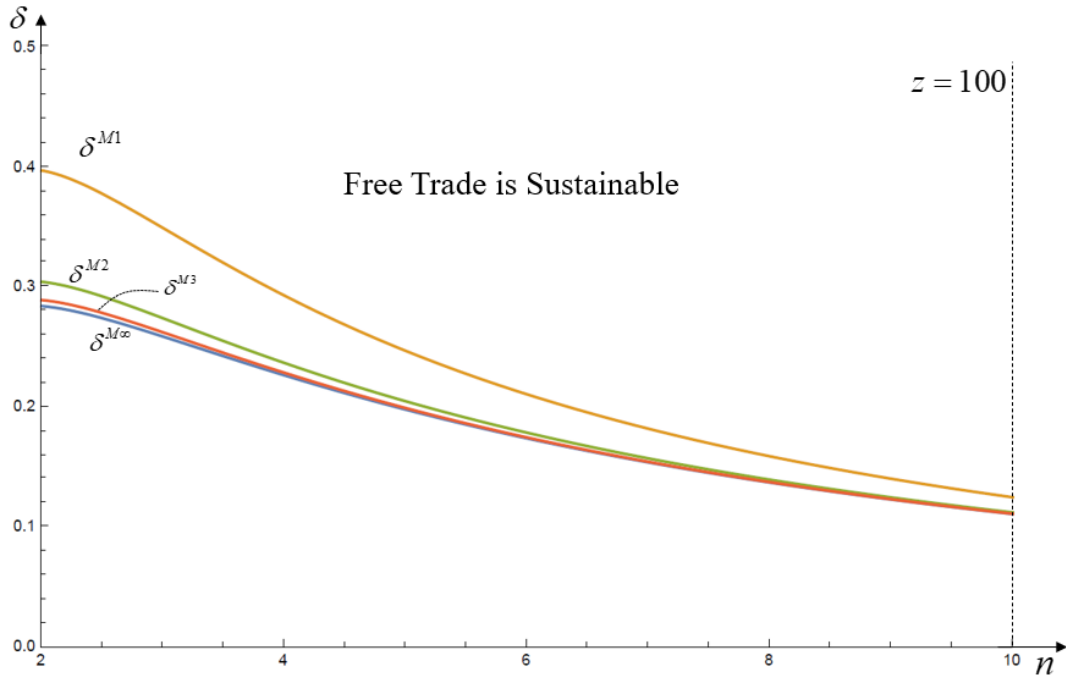


Figure 3.9 Minimax Reversion for a Limited Number of Rounds-up to 10 Countries

Free trade can always be sustained using minimax reversion when all the countries' discount factor are larger than 0.4, no matter a limited number of rounds or infinite rounds of punishment. Furthermore, with more countries join the trade policy game, free trade is easier to be sustained as the threshold decreases. However, it is not the case when countries are using Nash reversion as in Figure 3.7. A larger discount factor is required when there are more countries under Nash reversion. This leads to the following result:

Result 3.3: *Free trade is always possible to be sustained (the critical discount factor is always less than one) using both trigger strategies for a limited number of rounds when discount factors are large enough.*

3.3.2 Sustaining Free Trade in a Finitely Repeated Game

All the economic agents often have finite lives. The set of equilibria may be fewer than the folk theorem suggests if the game has a long but finite length. Since there are two Nash equilibria (the interior Nash equilibrium and autarky Nash equilibrium), one could consider the sustainability of free trade in a finitely repeated game. If there is a unique Nash equilibrium in a finitely repeated game, backward induction shows that all players will play the one-shot Nash equilibrium in each period,

hence, the SPNE would be to play the NE at each round of the game for all the countries. However, with two Nash equilibria, it is possible that cooperation can be supported on the equilibrium path when the Nash equilibrium that gives a lower welfare is considered as a punishment of deviation from cooperation. And as demonstrated by Benoit and Krishna (1985), when a game with multiple equilibria is repeated just a finite number of times, "folk theorem-like" outcomes can arise. This implies that cooperation can possibly be sustained when the constituent trade policy game is repeated for a finite number of rounds. Backwards induction is used in solving a finitely repeated game. In this chapter, I consider a T rounds repeated game with discounting. In this game, all the n countries' strategy is to play free trade for the first $T - k$ rounds, followed by k rounds of Nash equilibrium trade policies, where $k > 1$ and is determined exogenously. If any of the countries deviate in the first $T - k$ rounds, all the countries minimax each other and receive welfare under autarky for the remaining rounds of the game. Free trade is sustainable for $T - k$ rounds if no country desire to deviate in that round.⁹ Since it is always the case that a country deviates at $T - k$ round if it has an incentive to deviate from cooperation, I will refer to the parameter k as the length of punishment phase in the later context. If no deviation occurs, all countries receive welfare level under free trade for $T - k$ rounds and receive the welfare in the interior Nash equilibrium for the last k rounds. If any country deviates from free trade, all countries receive welfare under free trade for $T - k - 1$ rounds. At $T - k$ round, the cheating country receives a higher welfare compared to free trade and then goes to autarky and receive the welfare under autarky for the remainder of the game. With or without deviation, all the countries always receive welfare under free trade for the first $T - k - 1$ round, therefore, only the trade policies in the last k rounds matters when analysing the sustainability of cooperation in a finitely repeated game. It is worth mentioning that different from the two-country case in chapter two, deviation will only occur at the last possible moment in the n -country case. This is because in a symmetric structure where each of the n countries is endowed with the same size of the good, therefore there is no endowment asymmetries and all

⁹ If there is no incentive for any country to deviate in the $T - k$ round, then there is no incentive for them to deviate in the earlier round as the punishment phase will be longer. Countries' incentive to deviate appears to be the strongest one in the very last round among all the rounds of the game. For detailed proof, see Appendix B.3.

the countries are bounded to lose in a tariff war. A country would thus always deviate as late as possible. However, in the two-country case, a country may have incentive to deviate as early as possible provided that the country wins in a tariff war when it is sufficiently large.

To see how the sustainability of free trade (critical discount factor) is affected by z , n and k in a finitely repeated game, first consider the case when free trade is sustainable for $T-1$ round. Discount factors should satisfy $\delta > \delta^{T-1} = (U^D - U^F) / (U^N - U^A)$, which comes from the condition that the welfare received from no deviation exceeds the one from deviation, i.e., $U^F + \delta U^N > U^D + \delta U^A$. Similarly, to sustain free trade for $T-2$ round requires no incentives to deviate at the round $T-2$, that is, discount factors satisfy $U^F + \delta U^N + (\delta)^2 U^N > U^D + \delta U^A + (\delta)^2 U^A$.¹⁰ Setting both sides equal gives the critical discount factor δ^{T-2} , which is derived from the equation $\delta(1+\delta) = (U^D - U^F) / (U^N - U^A)$. Also, free trade can be sustained for $T-k$ round with discount factors $\delta > \delta^{T-k}$. δ^{T-k} is given by the solution of $\delta(1+\delta+(\delta)^2+...+(\delta)^{k-1}) = (U^D - U^F) / (U^N - U^A)$. Figure 3.10 plots the critical discount factors δ^{T-1} , δ^{T-2} and δ^{T-3} against the index of comparative advantage z when there are 164 countries.

¹⁰ Note that all the superscripts attached to a discount factor within parentheses indicate the power.

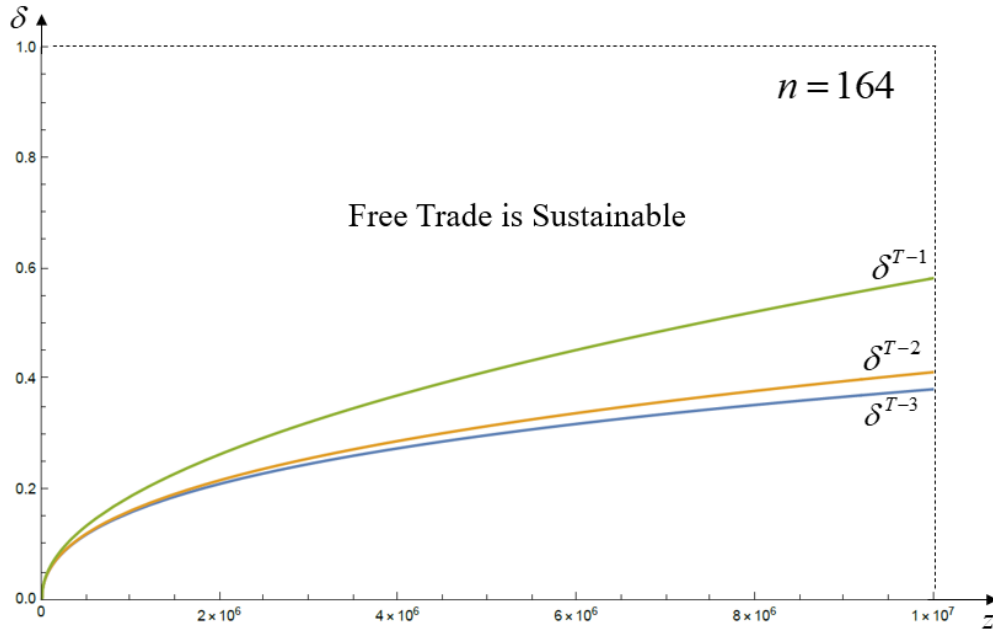


Figure 3.10 Critical Discount Factor and Comparative Advantages in Finitely-Repeated Game

All these three critical discount factors, which can be solved explicitly, are increasing in the comparative advantage and decreasing in k . It is more challenging to sustain free trade in a finitely repeated game when the countries are endowed with a larger amount of the good that they have a comparative advantage. Countries are more likely to deviate with a larger endowment and free trade is always sustainable if discount factors exceed the critical value, given the value of z goes up to 10 million in this example. However, when the index of comparative advantage keeps increasing, for example to 100 million, Figure 3.11 shows that free trade is not always sustainable for $T - 1$ round. The critical discount factor exceeds 1 when z exceeds a particular large value. One could then conjecture that with an even larger index of comparative advantage, free trade is not sustainable for $T - 2$ round.

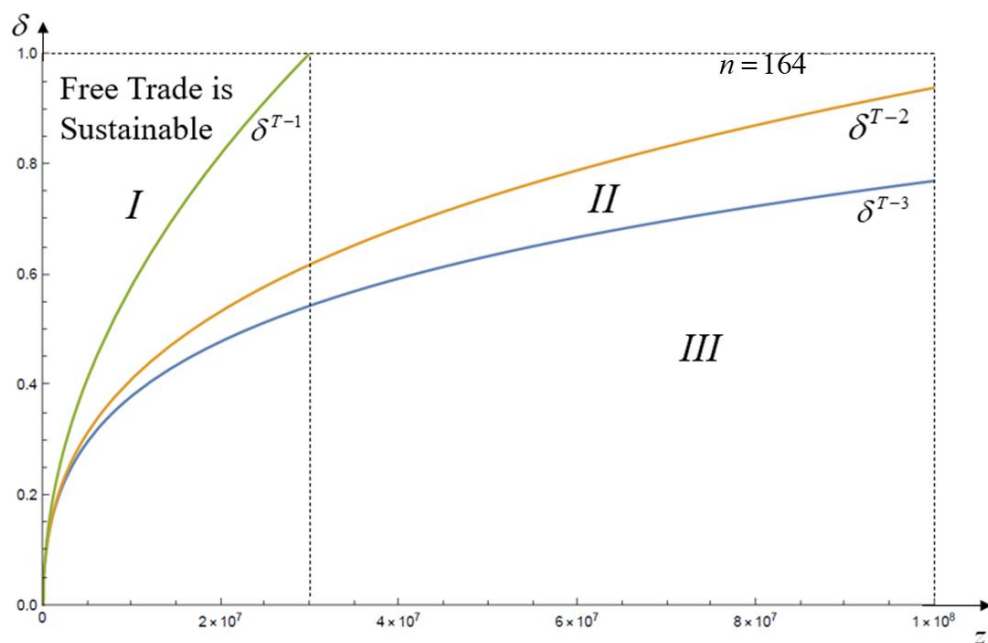


Figure 3.11 Critical Discount Factor in Finitely-Repeated Game

With a fixed amount of endowment size, the critical discount factors in a finitely repeated game are decreasing in the number of countries, as shown in Figure 3.12. Figure 3.13 emphasis the difference in sustainability when free trade is sustainable for $T-1$, $T-2$, and $T-3$ round. Clearly, it is easier to sustain free trade for a fewer round as the critical discount factor decreases in k . k is the length of the punishment phase and a larger k implies a strategy to use free trade policy for a fewer round. The critical discount factors in the finitely repeated game are also plotted together with those in an infinitely repeated game in Figure 3.12 for comparisons. An infinite minimax reversion is the most severe punishment among all the strategies.

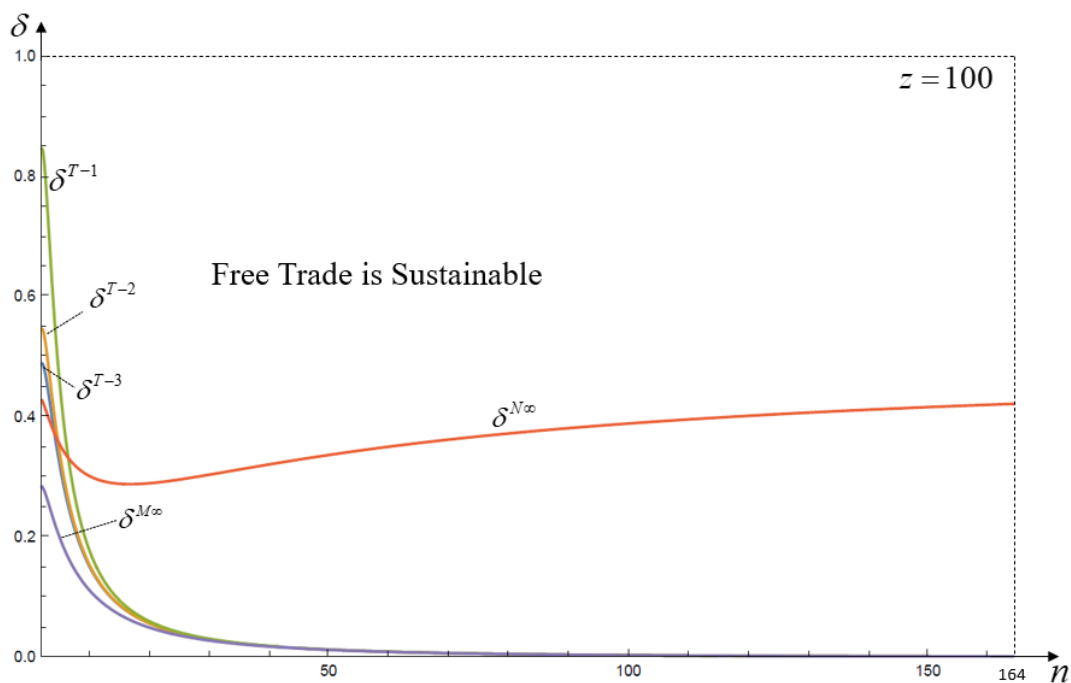


Figure 3.12 Critical Discount Factor and World Size

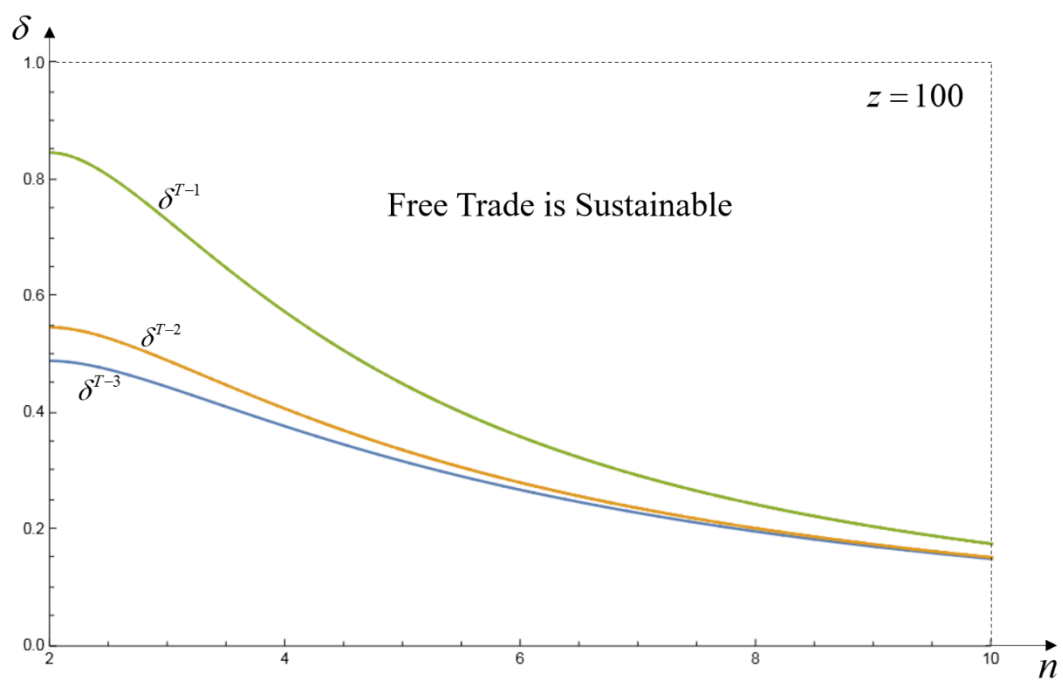


Figure 3.13 Critical Discount Factor in Finitely-Repeated Game-up to 10 Countries

All the above findings lead to the last result:

Result 3.4: δ^{T-k} increases in z , decreases in both n and k . In a finitely repeated game, comparative advantage makes it more difficult to sustain free trade whereas both the world size (the number of countries) and the length of punishment phase makes it easier to sustain free trade.

3.4 Conclusions

In summary, in a multi-country model with symmetric endowment size under perfect competition, where trade is determined by comparative advantages, both the degree of comparative advantage and the number of countries significantly affect the sustainability of free trade in a repeated trade game. Starting from a constituent game in which countries choose their own import tariffs, this chapter shows that such a trade policy game always leads to a Prisoners' Dilemma. In this Prisoners' Dilemma situation, all the countries use welfare-maximizing import taxes, which is the trade game's interior Nash equilibrium. Both the individual and the world receive a lower welfare level in the interior Nash equilibrium than under free trade.

As it is well-known that cooperation, which refers to multilateral free trade in this study, can be sustained among all the countries by the threat of being punished if any country deviates in a repeated game. This chapter analyses the enforceability of free trade in an infinitely and a finitely repeated game. As pointed out by Dixit (1987) that countries minimax each other by using prohibitive tariffs is also a Nash equilibrium in a trade policy game, this chapter considers two trigger strategies in an infinitely repeated game. They are known as Nash reversion trigger strategies, that using the reversion to interior Nash equilibrium as a threat to sustain free trade, and minimax reversion trigger strategies, that using reversion to autarky as a threat point. An infinite minimax reversion turned out to be the most severe punishment among all the other sanctions. This result is consistent with the case of two countries model in chapter two. The critical discount factor increases in the number of countries with Nash reversion but decreases with minimax reversion, which is a significant result. It implies that when more nations join the WTO and the punishment for deviation is the interior Nash equilibrium, free trade becomes more difficult to sustain. However, if deviations are followed by autarky, a greater number of WTO members make it easier to achieve and sustain free trade. Also, the degree of comparative advantage makes it easier to sustain free trade with infinite Nash reversion, whereas make it more difficult with infinite minimax reversion. Since an endless punishment seems implausible, this chapter considered the case when punishment phase only lasts for a few rounds. Results remain the same as compared to the case of infinite reversions, and the critical discount factor gets closer to that with infinite reversion when punishment phase last

longer. Free trade is also proved to be sustainable in a finitely repeated game and countries always have the strongest incentive to deviate at the last possible moment due to the fact that no country wins a tariff war in a symmetric endowment model. The critical discount factors are increasing in the degree of comparative advantages and decreasing in the number of countries.

This chapter is an extension to a traditional 2-country 2-good exchange trade model. Conventional wisdom might suggest that with more countries, it becomes more difficult for all of them to cooperate and choose free trade policy. However, this chapter demonstrated that this is not the case when the punishment for deviation is to revert to autarky. One might notice that critical discount factors are not always increasing in the number of countries with Nash reversion, such a positive relationship is observed when there are over 17 countries in the case of $z=100$. This result leads to the limitations of this chapter. Further studies could explore the connection between comparative advantages and the number of countries that gives the lowest critical discount factor. It can be numerically shown that with a larger scale of comparative advantage, more countries are needed to ensure the positive relationship between critical discount factor and the number of countries. For example, a positive relationship might only be observed when there are over 20 countries in the case of some z greater than one hundred. However, this conjecture still needs to be analytically proved. To address the problem of re-negotiation, this chapter used a limited number of round of punishment followed by cooperation, however, a renegotiation-proof equilibrium is worth to be considered. Besides Nash reversion and minimax reversion trigger strategies, one could also investigate in other strategies to explore the sustainability of cooperation. Also, the theoretical framework in this chapter could be examined empirically.

3.5 Appendix B

3.5.1 Appendix B.1

The representative country i 's equilibrium consumptions can be obtained by substituting:

$$\tau_i^D = \frac{-n(n-1)(n+1+z) + \Phi}{2(n-1)(2n-1+z)}$$

$$p_{-i}^D = \frac{2-2z-n(5-3z+n(n-4+z)) + \Phi}{2(n-1+z)(2n-1+z)}$$

where $\Phi = \sqrt{n(n-1)(n-1+z)(n(n+1)^2 + n(n+7)z + 4z^2)}$ into demand (3.2.6). It gives:

$$C_{ii}^D = \frac{x(\Phi + n(\Psi - \Phi))}{2n(2n-1+z)}$$

$$C_{ji}^D = \frac{nx(3n^2 + 1 + z(2z-1) + n(5z-2)) - x\Phi}{2n(1+n(n-1+z))}$$

where $\Psi = n^2(n-1) + 3n-1 + z(n+1)^2 + 2z^2$.

Welfare in (3.2.15) is then:

$$U^D = \frac{x}{2n} \left(\frac{\Phi + n(\Psi - \Phi)}{2n-1+z} \right)^{\frac{1}{n}} \left(\frac{n(3n^2 + 1 + z(2z-1) + n(5z-2)) - \Phi}{n(n-1+z) + 1} \right)^{\frac{n-1}{n}}$$

3.5.2 Appendix B.2

The optimisation problem faced by the i th country in a tariff war is:

$$\begin{aligned} \max_{\tau_i, p_{-i}} \quad & n \log(U_i) \\ & = n \log(x) - n \log(n + \tau_i) + \log(1 + \tau_i) + n \log(1 + z + (n-1)p_{-i}) - (n-1) \log(p_{-i}) \\ \text{s.t.} \quad & \frac{1 + \tau_i}{n + \tau_i} (1 + z + (n-1)p_{-i}) + \frac{n-1}{n + \tau_{-i}} ((n + z - 1)p_{-i} + 1) = n + z \end{aligned}$$

The Lagrangian for the model is:

$$\begin{aligned} \mathcal{L} = & n \log(x) - n \log(n + \tau_i) + \log(1 + \tau_i) + n \log(1 + z + (n-1)p_{-i}) - (n-1) \log(p_{-i}) \\ & - \lambda \left(\frac{1 + \tau_i}{n + \tau_i} (1 + z + (n-1)p_{-i}) + \frac{n-1}{n + \tau_{-i}} ((n + z - 1)p_{-i} + 1) - n - z \right) \end{aligned}$$

The first-order conditions are:

$$\frac{\partial \mathcal{L}}{\partial \tau_i} : \frac{-n}{n + \tau_i} + \frac{1}{1 + \tau_i} - \lambda (1 + z + (n-1)p_{-i}) \left(\frac{1}{n + \tau_i} - \frac{1 + \tau_i}{(n + \tau_i)^2} \right) = 0$$

$$\frac{\partial \mathcal{L}}{\partial p_{-i}} : \frac{n(n-1)}{1 + z + (n-1)p_{-i}} - \frac{n-1}{p_{-i}} - \lambda (n-1) \left(\frac{1 + \tau_i}{n + \tau_i} + \frac{n + z - 1}{n + \tau_{-i}} \right) = 0$$

$$\frac{\partial \mathcal{L}}{\partial \lambda} : p_{-i} - \frac{\tau_{-i} - \tau_i + (n + \tau_{-i})(n + z + \tau_i)}{n^2 + nz + \tau_{-i} + (2n + z + \tau_{-i} - 1)\tau_{-i}} = 0$$

Let $\tau_i = \tau_{-i} = \tau^N$, the first-order conditions simplify to:

$$\frac{\partial \mathcal{L}}{\partial \tau_i} : \frac{\tau^N}{1 + \tau^N} + \lambda \frac{1 + z + (n-1)p_{-i}}{n + \tau^N} = 0$$

$$\frac{\partial \mathcal{L}}{\partial p_{-i}} : \frac{n}{1 + z + (n-1)p_{-i}} - \frac{1}{p_{-i}} - \lambda \frac{\tau^N + n + z}{n + \tau^N} = 0$$

$$\frac{\partial \mathcal{L}}{\partial \lambda} : p_{-i} = 1$$

And one can get the solution for Nash tariff from solving a quadratic equation:

$$\left(\tau^N\right)^2 + n\tau^N - z = 0$$

$$\text{where } \tau^N = \frac{1}{2}(\sqrt{n^2 + 4z} - n).$$

3.5.3 Appendix B.3

To show that countries always want to deviate at the very last round when trying to sustain free trade for $T-k$ round in a finitely repeated game. Free trade is sustainable for $T-k$ round, if and only if there is no incentive for any country to deviate from the first round of the game till the $(T-k)$ th round. That is, $\delta^* = \text{Max}\{\delta^1, \delta^2 \dots \delta^i \dots \delta^{T-k}\}$, where δ^i is the incentive to deviate at the i th round. δ^* represents the largest discount factor throughout the game.

A country has no incentive to deviate at the $(T-k)$ th round if:

$$U^F + \delta U^N + (\delta)^2 U^N + \dots + (\delta)^k U^N > U^D + \delta U^A + (\delta)^2 U^A + \dots + (\delta)^k U^A$$

where δ^{T-k} is obtained by setting both sides equal.

δ^{T-k-1} is derived from the following inequality where $\delta > \delta^{T-k-1}$:

$$U^F + \delta U^F + (\delta)^2 U^N + \dots + (\delta)^{k+1} U^N > U^D + \delta U^A + (\delta)^2 U^A + \dots + (\delta)^{k+1} U^A$$

...

The incentive for a country to deviate in the 2nd round of game δ^2 comes from:

$$\begin{aligned} U^F + \delta U^F + \dots + (\delta)^{T-k-2} U^F + (\delta)^{T-k-1} U^N + \dots + (\delta)^{T-2} U^N \\ > U^D + \delta U^A + (\delta)^2 U^A + \dots + (\delta)^{T-2} U^A \end{aligned}$$

And δ^2 is obtained from setting the following inequality equal:

$$\begin{aligned} U^F + \delta U^F + \dots + (\delta)^{T-k-1} U^F + (\delta)^{T-k} U^N + \dots + (\delta)^{T-1} U^N \\ > U^D + \delta U^A + (\delta)^2 U^A + \dots + (\delta)^{T-1} U^A \end{aligned}$$

By rearranging those inequalities, one could observe that any of them can be nested in the later one. For example, the above four inequalities can be arranged sequentially as:

$$U^F + \delta U^N + (\delta)^2 U^N + \dots + (\delta)^k U^N - U^D - \delta U^A - (\delta)^2 U^A - \dots - (\delta)^k U^A > 0$$

$$U^F + \delta U^N + (\delta)^2 U^N + \dots + (\delta)^k U^N - U^D - \delta U^A - (\delta)^2 U^A - \dots - (\delta)^k U^A \\ + \delta (U^F - U^N) + (\delta)^{k+1} (U^N - U^A) > 0$$

$$U^F + \delta U^F + \dots + (\delta)^{T-k-2} U^F + (\delta)^{T-k-1} U^N + \dots + (\delta)^{T-2} U^N \\ - U^D - \delta U^A - (\delta)^2 U^A - \dots - (\delta)^{T-2} U^A > 0$$

$$U^F + \delta U^F + \dots + (\delta)^{T-k-2} U^F + (\delta)^{T-k-1} U^N + \dots + (\delta)^{T-2} U^N \\ - U^D - \delta U^A - (\delta)^2 U^A - \dots - (\delta)^{T-2} U^A \\ + (\delta)^{T-k-1} (U^F - U^N) + (\delta)^{T-1} (U^N - U^A) > 0$$

Since there are always gains from trade, as demonstrated in section 3.2.2, and countries always lose in a tariff war in a symmetric structure, we have $U^F > U^N > U^A$. Therefore, if the first inequality holds, the second one holds. The same applies to the third and fourth one above. The monotonicity feature is showed in the incentives to deviate such that $\delta^{T-k} > \delta^{T-k-1} > \dots > \delta^2 > \delta^1$. Countries have the strongest incentive to deviate as late as possible, $\delta^* = \text{Max}\{\delta^1, \delta^2 \dots \delta^i \dots \delta^{T-k}\} = \delta^{T-k}$. In that case, in a finitely repeated game, free trade is sustainable for $T-k$ round if no country wants to deviate at the $(T-k)$ th round.

Chapter 4 : International Trade and Environmental Policy

under Oligopoly: Are IEAs Sustainable?

4.1 Introduction

Prior to the globalized world, there were two basic environmental concerns: natural resource protection and pollution damage. Since both pollution and wildlife cause environmental issues across national boundaries, action to alleviate them sometimes required cooperation from several countries. Following the economic recovery after Second World War in the 1950s and 1960s, pollution such as oil tanker discharges, which do not respect borders arose. Since the 1970s, new forms of pollution, such as "acid rain", have made people realise that some environmental problems, including the thinning of the stratospheric ozone layer and the possibility of climate change, could truly cause problems globally (Vogler, 2019). For environmental problems that have a transboundary nature and a global scope, such as the typical climate issue, there is a need for cooperation through an international environmental agreement (IEA) to implement the social optimum. Since the early 1900s, countries have negotiated and signed hundreds of international legal agreements to address environmental problem that cannot be solved by an individual country.¹ The first international environmental treaty perhaps goes to the International Convention for the Regulation of Whaling in 1946, which aimed at the "proper conservation of whale stocks and thus make possible the orderly development of the whaling industry". By January 2021, there are 88 parties to the convention.² Up to 2020, there were over 1,300 multilateral environmental agreements (MEAs) and over 2,200 bilateral environmental agreements (BEAs) in force, dealing with various environmental issues, for example, marine pollution, air and atmospheric pollution,

¹ See Barrett (2003), who presented a comprehensive list of multilateral IEAs, Barrett (2005), and Mitchell (2003) for a substantial survey on the international environmental agreement.

² For the information of membership, please see: [International Whaling Commission](https://www.whalingcommission.org/).

civil nuclear, nature and wildlife protection and international river, lakes and groundwaters pollution etc.

The potential use of border taxes to resolve environmental externalities is a focused area in most industrialised countries. Since carbon neutrality has been brought to the fore by data as the rapid rise of greenhouse gas emissions and becomes a topic of major interest in international environmental area, the OECD, the WTO, the European Commission, and other international organisations are currently evaluating possible environmental tax reforms and their effect on national welfare and competitiveness.³ Different to an import tariff, a border adjustment tax is a value-added tax levied on imported goods and is levied depending on where a good is consumed rather than where it is produced. It would limit the incentives for profit shifting across countries by means of transfer pricing towards lower tax jurisdictions (Auerbach and Holtz-Eakin, 2016). The border tax also has its political rationale and is expected to help raise government revenues to cover the deficit that would emerge from a reduction in the corporate tax rate, as in Amiti et al. (2017). A carbon border tax levied by one country could offset untaxed CO₂ emissions in another producing countries and mitigate the environmental externality. The EU prepares to become the first bloc in the world to impose a levy on carbon-intensive goods at its border. The UK is also preparing to introduce its own unilateral carbon border adjustment mechanisms (CBAMs), and the OECD is seeking for global plan for carbon prices to a prevent trade wars between countries with different environmental policies.

It is well known that the optimal price of pollution should be equal to marginal social damage under perfect competition, as in Pigouvian rule. However, in the case of an imperfectly competitive market where firms have market power, there could be misallocation attribute to distortions form environmental externality and

³ At the U.S. Climate Summit in April 2021, U.S. President Biden pressured countries to either speed up carbon neutral pledges, or commit to them in the first place, which is treated as a follow-up to Paris Agreement. There are 136 countries have committed to carbon neutrality and confirmed by pledges to the Carbon Neutrality Coalition, as tracked by *Energy and Climate Intelligence Unit*. Suriname and Bhutan have achieved net zero emissions, but there are still numerous countries in the race. For tackling this issue, see various articles relating to carbon prices and policies of limiting climate change from *Financial Times*.

monopoly/oligopoly distortion. A tax on pollution can undoubtedly reduce environmental damages, but it may cause firms to reduce production. In monopoly, the Pigouvian rule failed to consider the market distortion since production was discouraged, as first challenged by Buchanan and Wm. Craig (1962) and Buchanan (1969). Since then, research has begun to reconsider the implication of the Pigouvian rule in imperfect competitions. Barnett (1980) was the first to address the problem of taxation for control of external effects in monopoly and therefore determined the second-best optimal emission tax. The first-best environmental tax is based solely on marginal external damages and ignores the social cost of output contraction by a producer whose output is already below an optimum level. When polluters are imperfectly competitive, Barnett (1980) demonstrated that the second-best optimal policies lead to a tax rate that may be less than marginal damage. In between of a perfect competition and monopoly models, Cournot model where firms compete over quantities, is the one discussed in the literature in most detail. Levin (1985) was the first to discuss the effect of an emission tax in Cournot oligopoly in an asymmetric framework and did comparative statics analyses. Simpson (1995) also presented the case of asymmetric Cournot duopoly. In Levin's model, there is no abatement technology, and emission is proportional to output. Government imposes a uniform tax rate on all output, which is the only source of firm's cost. He demonstrated that an emission tax can exacerbate pollution, in which case a small emission subsidy could improve a country's welfare by lowering emissions while increasing output. However, the optimum subsidy was not derived. Ebert (1991) then analysed the second-best environmental policy under Cournot oligopoly within a symmetric structure where pollution was solely determined by output. It was showed that a tax can either be put on emission or on output, and there existed a tax rate that achieve social optimal outcome.⁴

While environmental policy under imperfect competition has been thoroughly investigated, environmental issues in an open economy have also been a hot topic ever since Markusen (1975) pointed out that in perfect competition, environmental policy

⁴ Studies investigating in environmental policy under imperfect competition also include the effect of market structure, the form of policies (taxes, standards, trading permits etc.) and abatement technologies etc. For extensive survey of the subsequent literature, see Requate (2005).

can effectively affect a country's terms of trade. Assuming that all markets are competitive, in a simple two-commodity, two-country model, he analytically showed that in the absence of trade barriers, emission taxes can serve as a substitute for trade policy. Therefore, in order to improve the terms of trade, a country could potentially impose a small emission tax on emissions or output (in the case of emission is completely determined by output) and over-internalise damage. In trade theory, Brander and Spencer (1985) showed that rather than taxing exports to improve the terms of trade, which is optimal under perfect competition, the optimal trade policy under Cournot oligopoly results in an export subsidy that makes exports cheaper than under free trade while increasing market share. An export subsidy is used to shift profit to domestic firms at the expense of worsening the terms of trade, known as the profit-shifting effect. This result also presented by Dixit (1984), who considered import tariffs and production subsidies as well as an export subsidy when discussing appropriate policies in international trade under oligopolistic market. When it comes to environmental policy in a strategic trade structure, Barrett (1994b), Conrad (1993) and Kennedy (1994) discovered that environmental policy has an impact on the terms of trade and can shift profit the same way as trade policies. An emission tax can be viewed as an implicit trade tax that can be used to subsidise exports indirectly. There are two countries in their models, each with a polluting firm, and firms compete to export output to a third country.⁵ Conrad (1993) and Kennedy (1994) considered emission taxes whereas Barrett (1994b) analysed environmental standards under both quantity and price competition. Barrett (1994b) considered two types of environmental policy: an environmentally optimal emission standard, in which pollution is lowered to the point where marginal environmental damage equals marginal abatement cost, and a strategically optimal emission standard, in which welfare is maximised. In a non-cooperative trade game, the strategic outcome of environmental policy is lower than the Pigouvian level, and a government has incentives to set an environmental tax below marginal damage and over-internalise marginal damage. This is because the incentive to internalise environmental damages is affected by a country's profit/rent shifting ability. Conrad (1996b) extended his previous research from 1993 by

⁵ If the domestic firm engaging in imperfect competition also serve domestic consumers, government has to balance the trade-off between domestic consumer surplus and the terms of trade effect or the profit shifting effect.

including domestic consumers. Conrad (1996a) also extended Barrett (1994b)'s paper by studying differentiated product under Bertrand duopoly.⁶ Duval and Hamilton (2002) analysed cooperative and non-cooperative environmental taxes under oligopoly, in which a polluting input is used to produce a single non-differentiated product. They studied the impacts of asymmetries in consumption, production, and environmental damage leakage on the optimal environmental tax policies using a specific environmental damage function that incorporates several forms of transboundary pollution. It was shown that optimum cooperative tax depends on marginal environmental damage whereas the optimum non-cooperative tax is influenced by the terms of trade, pollution leakage (transboundary effect) and market power, and is below the cooperative level.

Since international trade policy can be analysed using game theory and environmental policy can be used as a substitute for trade policy, the game-theoretical analysis of international environmental problems has received increasing attention. Game theory is a mathematical method that studies the interaction between agents based on behavioural assumptions about the preference of agents and makes prediction about the outcome of these interactions by applying various equilibrium concepts. As pointed out by Finus (2008) that game theory seems to be ideal tool to study International Environmental Agreements as IEAs provide a public good with transboundary externalities from which nobody can be excluded. He discussed membership models that deal with the problems of participation and used an empirical climate module linked to STACO model, which is a game theoretic module and illustrated the impact of the design of an IEA on cooperation. Although, there some scholars point out that game theoretic analyses are assuming too much about the rationality of agents and argue that such analyses do not capture important aspects of international pollution problems. Finus (2000) surveyed the application to the Kyoto-Protocol and qualified such critique by showing the importance of game theoretical analyses for policy analyses and recommendations. He defines and discusses the need and the difficulties for cooperation using game theoretical analyses, and also discusses

⁶ Plenty of literature were based on Conrad-Kennedy-Barrett model, these includes Ulph (1994a), (1994b), (1996a), (1996b), Simpson and Bradford (1996) and others. For studies about environmental policy in the presence of international trade see, for example Rauscher (1997), Althammer and Buchholz (1995, 1999).

policy instruments in global pollution control. Then he applied the theoretical results to the analysis of the Kyoto-Protocol to show that the theoretical results are helpful in evaluating IEAs.⁷ The majority of literature shows that cooperative behaviour in setting environmental policy generates higher welfare than non-cooperative behaviour, which is described in game theory as the Nash equilibrium. It is, however, not easy for countries to cooperate. This is because each country may have an incentive to be a free-rider, and there is no supranational institution that can enforce cooperation from a game-theoretical perspective. Barrett (2003) and Finus (2003) also give examples which prove that participation and compliance is a problem when dealing with global environmental problems. The OECD, the WTO and many other institutions only provide a guidance which is not binding. They have rules and dispute resolution processes, but nations are sovereign. As a result, whether a treaty can be self-enforced after signed an IEA, still need to be investigated. The most commonly used model to discuss the enforceability of an IEA is the dynamic game model where the game is modelled in a repeated game, as in Barrett (1994b), Barrett (1994a), Finus and Rundshagen (1998) and Stähler (1994). The use of a repeated game is not only a result of the idea of the Folk Theorem by Friedman (1971), who pointed out that cooperation can be supported as a subgame perfect equilibrium when players are patient enough, but also because, as Finus (2002) presented, IEAs are generally in force for a long period of time and by the time countries sign them, they are faced with an apparently infinite game. Countries are punished if they violate the terms of an IEA in a repeated game, in which case, with the fear of being punished, a country may prefer collusion.

This chapter extends the analyses of strategic environmental policy under imperfect competition (Cournot duopoly) and uses game theory approach to analyse international environmental policy in international trade. Both cooperative and non-cooperative equilibrium in trade and environmental policies are considered. There are very few papers that look at the simultaneous regulation of both monopoly/oligopoly distortion and environmental externality. To regulate both market power and pollution, I follow the idea of policy targeting literature, for example Bhagwati and Srinivasan

⁷ For publications that analyse the formation and stability of international environmental agreements using game theory, see for example Folmer and De Zeeuw (1999,2000), Finus (2001,2003), Wagner (2001).

(1995), and assume that governments deal with trade and environmental issues separately. Specifically, using trade policy instruments to deal with trade issues and environmental policy instrument to deal with environmental problems. Cooperation is the case that countries pledge to an IEA and use an environmental optimal emission tax as in Barrett (1994b) in a two-country, two-firm symmetric framework and is examined in a repeated game. Although free trade is not efficient in an imperfectly competitive market, it is assumed that by cooperating, countries agree to refrain from intervening in international trade since free trade is a focal point.⁸ Within a Cournot duopoly market structure, the IEA cannot result in a first-best allocation. To mitigate the issue, I allow countries to subsidise production to deal with oligopolistic distortion domestically. If the government could regulate emissions and output simultaneously, the optimum policy would be to tax emissions and subsidise firms. Although such a production policy is not practical as subsidy is generally prohibited in global market by some international agreement (EU Treaties, WTO rules etc.). Theoretically, government has incentives to unilaterally subsidise output as well as use a strategic environmental policy to improve welfare. In the presence of retaliation, a non-cooperative environmental and trade policy is modelled as a Nash equilibrium in a constituent policy game, in which case both countries receive a lower welfare as compared the welfare level under cooperation. A non-cooperative behaviour results in the prisoners' dilemma. It is well-known that the prospects for cooperation in the prisoners' dilemma are enhanced in repeated game, therefore, cooperation can be self-sustained by the threat of getting into a worse situation in a repeated game. This chapter focuses on self-enforcing cooperation that is sustained by trigger strategies where countries obey the cooperation rule until a deviation is observed. If any countries defects, all countries revert to the non-cooperative equilibrium. The following questions are analysed: Can cooperation in terms of a multilateral free trade and an IEA be self-enforced? Is such a cooperation sustainable? If so, which measures affect the sustainability and how the variables in interest (relative environmental damage, product differentiation and pollution leakage) influence the sustainability? It will be shown that an IEA with free trade is sustainable provided that both countries

⁸ For extensive the trade agreement literature, see Riezman (1991), Bagwell and Staiger (1997a, 1997b, 1998, 2016), Bond et.al (2001) and Saggi (2006).

are patient enough. Both the level of environmental damage and spillover effect play important roles in determine the level of sustainability.

The structure of the chapter is as follows. In the next section I set out the structure of the model, which is a two-stage game. In section 3, I analyse the welfare effect of different trade and environmental policies and present two Nash equilibria – the interior Nash equilibrium and an equilibrium that results in autarky. In section 4, cooperative equilibrium is analysed as a subgame perfect equilibrium in a repeated game and the sustainability of such a cooperation is discussed. Section 5 offers some conclusions.

4.2 The Model

The constituent trade and environmental policy game with two countries is a two-stage game. In the first stage, government in each country use a set of production, trade, and environmental policies. In the second stage, producers treat stage one policies as parametric and play as Cournot duopolies.

The model is set up with two countries, $i = 1, 2$, in each of which is located a single producer. Firms produce differentiated products and sell in the segmented markets of the two countries. The costs of producing output in both countries are given by the same constant marginal cost c and there are no trade costs. Firm in the i th country produces x_i of the total output. It consists of production for domestic market x_{ii} , which sells at price p_{ii} , and the production for exports x_{ij} , which sells at price p_{ij} in the j th country. During the production process, firms produce a pollutant that is discharged into the environment. The pollutant does not immediately affect a firm's profit, but it does worsen a country's welfare and creates an externality. Following Brian and Taylor (1995), the generated pollution could be a transboundary bad that affects not only the producing country but also the other country completely or in some percentages. Each country i imposes a specific tax t_i on domestic production, a specific import tariff τ_i on its imports and a specific export tax ε_i on exports. In the policy game, each of the three taxes plays two roles. One role is to act as a production or trade policy, while the other is to act as an environmental policy to reduce the environmental damage. If any of the taxes is negative, then it is a subsidy.

Preferences of the representative consumer in both countries are given by a quasi-linear quadratic utility function, as in Vives (1985) and Clarke and Collie (2003):

$$U_i = \alpha(x_{1i} + x_{2i}) - \frac{\beta}{2}(x_{1i}^2 + x_{2i}^2 + 2\phi x_{1i}x_{2i}) + z_i \quad i = 1, 2 \quad (4.2.1)$$

where z_i is the consumption of a numeraire good produced by a perfectly competitive industry with a constant return to scale (CRS) technology and no externality. $0 < \phi < 1$ is a measure of the degree of product substitutability ranging from zero when products are independent to one when products are perfect substitutes.

With all the parameters positive and $\alpha > c$, the inverse demand functions from utility maximisation for two countries are:

$$\begin{aligned} p_{1i} &= \alpha - \beta(x_{1i} + \phi x_{2i}) \\ p_{2i} &= \alpha - \beta(x_{2i} + \phi x_{1i}) \quad i = 1, 2 \end{aligned} \quad (4.2.2)$$

The game is solved by backwards induction to obtain the subgame perfect equilibrium. The first step is to solve the second stage of the game where firms compete as Cournot oligopolists given the policies set by the governments.

Firm i 's total profits Π_i includes profits from sales in the domestic market π_{ii} and profits from exporting π_{ij} , i.e., $\Pi_i = \pi_{ii} + \pi_{ij}$. Given the government's policies on production and trade, profit functions are:

$$\begin{aligned} \pi_{ii} &= (p_{ii} - c - t_i)x_{ii} \\ \pi_{ij} &= (p_{ij} - c - \varepsilon_i - \tau_j)x_{ij} \quad i, j = 1, 2 \end{aligned} \quad (4.2.3)$$

where t_i , ε_i and τ_i are production tax, export tax and import tariff, respectively, imposed by the i th country. In the Cournot duopoly, each firm chooses the level of output to maximise its profits, taking its rival's and government's policies as given. The optimum outputs are solved:

$$\begin{aligned} x_{ii} &= \frac{A + \phi \varepsilon_j - (2t_i - \phi \tau_i)}{B} \\ x_{ij} &= \frac{A - 2\varepsilon_i - (2\tau_j - \phi t_j)}{B} \quad i, j = 1, 2 \quad i \neq j \end{aligned} \quad (4.2.4)$$

where $A = (2 - \phi)(\alpha - c) > 0$ and $B = \beta(4 - \phi^2) > 0$. Substituting the Cournot equilibrium outputs (4.2.4) into the inverse demand function (4.2.2) yields the Cournot equilibrium prices. Such equilibrium prices can be used to derive Cournot equilibrium total profit in (4.2.3), so that firm's profit depends on a country's policies. An export tax reduces a country's export amount and increases its rival's domestic production while an import tariff decreases the other country's export and increases the country's own domestic output. Country i ceases to export when there exists a set of

prohibitive policies, which leads to $2\tau_j - \phi t_j \geq A - 2\varepsilon_i$. Note that whether a country will trade or not is only affected by its own export tax choice and the other country's import tariff and production tax. Given any rate of an export tax, there will be no profit from exporting if the other country sets a prohibitive import tariff or/and a prohibitive production subsidy, then exports are zero.

Having derived the Cournot equilibrium, the next step is to solve the first stage of the game. Government in each country is assumed to be indifferent about the redistribution of tax revenues and collecting tax is not a government objective. Governments focus on maximising welfare, which includes consumer welfare, producer profits, tax revenue and the negative environmental externality caused by pollution from production. Collected taxes will be redistributed to the consumers in a lump-sum way.

Since utility function is quadratic, the demand functions are linear in prices. Also, since preferences are assumed to be quasi-linear, consumer surplus will be a valid measure for consumer welfare. And it can be derived from the quadratic utility function by deducting the expenditure of the consumption goods from total utility as in Vives (1985):

$$\begin{aligned} CS_i &= U_i - p_{ii}x_{ii} - p_{ji}x_{ji} - z_i \\ &= \frac{\beta}{2}(x_{ii}^2 + x_{ji}^2 + 2\phi x_{ii}x_{ji}) \quad i=1,2 \quad i \neq j \end{aligned} \quad (4.2.5)$$

Environmental damage is caused by pollution that depends upon output. The social damage function is assumed to be quadratic:

$$D_i = \frac{\sigma}{2}(x_i + \rho x_j)^2 \quad (4.2.6)$$

where $\rho \in (0,1)$ is an environmental spillover effect, which measures the geographic scope of pollution.⁹ Following Ulph (1996a), it is assumed that there is no pollution

⁹ The damage function follows the idea from Ulph (1996a) and Barrett (1994a), who presented the damage costs as quadratic functions of output. This chapter further adds on an effect of environmental spillover to include the possibility of local, transboundary and global externalities.

associated with the numeraire good, only good x generates pollution emission. The pollutant causes damage only to the local economy if ρ equals zero, while it results in a global damage when ρ is equal to one. σ is a damage parameter that shows the degree to which environmental damage depends on output.

Then, the i th country's welfare is the summation of consumer surplus, producer's profits from selling good in domestic and foreign market, government revenues from taxing domestic production, exports and imports, and the negative environmental externality specified by the damage function. It can be expressed explicitly as follows:

$$\begin{aligned}
 W_i &= CS_i + \Pi_i + t_i x_{ii} + \varepsilon_i x_{ij} + \tau_i x_{ji} - D_i \quad i, j = 1, 2 \quad i \neq j \\
 &= \frac{\beta}{2} (x_{ii}^2 + x_{ji}^2 + 2\phi x_{ii} x_{ji}) + \Pi_i + t_i x_{ii} + \varepsilon_i x_{ij} + \tau_i x_{ji} - \frac{\sigma}{2} ((x_{ii} + x_{ij}) + \rho (x_{jj} + x_{ji}))^2
 \end{aligned} \tag{4.2.7}$$

Denoting $\kappa = \sigma/\beta$ as the relative environmental damage, welfare of the two countries can then be written as functions of production and trade policies by substituting the Cournot equilibrium profits and outputs into the welfare function (4.2.7).¹⁰

$$\begin{aligned}
 W_i &= \frac{1}{\beta(2+\phi)^2} \left(\lambda_0 + \lambda_4 t_i^2 + \lambda_5 \varepsilon_i^2 + \lambda_8 \tau_i^2 + \lambda_1 t_j^2 + \lambda_2 \varepsilon_j^2 + \lambda_3 \tau_j^2 \right. \\
 &\quad + (\lambda_{17} + \lambda_{19} \tau_j + \lambda_9 \varepsilon_j + \lambda_{18} t_j) \varepsilon_i \\
 &\quad + (\lambda_{14} + \lambda_9 \varepsilon_i + \lambda_{16} t_i + \lambda_9 \tau_j + \lambda_{15} \varepsilon_j + \lambda_{10} t_j) \tau_i \\
 &\quad + (\lambda_{11} + \lambda_7 \varepsilon_i + \lambda_7 \tau_j + \lambda_9 \varepsilon_j + \lambda_9 t_j) t_i \\
 &\quad \left. + (\lambda_{12} + \lambda_9 \varepsilon_j + \lambda_{13} t_j) \tau_j + (\lambda_6 + \lambda_{10} \varepsilon_j) t_j + \lambda_{20} \varepsilon_j \right)
 \end{aligned} \tag{4.2.8}$$

¹⁰ The parameter κ shows the environmental damage relative to market size. The reason to create such a parameter is to simplify the model so that there are fewer variables. Also, since market size positively affects consumer welfare, whereas environmental damage parameter decreases a country's benefits, σ/β tells the significance of the negative environmental externality in terms of consumer surplus in welfare function, given the quadratic form of both consumer surplus and the damage function.

It is a quadratic function of three policies of each country $(t_i, \tau_i, \varepsilon_i, t_j, \tau_j, \varepsilon_j)$,

where the coefficients are:

$\lambda_0 \equiv (\alpha - c)^2 (3 + \phi - 2\kappa(1 + \rho)^2)$	$\lambda_0 > 0$ if $\kappa < (3 + \phi) / (2(1 + \rho)^2)$
$\lambda_1 \equiv (2\phi^2 - \kappa(\phi - 2\rho)^2) / (2(2 - \phi)^2)$	$\lambda_1 > 0$ if $\kappa < 2\phi^2 / (\phi - 2\rho)^2$
$\lambda_2 \equiv (4 - \phi^2 - \kappa(\phi - 2\rho)^2) / (2(2 - \phi)^2)$	$\lambda_2 > 0$ if $\kappa < (4 - \phi^2) / (\phi - 2\rho)^2$
$\lambda_3 \equiv (8 - \kappa(\rho\phi - 2)^2) / (2(2 - \phi)^2)$	$\lambda_3 > 0$ if $\kappa < 8 / (\rho\phi - 2)^2$
$\lambda_4 \equiv (\phi^2 - 4 - \kappa(\rho\phi - 2)^2) / (2(2 - \phi)^2)$	$\lambda_4 < 0$
$\lambda_5 \equiv (4\phi^2 - 8 - \kappa(\rho\phi - 2)^2) / (2(2 - \phi)^2)$	$\lambda_5 < 0$
$\lambda_6 \equiv 2(\alpha - c)(\kappa(1 + \rho)(2\rho - \phi) + \phi) / (2 - \phi)$	$\lambda_6 > 0$ if $\kappa(\phi - 2\rho) < \phi / (1 + \rho)$
$\lambda_7 \equiv -\kappa(\phi\rho - 2)^2 / (2 - \phi)^2$	$\lambda_7 < 0$
$\lambda_8 \equiv (3(\phi^2 - 4) - \kappa(\phi - 2\rho)^2) / (2(2 - \phi)^2)$	$\lambda_8 < 0$
$\lambda_9 \equiv \kappa(2\rho - \phi)(\phi\rho - 2) / (2 - \phi)^2$	$\lambda_9 > 0$ if $\rho < \phi/2$
$\lambda_{10} \equiv -\kappa(\phi - 2\rho)^2 / (2 - \phi)^2$	$\lambda_{10} < 0$
$\lambda_{11} \equiv (c - \alpha)(2 + \phi + 2\kappa(1 + \rho)(\phi\rho - 2)) / (2 - \phi)$	$\lambda_{11} > 0$ if $\kappa > (2 + \phi) / (2(2 - \phi\rho)(1 + \rho))$
$\lambda_{12} \equiv 2(c - \alpha)(2 + \kappa(1 + \rho)(\phi\rho - 2)) / (2 - \phi)$	$\lambda_{12} > 0$ if $\kappa > 2 / ((2 - \phi\rho)(1 + \rho))$
$\lambda_{13} \equiv (\kappa(2\rho - \phi)(\phi\rho - 2) - 4\phi) / (2 - \phi)^2$	$\lambda_{13} > 0$ if $\kappa(2\rho - \phi) < 4\phi / (\phi\rho - 2)$
$\lambda_{14} \equiv (\alpha - c)(2 + 2\kappa(1 + \rho)(2\rho - \phi) + \phi) / (2 - \phi)$	$\lambda_{14} > 0$ if $2\kappa(2\rho - \phi) > -(2 + \phi) / (1 + \rho)$
$\lambda_{15} \equiv (\phi^2 - 4 - \kappa(\phi - 2\rho)^2) / (2 - \phi)^2$	$\lambda_{15} < 0$
$\lambda_{16} \equiv (4\phi - \phi^3 + \kappa(2\rho - \phi)(\rho\phi - 2)) / (2 - \phi)^2$	$\lambda_{16} > 0$ if $\kappa(2\rho - \phi) < \phi(4 - \phi^2) / (2 - \phi\rho)$
$\lambda_{17} \equiv (c - \alpha)(\phi^2 + 2\kappa(1 + \rho)(\phi\rho - 2)) / (2 - \phi)$	$\lambda_{17} > 0$ if $\kappa > \phi^2 / ((1 + \rho)(2 - \phi\rho))$

$\lambda_{18} \equiv \left(-\phi^3 + \kappa(2\rho - \phi)(\rho\phi - 2) \right) / (2 - \phi)^2$	$\lambda_{18} > 0$ if $\kappa(2\rho - \phi) < \phi^3 / (\phi\rho - 2)$
$\lambda_{19} \equiv \left(2\phi^2 - \kappa(\rho\phi - 2)^2 \right) / (2 - \phi)^2$	$\lambda_{19} > 0$ if $\kappa < 2\phi^2 / (\phi\rho - 2)^2$
$\lambda_{20} \equiv \frac{(\alpha - c)(-2 + 2\kappa(1 + \rho)(2\rho - \phi) + \phi + \phi^2)}{(2 - \phi)}$	$\lambda_{20} > 0$ if $\kappa(2\rho - \phi) > \frac{(2 - \phi - \phi^2)}{(2 + 2\rho)}$

The welfare function of the i th country is strictly concave in its own production tax, export tax and import tariff.¹¹ Government in the i th country chooses a set of policies $(t_i, \varepsilon_i, \tau_i)$, which include production and trade policies on output for oligopolistic distortion and international trade, and an environmental policy for the negative environmental externality to maximise welfare.

¹¹ See Appendix C for the detailed proof.

4.3 Equilibrium of the Constituent Policy Game

Governments in two countries, both with noncooperative behaviour, set policies aiming at maximising welfare. I first consider the autarky case and then the possibility of countries cooperating by signing an IEA that is optimal to environment together with adopting a free trade agreement. In this chapter, the cooperative equilibrium is defined as a situation in which both countries do not intervene in international trade but use an environmental and production policy to maximise global welfare. If each country focuses on its own individual benefit and act non-cooperatively, government in each country would use a set of policies that potentially lead to a war in terms of trade and environmental policies. In this section, such a policy war is modelled as an interior Nash equilibrium in a trade and environmental policy game, and various production, trade and environmental policies are discussed to compare the associated welfare level.

When there is no trade, either because of prohibitive trade policies that lead to zero profits from trading, or simply as a result of government's decision, firm in each country would act as a monopoly and only supply domestic market. Governments set policies on domestic production to maximise each country's individual welfare. Setting export x_{ij} and x_{ji} equal zero at the beginning of the two stage game and solve firm's problem first.¹² The monopoly in each country i produces $x_{ii} = (\alpha - c - t_i)/2\beta$ where t_i plays two roles. One role is from environmental point of view to cope with environmental externality, and another from production side to deal with monopolistic distortion.¹³ It can be solved that the optimal production tax under autarky is

¹² One could also set the policies to a prohibitive level, i.e., $2\tau_2 - \phi t_2 = (2 - \phi)(\alpha - c) - 2\varepsilon_1$ and $2\tau_1 - \phi t_1 = (2 - \phi)(\alpha - c) - 2\varepsilon_2$ once obtained Cournot equilibrium output. This chapter solves autarky welfare by assuming autarky is the trade policy used by governments in the global market. The calculation is simplified since there is no need to consider export and import policies.

¹³ One would expect that the production policy is a production subsidy, as in a standard monopoly model where there is no environmental damage, resulting policy is a production subsidy equals $\alpha - c$, so that price equals marginal cost, and the oligopolistic distortion is eliminated.

$t^M = (\alpha - c)(\kappa(1 + \rho) - 1)/(\kappa(1 + \rho) + 1)$ in both countries due to symmetries. In autarky, a production tax is implemented from an environmental point of view by being set equal to marginal damage of each country, and a subsidy is used from production perspective by setting price equal to the marginal cost plus marginal environmental damage. The production tax can be decomposed as:

$$t^M = -\frac{(\alpha - c)}{\kappa(1 + \rho) + 1} + \frac{\kappa(1 + \rho)(\alpha - c)}{\kappa(1 + \rho) + 1}$$

where the first term represents a production policy and the second is an environmental policy. Parameter values determine which policy is the dominant one. When κ is large enough such that $\kappa > 1/(1 + \rho)$, tax imposed for the purpose of addressing environmental issues exceeds the production subsidy leaving the total effect on output a positive tax. The total effect, however, also depends on ρ . As the spillover impact grows greater, environmental policies begin to take priority over the production effect.

Welfare under autarky can then be obtained:

$$W^A = \frac{(1 + \kappa(1 - \rho^2))}{(\kappa(1 + \rho) + 1)^2} \cdot \frac{(\alpha - c)^2}{2\beta} \quad (4.3.1)$$

which is independent of the degree of product differentiation ϕ , and is always positive.

4.3.1 Cooperative Equilibrium: Trade Liberalisation and IEAs

In the cooperative equilibrium, an environmental policy is implemented by having taxes on domestic production and traded goods, and a production policy is applied by having a tax on domestic production only. There are no taxes being imposed from the trade point of view. Countries only intervene trade by using an environmental policy, and both countries are assumed to pursue a free trade policy when cooperating. Specifically, in the i th country, a production tax, that has two roles, is used to maximise the total world's welfare and to reduce pollution to the level where the marginal

damage caused by the production just equals the tax applied on output.¹⁴ When it comes to traded goods, countries could use environmental policy either on exported goods or imported goods, suggesting that traded goods are only taxed once for environmental purpose. In this study, I only consider the case when both countries tax emissions from imports, i.e., implement a border tax.¹⁵ Policies in the cooperative equilibrium include a zero tax on exports, and tax equals to marginal environmental damage on imports, and a welfare maximising tax on domestic production.

Countries cooperate by maximising the joint welfare $W_i + W_j$. Each country takes the other country's environmental damage into account when choosing the environment policy, and the tax applied for environmental purpose is $\tau_i = \partial(D_i + D_j)/\partial x_i$, which will be imposed on domestic output as a production tax and be use imports as a tariff.

Production x_i in country i affects the other country j 's welfare through the spillover parameter ρ . Denote the local marginal damage in the i th country by $MD_i = \partial D_i / \partial x_i = \sigma(x_i + \rho x_j)$ with $i = 1, 2$. Total damage to the world economy is measured by $D_i + D_j = \sigma(x_i + \rho x_j)^2 / 2 + \sigma(x_j + \rho x_i)^2 / 2$, and the global marginal damage of producing x_i is derived:

$$\frac{\partial(D_i + D_j)}{\partial x_i} = MD_i + \rho MD_j = \sigma(x_i + \rho x_j) + \sigma(x_j + \rho x_i)\rho, \quad i \neq j$$

¹⁴ The tax imposed for environmental purposes is not essentially the first-best optimum due to the oligopolistic market structure. However, there would be no justification for departing from the Pigouvian rule of environmental policy under a full set of instruments: an export tax or subsidy to shift the profit and a production tax or subsidy to counteract oligopolistic distortion.

¹⁵ One case is that each country imposes a tax on imported goods that are not taxed at source, which follows the concept of a carbon border tax from the Climate Change Committee, [The Sixth Carbon Budget \(December 2020\)](#). And another case is that both countries only tax emissions attributed to exports. Although, given a symmetric structure of the two countries model, the resulting welfare in the two cases are the same under cooperation due to the fact that country i 's imports are country j 's exports.

(4.3.2)

Country i solves the following maximising problem:

$$\begin{aligned} \underset{s_i}{Max} \quad & W_i + W_j \Big|_{(\varepsilon_i=0, \varepsilon_j=0)} \\ s.t. \quad & \tau_i = \sigma(x_i + \rho x_j) + \sigma(x_j + \rho x_i) \rho \end{aligned}$$

where the outputs are Cournot equilibrium outputs from equation (4.2.4).

To solve the welfare maximising problem, one could impose the symmetry assumptions that $t_1 = t_2$ after obtaining the first order conditions.

Solving the welfare maximisation problem yields:

$$\begin{aligned} \tau^C &= \frac{(\alpha - c)\Psi}{3\phi^2 - 4 + \Psi} \\ t^C &= \frac{(\alpha - c)\Psi}{3\phi^2 - 4 + \Psi} + \frac{(\alpha - c)(\phi - 2)^2}{3\phi^2 - 4 + \Psi} \end{aligned} \tag{4.3.3}$$

where $\Psi = \kappa(1 + \rho)^2(5\phi - 6) < 0$. τ^C is the border tax on imports that are not taxed at source. A production tax is applied on domestic production, and t^C implies two policies. The first term in t^C , which is the same as τ^C represents an environmental policy and the second term is a production policy.

It can be seen that the production tax imposed to address oligopolistic distortion (the second term in t^C) is negative, provided that $\alpha > c$, $\kappa > 0$ and $0 < \phi < 1$. It suggests that there is a positive tax to address environmental issues and as one would expect under a Cournot oligopoly, a production subsidy to counterbalance oligopolistic under-production.¹⁶ The total policy effect on domestic production is ambiguous as the tax imposed for environmental purpose could counteract the effect

¹⁶ Such a cooperative equilibrium is not the first best result as both countries are implementing production subsidy optimal to the world rather to the country itself, and the price is above marginal cost.

of a subsidy. It can be seen from (4.3.3) that whether t^C gives a positive solution which implies a tax, or a negative value that represents a subsidy, depends on parameter values. If $(\phi - 2)^2 + \Psi > 0$, that is $\kappa < (\phi - 2)^2 / ((1 + \rho)^2 (6 - 5\phi))$, we have a negative production tax.

Substituting (4.3.3) into Cournot output (4.2.4) and then welfare function (4.2.7) yields welfare under cooperation:

$$W^C = \frac{(\Psi(5\phi - 6) + (7 - 6\phi)(4 - 3\phi^2))}{(\Psi - 4 + 3\phi^2)^2} \cdot \frac{(\alpha - c)^2}{2\beta} \quad (4.3.4)$$

It is a decreasing function of the environmental effect and the relative damage parameter.¹⁷ When the environmental externality becomes transboundary or even global, countries receive a lower welfare in the cooperative equilibrium.

By comparing the cooperative outcome and autarky, one could prove the gains from cooperation. When products produced by two firms are perfect substitutes, and pollutant only cause environmental damage to local economy, that is, when $\phi = 1$, $\rho = 0$, there is no difference between cooperative welfare and autarky welfare. Prices are the same across two countries in the case of perfect substitutes and local environmental damage, and there will be no trade in the cooperative equilibrium for any relative damage κ .

To see whether there are gains, one could solve the first order derivative of welfare difference with respect to product substitutability:

$$\frac{\partial(W^C - W^A)}{\partial\phi} = \frac{(\alpha - c)^2(1 - \phi)(3(4 - 3\phi)(4 - 3\phi^2) + 2A_1A_2)}{\beta(3\phi^2 - 4 + \Psi)^3} < 0$$

¹⁷ Even though the resulting welfare under cooperation is always positive, the possibility that welfare being negative cannot be ruled out from this model due to the negative environmental externality.

where $A_1 = \kappa(1 + \rho)^2 > 0$, $A_2 = 15\phi^2 - 39\phi + 26 > 0$ for $0 \leq \phi \leq 1$. The gains from cooperation decreases in ϕ . When product becomes more differentiated so that ϕ becomes smaller, for any given spillover and relative damage, the gains from cooperation become greater. Since there is no gain when products are homogenous ($\phi = 1$), it is proved that there are always gains from cooperation.

These results lead to the following result:

Result 4.1: $W^C > W^A$, there are always gains from cooperation on environmental and trade policy as compared to autarky. Such a gain from trade is increasing in the degree of product differentiation.

4.3.2 Non-Cooperative Equilibrium

When markets are imperfectly competitive, a government may be tempted to use trade policy as a means of extracting profit from foreign exporters and shifting profits to the domestic firm. The world price of imported good is reduced when a government raises its import tariff in the case of a large country. The importing country can then enjoy an improvement in its terms of trade, which benefits the taxing country. Profits are shifted to domestic firm when a country uses an export subsidy. Even though the subsidising country suffers a negative terms of trade externality, the firm being subsidised can expand its market share and the country becomes better off since price is above marginal cost. It was suggested that a country has motives to use trade and environmental policies to boost its welfare. Despite the gains from cooperation, a country has an incentive to cheat on the cooperation agreements and deviates from free trade and social optimum environmental policy.

To analyse the policy effect, it is useful to write the welfare function (4.2.7) using the indirect utility function:

$$W_i = V_i(p_{ii}, p_{ji}) + \Pi_i + t_i x_{ii} + e_i x_{ij} + \tau_i x_{ji} - D_i \quad i, j = 1, 2 \quad i \neq j$$

If a country unilaterally moves away from the cooperative outcome, while the other country pursues free trade and uses an environmental optimal policy, the country

will set all the policies optimally to maximise its own welfare. An import tariff will be implemented, taking the other country's policy as given:

$$\begin{aligned}\frac{\partial W_i}{\partial \tau_i} = & \frac{\partial V_i}{\partial p_{ii}} \frac{\partial p_{ii}}{\partial \tau_i} + \frac{\partial V_i}{\partial p_{ji}} \frac{\partial p_{ji}}{\partial \tau_i} + (p_{ii} - c - t_i) \frac{\partial x_{ii}}{\partial \tau_i} \\ & + \frac{\partial p_{ii}}{\partial \tau_i} x_{ii} + x_{ji} + \frac{\partial x_{ji}}{\partial \tau_i} \tau_i - \left(\frac{\partial D_i}{\partial x_{ii}} \frac{\partial x_{ii}}{\partial \tau_i} + \frac{\partial D_i}{\partial x_{ji}} \frac{\partial x_{ji}}{\partial \tau_i} \right)\end{aligned}$$

Given the quasi-linear utility function, the marginal utility of income equals one. Therefore, by Roy's identity, consumption in each market is given by $x_{ij} = -\partial V_i / \partial P_{ij}$ and the first order condition can be simplified to:

$$\begin{aligned}\frac{\partial W_i}{\partial \tau_i} = & -\frac{\partial p_{ii}}{\partial \tau_i} x_{ii} - \frac{\partial p_{ji}}{\partial \tau_i} x_{ji} + (p_{ii} - c - t_i) \frac{\partial x_{ii}}{\partial \tau_i} + \frac{\partial p_{ii}}{\partial \tau_i} x_{ii} \\ & + x_{ji} + \frac{\partial x_{ji}}{\partial \tau_i} \tau_i - \left(\frac{\partial D_i}{\partial x_{ii}} \frac{\partial x_{ii}}{\partial \tau_i} + \frac{\partial D_i}{\partial x_{ji}} \frac{\partial x_{ji}}{\partial \tau_i} \right) \quad i, j = 1, 2 \quad j \neq i \\ = & (p_{ii} - c - t_i) \frac{\partial x_{ii}}{\partial \tau_i} + \left(1 - \frac{\partial p_{ji}}{\partial \tau_i} \right) x_{ji} + \frac{\partial x_{ji}}{\partial \tau_i} \tau_i - MD_i \frac{\partial x_{ii}}{\partial \tau_i} - \rho MD_i \frac{\partial x_{ji}}{\partial \tau_i} \\ = & (p_{ii} - c - t_i - MD_i) \frac{\partial x_{ii}}{\partial \tau_i} + \left(1 - \frac{\partial p_{ji}}{\partial \tau_i} \right) x_{ji} + \frac{\partial x_{ji}}{\partial \tau_i} \tau_i - \rho MD_i \frac{\partial x_{ji}}{\partial \tau_i} = 0\end{aligned}\tag{4.3.5}$$

Since the environmental damage is deducted from profit in the first term of the first order derivative, it is a profit-shifting effect from the government's point of view. Without the subtraction of marginal damage, $p_{ii} - c - t_i$ is the profit shifting effect from the firm's point of view. Price is greater than the summation of marginal cost and a production tax. An import tariff increases the output of the domestic firm. i.e., $\partial x_{ii} / \partial \tau_i = \phi / (\beta(4 - \phi^2)) > 0$, thereby shifting profits to the domestic firm. From firm's perspective, there is a positive profit shifting effect, and from the government's perspective, such an effect ambiguously depends on the damage. The second term is the terms of trade effect: the import tariff increases the market price of imports and improves the terms of trade. It can be derived from the Cournot equilibrium price that

$\partial p_{ji} / \partial \tau_i = (2 - \phi^2) / (4 - \phi^2) < 1$, so that the price of imports changes less than the change of the import tariff. This effect is positive if there exist positive imports. The third term shows the effect of an import tariff on the tariff revenue. Import tariffs reduce the volume of imports, resulting in a negative effect when import tariffs are positive. It can also be explicitly solved that $\partial x_{ji} / \partial \tau_i = -2 / (\beta(4 - \phi^2)) < 0$. The last term shows the environmental effect of imports, which is positive as import tariff decreases the volume of imports, and the marginal damage is increasing in output. Imports have no environmental effect on welfare if pollution only affects local economy i.e., $\rho = 0$.

Without environmental effects, which are represented by the terms including a marginal environmental damage, the first order condition in (4.3.6) is positive when import tariff is zero. That is, starting at zero import tariff, welfare increases in import tariff, resulting in a positive optimum import tariff.

Such an optimum tariff can also be generated from the first order condition of the explicit welfare (4.2.8):

$$\frac{\partial W_i}{\partial \tau_i} = \frac{\lambda_{14} + \lambda_{16}t_i + \lambda_9\varepsilon_i + 2\lambda_8\tau_i + \lambda_{10}t_j + \lambda_{15}\varepsilon_j + \lambda_9\tau_j}{\beta(2 + \phi)^2} = 0$$

which yields:

$$\tau_i^*(t_i, \varepsilon_i, t_j, \varepsilon_j, \tau_j) = \frac{\lambda_{14} + \lambda_{16}t_i + \lambda_9\varepsilon_i + \lambda_{10}t_j + \lambda_{15}\varepsilon_j + \lambda_9\tau_j}{-2\lambda_8} \quad (4.3.6)$$

An export tax is also used to maximise the deviating country's welfare, taking the other country's policy as given. The first order condition for choosing an export tax is:

$$\begin{aligned}
\frac{\partial W_i}{\partial \varepsilon_i} &= (p_{ij} - c - \tau_j) \frac{\partial x_{ij}}{\partial \varepsilon_i} + \frac{\partial p_{ij}}{\partial \varepsilon_i} x_{ij} - \left(\frac{\partial D_i}{\partial x_{ij}} \frac{\partial x_{ij}}{\partial \varepsilon_i} + \frac{\partial D_i}{\partial x_{jj}} \frac{\partial x_{jj}}{\partial \varepsilon_i} \right) \\
&= (p_{ij} - c - \tau_j) \frac{\partial x_{ij}}{\partial \varepsilon_i} + \frac{\partial p_{ij}}{\partial \varepsilon_i} x_{ij} - MD_i \frac{\partial x_{ij}}{\partial \varepsilon_i} - \rho MD_i \frac{\partial x_{jj}}{\partial \varepsilon_i} \\
&= (p_{ij} - c - \tau_j - MD_i) \frac{\partial x_{ij}}{\partial \varepsilon_i} + \frac{\partial p_{ij}}{\partial \varepsilon_i} x_{ij} - \rho MD_i \frac{\partial x_{jj}}{\partial \varepsilon_i} = 0 \quad i, j = 1, 2 \quad j \neq i
\end{aligned} \tag{4.3.7}$$

The first term is the profit shifting effect which is negative in terms of firm, given price above marginal cost, and an export tax decreases the volume of export by raising the export cost. Such an effect ambiguously depends on marginal environmental damage from the government point of view as a positive marginal damage (which is a local environmental effect) is subtracted from firm's profit. The second term is the terms of trade effect, which is negative as an export tax increases the price of exports. The third term is a spillover environmental effect, which is negative. This effect exists because a country's rival's output affects the country's welfare through the spillover parameter. An export tax reduces exports and encourages firm in the other country to expand domestic production. Although, there is no environmental effect if spillover equals zero.

The optimum export tax is solved as a function of policy choices from the explicit first order condition from the welfare function (4.2.8) as follows:

$$\varepsilon_i^* (t_i, \tau_i, t_j, \varepsilon_j, \tau_j) = \frac{\lambda_{17} + \lambda_{10} t_i + \lambda_9 \tau_i + \lambda_{18} t_j + \lambda_9 \varepsilon_j + \lambda_{19} \tau_j}{-2\lambda_5} \tag{4.3.8}$$

A production tax is set to maximise the deviating country's welfare, and the first order condition is:

$$\begin{aligned}
\frac{\partial W_i}{\partial t_i} &= \frac{\partial V_i}{\partial p_{ii}} \frac{\partial p_{ii}}{\partial t_i} + \frac{\partial V_i}{\partial p_{ji}} \frac{\partial p_{ji}}{\partial t_i} + (p_{ii} - c - t_i) \frac{\partial x_{ii}}{\partial t_i} + \frac{\partial p_{ii}}{\partial t_i} x_{ii} + x_{ii} \\
&\quad + \frac{\partial x_{ii}}{\partial t_i} t_i + \frac{\partial x_{ji}}{\partial t_i} \tau_i - \left(\frac{\partial D_i}{\partial x_{ii}} \frac{\partial x_{ii}}{\partial t_i} + \frac{\partial D_i}{\partial x_{ji}} \frac{\partial x_{ji}}{\partial t_i} \right) \\
&= -\frac{\partial p_{ii}}{\partial t_i} x_{ii} - \frac{\partial p_{ji}}{\partial t_i} x_{ji} + (p_{ii} - c - t_i) \frac{\partial x_{ii}}{\partial t_i} + \left(\frac{\partial p_{ii}}{\partial t_i} - 1 \right) x_{ii} + x_{ii} \\
&\quad + \frac{\partial x_{ii}}{\partial t_i} t_i + \frac{\partial x_{ji}}{\partial t_i} \tau_i - \frac{\partial D_i}{\partial x_{ii}} \frac{\partial x_{ii}}{\partial t_i} - \frac{\partial D_i}{\partial x_{ji}} \frac{\partial x_{ji}}{\partial t_i} \\
&= (p_{ii} - c - MD_i) \frac{\partial x_{ii}}{\partial t_i} - \frac{\partial p_{ji}}{\partial t_i} x_{ji} + \frac{\partial x_{ji}}{\partial t_i} \tau_i - \rho MD_i \frac{\partial x_{ji}}{\partial t_i} = 0 \quad i, j = 1, 2 \quad j \neq i
\end{aligned} \tag{4.3.9}$$

The production tax is implemented by having a tax on emission and a subsidy on domestic production. Tax revenue from the production tax $t_i \cdot \partial x_{ii} / \partial t_i$ is transferred from firm to the government directly, therefore has no effect on total welfare.

The first term shows the profit shifting effect which is negative in terms of firms as price is above marginal production cost and a production tax reduces domestic output. There is a positive local environmental effect $-MD_i \cdot \partial x_{ii} / \partial t_i$. As a result, the profit shifting effect in terms of government is ambiguous. The second term is a negative terms of trade effect, and it describes how a production tax on domestic output could affect the trading market through price of imports. A positive production tax reduces domestic production and increases the demand for imports. With an increased import, the third term, which is a tariff revenue effect, is positive and the last term, which is a spillover environmental effect, is negative. An explicit first order condition can be obtained from welfare function (4.2.8), which is used to solve for the optimum production tax:

$$t_i^* (\varepsilon_i, \tau_i, t_j, \varepsilon_j, \tau_j) = \frac{\lambda_{11} + \lambda_{10} \varepsilon_i + \lambda_{16} \tau_i + \lambda_9 (t_j + \varepsilon_j) + \lambda_{10} \tau_j}{-2\lambda_4} \tag{4.3.10}$$

Assuming an interior solution, and given that country j , the one being cheated, continues to use the collusive policy, the welfare maximising policies that country i implements can be obtained by substituting $\varepsilon_j = o$, $\tau_j = \tau^C$, $t_j = t^C$ into the three first order conditions (4.3.7), (4.3.9), and (4.3.11) and solving them simultaneously. The optimum policies that a country uses to unilaterally deviates from multilateral free trade are:

$$t^D = \frac{(\alpha - c)(4(\phi - 3)(\phi^2 - 2)(3\phi^2 - 4) - \kappa(\Psi\gamma_1 + \gamma_2 + \gamma_3 + \gamma_4))}{(3\phi^2 - 4 + \Psi)\gamma_0}$$

$$\varepsilon^D = \frac{(\alpha - c)(\phi^2 - 4)(2\phi^2(\phi - 1)(\phi^2 - 3) + \kappa(\Psi\gamma_5 + \gamma_6 + \gamma_7 - \gamma_8))}{(3\phi^2 - 4 + \Psi)\gamma_0}$$

$$\tau^D = \frac{(\alpha - c)(4(1 - \phi)(\phi^2 - 2)(3\phi^2 - 4) - \kappa(\Psi\gamma_9 + \gamma_{10} + \gamma_{11} + \gamma_{12}))}{(3\phi^2 - 4 + \Psi)\gamma_0}$$

where coefficients are:

$\gamma_0 \equiv \kappa(16\phi^2 - 36 + 4\phi\rho(7 - 3\phi^2) + \rho^2(\phi^4 + \phi^2 - 8)) - 4(6 - 5\phi^2 + \phi^4)$
$\gamma_1 \equiv 4(\phi - 3)(\phi^2 - 1) + 4\rho(4 + \phi - 3\phi^2 + \phi^3) + \rho^2(\phi^3 + \phi^2 - 8)$
$\gamma_2 \equiv 4\phi(\phi(1 + \phi)(23 + \phi(4\phi - 19)) - 14)$
$\gamma_3 \equiv 2\rho(16 - 96\phi + 72\phi^2 + \phi^3(\phi - 1)(\phi^2 + 12\phi - 38))$
$\gamma_4 \equiv \rho^2(176 - 136\phi - 84\phi^2 + 64\phi^3 - 7\phi^4 + 5\phi^5)$
$\gamma_5 \equiv (\phi\rho - 2)(\phi - \rho + \phi\rho - 3)$
$\gamma_6 \equiv \rho(\phi - 2)(16 - 14\phi - 9\phi^2 + 9\phi^3)$
$\gamma_7 \equiv \rho^2(16\phi - 11\phi^2 - 9\phi^3 + 6\phi^4)$

$\gamma_8 \equiv 36 - 20\phi - 28\phi^2 + 16\phi^3$
$\gamma_{26} \equiv 18 - 19\phi - 4\phi^2 + 5\phi^3 + \phi^4$
$\gamma_{10} \equiv -96 + 88\phi + 52\phi^2 - 52\phi^3 + 4\phi^4$
$\gamma_{11} \equiv 2\rho \left(-96\phi \left(112 + \phi(4 + \phi)(10 - 21\phi + 7\phi^2) \right) \right)$
$\gamma_{12} \equiv \rho^2 (-3 + 2\phi) \left(48 + \phi(3 + \phi)(-8 - 12\phi + 8\phi^2 + \phi^3) \right)$

The optimum import tariff is positive, which includes a positive tariff from the trade point of view and a positive tax from the environmental point of view. Export subsidy can appear as an attractive policy in an imperfect competition as in Brander and Spencer (1985), however, the resulting export tax from deviation depends on parameter values and it is positive when environmental damage is sufficiently large. This is because the country that deviates uses a welfare maximising environmental policy on both imports and exports. If the environmental damage is severe enough, the effect of the tax on exports for environmental purposes will exceed the effect of the subsidy for oligopolistic distortion, leaving the entire effect a positive export tax. The same argument applies to the production tax as one would expect a production subsidy in an imperfectly competitive market, and a negative environmental externality requires a tax. Such a tax for environmental purposes takes effect together with a subsidy for oligopolistic distortions, leaving the total effect ambiguously depends on parameter values. Welfare from unilaterally deviating from cooperation is:

$$W^D = \frac{(\alpha - c)^2 \left(2(\phi - 2)\gamma_{17} + \kappa \left(\Psi^2 \gamma_{13} + 2\Psi \gamma_{14} + 2\Psi \gamma_{15} + 2\Psi \gamma_{16} + \gamma_{18} + \gamma_{19} + \gamma_{20} \right) \right)}{\beta \left(3\phi^2 - 4 + \Psi \right)^2 \gamma_0} \quad (4.3.11)$$

where coefficients are:

$\gamma_{13} \equiv -12 + 4\phi + 2\phi^2 + 8\rho(1 + \phi - \phi^2) + \rho^2(\phi^3 - 4)$
$\gamma_{14} \equiv 72 - 48\phi - 50\phi^2 + 36\phi^3 - 2\phi^4$

$\gamma_{15} \equiv \rho^2 (48 + (\phi - 2)(18\phi + 19\phi^2 + 2\phi^3 + 4\phi^4))$
$\gamma_{16} \equiv \rho (8 - 92\phi + 54\phi^2 + 61\phi^3 - 40\phi^4 + \phi^5)$
$\gamma_{17} \equiv 88 - 36\phi - 142\phi^2 + 33\phi^3 + 86\phi^4 - 10\phi^5 - 18\phi^6 + \phi^7$
$\gamma_{18} \equiv -864 + 1024\phi + 782\phi^2 - 1216\phi^3 - 30\phi^4 + 384\phi^5 - 96\phi^6$
$\gamma_{19} \equiv 2\rho(\phi - 1)(384 - 320\phi - 512\phi^2 + 428\phi^3 + 156\phi^4 - 139\phi^5 + 7\phi^6)$
$\gamma_{20} \equiv \rho^2 (-544 + 576\phi + 592\phi^2 - 784\phi^3 + 10\phi^4 + 212\phi^5 - 90\phi^6 + 21\phi^7)$

For the interior solution to be valid, each country's exports (imports) must be positive; otherwise, there will be a corner solution. As in the Cournot equilibrium output in (4.2.4), a country's trade volume is affected by the country's own export tax and its rival's import tariff and production tax. Assuming country i deviates and country j continues to cooperate, policies implemented by the two countries are: $t_i = t^D$, $\varepsilon_i = \varepsilon^D$, $\tau_i = \tau^D$, $t_j = t^C$, $\varepsilon_j = 0$, $\tau_j = \tau^C$. Interior solution only exists when both x_{ij} and x_{ji} are positive. The condition $\varepsilon^D \leq \phi t^C / (2 - \tau^C) + A/2$ is required to keep a non-negative x_{ij} and $2\tau^D - \phi t^D \leq A$ for a positive x_{ji} , where $A = (2 - \phi)(\alpha - c) > 0$. Substituting the resulting policies, it can be seen that x_{ji} , which is the exports of country j (the imports of country i), is always positive. Whereas x_{ij} , country i 's exports (country j 's imports) can possibly be negative when the export tax from unilaterally deviation ε^D exceeds the prohibitive level. Substituting the cooperative production tax in (4.3.3) into the critical value of export tax $\phi t^C / (2 - \tau^C) + A/2$ yields:

$$\varepsilon^P = \frac{(\alpha - c)(1 - \phi)(\phi^2 - 4)}{3\phi^2 - 4 + \Psi} \quad (4.3.12)$$

The prohibitive level of export tax is decreasing in κ , which is the relative environmental damage. Export tax from unilateral deviation ε^D is increasing in the relative damage parameter. As a result, when κ becomes larger, the prohibitive level

of export tax that stops country i from exporting gradually goes down while the optimal export tax goes up until $\varepsilon^D = \varepsilon^P$, and $x_{ij} = 0$. The rest of the policies are implemented based on welfare maximisation when there is no export but imports. Substituting the policy $\varepsilon_i = \varepsilon^P$, $t_j = t^C$, $\varepsilon_j = 0$, $\tau_j = \tau^C$ into country i 's welfare function (4.2.8), the optimum import tariff and production tax that the deviating country would impose are obtained by maximising country i 's welfare.

$$t^P = \frac{(\alpha - c)(\Psi \kappa(1 + \rho)(\phi + \rho - 3) - (3 - \phi)(4 - 3\phi^2) + \kappa(\gamma_{21} + \gamma_{22}\rho + \gamma_{23}\rho^2))}{(4 - 3\phi^2 - \Psi)(3 - \phi^2 + \kappa(3 + \rho^2 - 2\rho\phi))}$$

$$\tau^P = \frac{(\alpha - c)(\Psi \kappa(1 + \rho)(\phi\rho - \rho - 1) + (1 - \phi)(4 - 3\phi^2) + \kappa(\gamma_{24} + \gamma_{25}\rho + \gamma_{26}\rho^2))}{(4 - 3\phi^2 - \Psi)(3 - \phi^2 + \kappa(3 + \rho^2 - 2\rho\phi))}$$

where:

$\gamma_{21} \equiv -6 + 17\phi - 14\phi^2 + 3\phi^3$	$\gamma_{24} \equiv 10 - 11\phi + 2\phi^2$
$\gamma_{22} \equiv -4 + 26\phi - 26\phi^2 + 5\phi^3 + \phi^4$	$\gamma_{25} \equiv 20 - 22\phi + 2\phi^2 + 2\phi^3$
$\gamma_{23} \equiv -22 + 17\phi + \phi^3$	$\gamma_{26} \equiv 18 - 19\phi - 4\phi^2 + 5\phi^3 + \phi^4$

Therefore, when a country unilaterally deviates from cooperation and uses a set of prohibitive policies, it receives the level of welfare:

$$W^P = \frac{(\alpha - c)^2(\Psi^2 \kappa(\rho - 1)^2 + \Psi \kappa(\gamma_{27} + \rho\gamma_{28} + \rho^2\gamma_{29}) + \kappa(\gamma_{30} + \rho\gamma_{31} + \rho^2\gamma_{32}) - \gamma_{33})}{2\beta(3\phi^2 - 4 + \Psi)^2(3 - \phi^2 + \kappa(3 + \rho^2 - 2\rho\phi))} \quad (4.3.13)$$

where:

$\gamma_{27} \equiv -32 + 32\phi - 4\phi^2$	$\gamma_{28} \equiv -8 + 44\phi - 44\phi^2 + 2\phi^3$
$\gamma_{29} \equiv -24 + 20\phi - 2\phi^2 + 2\phi^3$	$\gamma_{30} \equiv 208 - 256\phi - 88\phi^2 + 192\phi^3 - 51\phi^4$

$\gamma_{31} \equiv 256 - 432\phi + 316\phi^3 - 144\phi^4 + 6\phi^5$	$\gamma_{32} \equiv 128 - 160\phi - 44\phi^2 + 120\phi^3 - 54\phi^4 + 10\phi^5 + \phi^6$
$\gamma_{33} \equiv 2(\phi - 2)(4 - 3\phi^2)^2$	

Figure 4.1 shows welfare as a function of κ . Welfare in the figure is simplified by multiplying $\beta/(\alpha - c)^2$, which is a common term in both welfare functions (4.3.12) and (4.3.14) and is plotted against relative damage when products are differentiated with transboundary environmental damage. The blue curve (the part to the left of the first vertical dashed line) is the interior solution of welfare from deviation and the brown curve (the part to the right of the first vertical dashed line) is the welfare under prohibitive policy. A country receives W^D when unilaterally uses optimum policies. However, if environmental damage is large enough relative to market size, the optimum export tax of the cheating country becomes prohibitive. No export occurs and the country receives W^P . Welfare level from unilateral deviating from cooperation is shown by the combination of blue and brown curves.

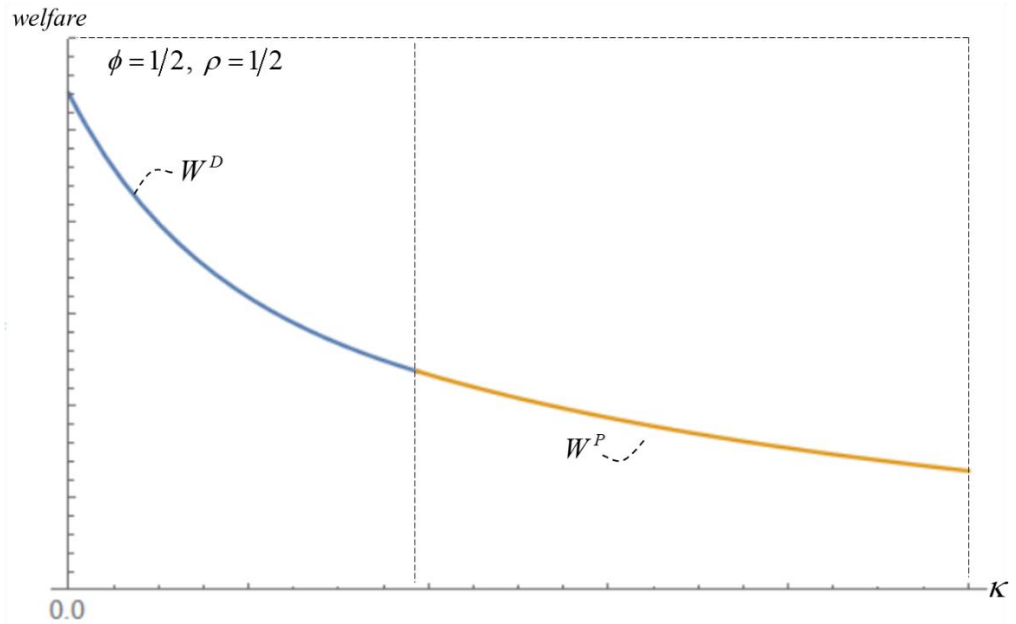


Figure 4.1 Welfare from Unilaterally Deviation

The welfare from unilaterally deviating from cooperation is greater than the welfare level in cooperative equilibrium, even when the deviating country uses a

prohibitive export tax that stops export.¹⁸ However, the country that passively pursue a policy of free trade and an IEA becomes worse off than being in multilateral cooperation. If the cheated country retaliates by using its optimum trade and environmental policy, there will be wars in terms of both trade and environmental policies in which both countries act non-cooperative and only focus on their own benefit by using policies to maximise individual welfare.

Assuming interior solution which leads to an interior Nash equilibrium with positive volumes of trade, the optimum policies are obtained by solving (4.3.7), (4.3.9) and (4.3.11) for both countries:

$$\begin{aligned}
 t^N &= \frac{(\alpha - c)(\kappa(1 + \rho)(8 - 2\rho + (\rho - 4)\phi - \phi^2) + 2\phi + \phi^2 - 6)}{6 - 3\phi^2 + \Omega} \\
 \varepsilon^N &= \frac{(\alpha - c)(\kappa(1 + \rho)(8 - 4(1 + \rho)\phi + (3\rho - 1)\phi^2) - \phi^2 + \phi^3)}{6 - 3\phi^2 + \Omega} \\
 \tau^N &= \frac{(\alpha - c)(\kappa\rho(1 + \rho)(6 - 3\phi - \phi^2) + 2(1 - \phi))}{6 - 3\phi^2 + \Omega}
 \end{aligned} \tag{4.3.14}$$

where $\Omega \equiv \kappa(1 + \rho)(8 + 2\rho - (4 + 3\rho)\phi - (1 - \rho)\phi^2) > 0$. The Nash import tariff is always positive.

Substituting the Nash policies (4.3.15) into the welfare function (4.2.8) yields the interior Nash equilibrium welfare:

$$W^N = \frac{(\alpha - c)^2 (56 - 2\kappa^2 \rho^2 (1 + \rho)^2 \theta_1 + \theta_2 + \kappa(1 + \rho)(\theta_3 - \rho\theta_4))}{2\beta(6 - 3\phi^2 + \Omega)^2} \tag{4.3.15}$$

¹⁸ The comparison of welfare is analysed in Figure 4.2, Figure 4.3 and Figure 4.4 in the following text and it will be shown that a country becomes better off deviating from free trade and an IEA.

where $\theta_1 \equiv 4 - 8\phi + 5\phi^2 - \phi^3$, $\theta_2 \equiv -40\phi - 24\phi^2 + 16\phi^3 + \phi^4$, $\theta_3 \equiv 64 - 64\phi + 8\phi^3 + \phi^4$, and $\theta_4 \equiv 48 - 24\phi - 32\phi^2 + 16\phi^3 + \phi^4$.

In the interior Nash equilibrium of the trade and environmental policy game, outputs of the two firms are obtained by substituting the Nash trade policies (4.3.15) into Cournot outputs (4.2.4), which yields:

$$x_{ii}^N = \frac{(\alpha - c)(6 + \kappa\rho(1 + \rho)(2 - \phi) - 2\phi - \phi^2)}{\beta(6 - 3\phi^2 + \kappa(1 + \rho)(8 + \rho(2 - 3\phi + \phi^2) - 4\phi - \phi^2))} > 0$$

$$x_{ij}^N = \frac{(\alpha - c)(2 - \kappa\rho(1 + \rho)(2 - \phi) - 2\phi)}{\beta(6 - 3\phi^2 + \kappa(1 + \rho)(8 + \rho(2 - 3\phi + \phi^2) - 4\phi - \phi^2))}$$

Nash domestic output is always positive while exports of the i th country are only positive if parameters satisfy the condition that $2 - \kappa\rho(1 + \rho)(2 - \phi) - 2\phi > 0$.

One could interpret such a condition in terms of relative damage that there is an interior solution only if $\kappa < 2(1 - \phi) / ((\rho + \rho^2)(2 - \phi))$. When the relative damage exceeds the critical value, there is no exports in both markets, and both countries receive welfare under autarky. This result leads to the following result:

Result 4.2: *Under Cournot duopoly with environmental damage, there exists an interior Nash equilibrium if and only if $\kappa < 2(1 - \phi) / ((\rho + \rho^2)(2 - \phi))$. When relative damage is sufficiently large such that $\kappa \geq 2(1 - \phi) / ((\rho + \rho^2)(2 - \phi))$, there is a unique Nash equilibrium that results in autarky for both countries.*

The following figures show the comparison of welfare under different trade policies with different parameter values, and trade policy game is a prisoners' dilemma in the symmetric model as expected.¹⁹ A country could cooperate and receive welfare

¹⁹ All the welfare are simplified by multiplying $\beta/(\alpha - c)^2$ so to explore the welfare effect of ϕ, ρ , and κ only.

W^C . Figure 4.2 and 4.3 imply that a country could be better off from unilateral deviation and receive a higher welfare W^D or W^N , depending on its policy. However once its trade partner retaliates, all the countries receive welfare W^N , which is always lower than the welfare from cooperation. The policy game leads to a Prisoner's Dilemma outcome where all the countries lose in the non-cooperative equilibrium. A country receives a higher welfare in the interior Nash equilibrium than in autarky provided that the unique NE condition does not hold and there exists an interior Nash equilibrium.

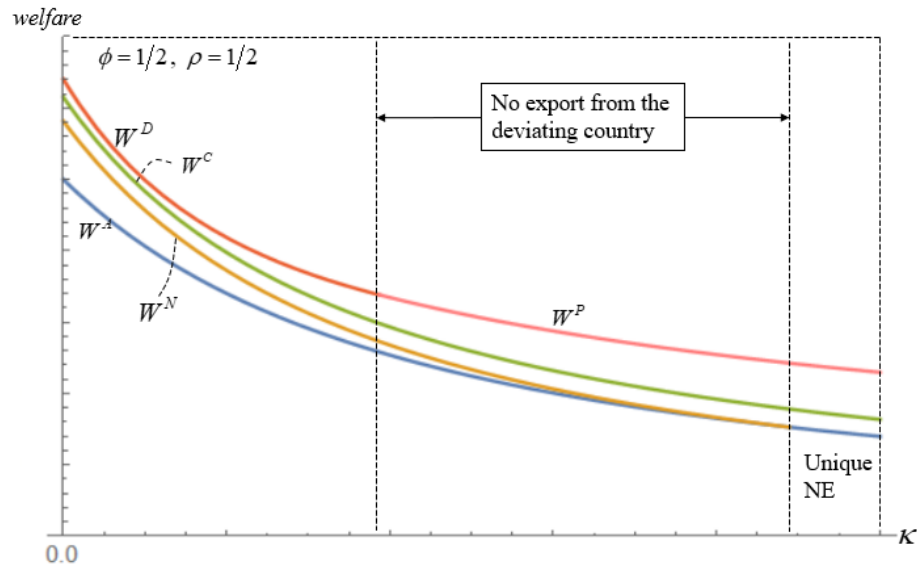


Figure 4.2 Welfare and the Relative Environmental Damage

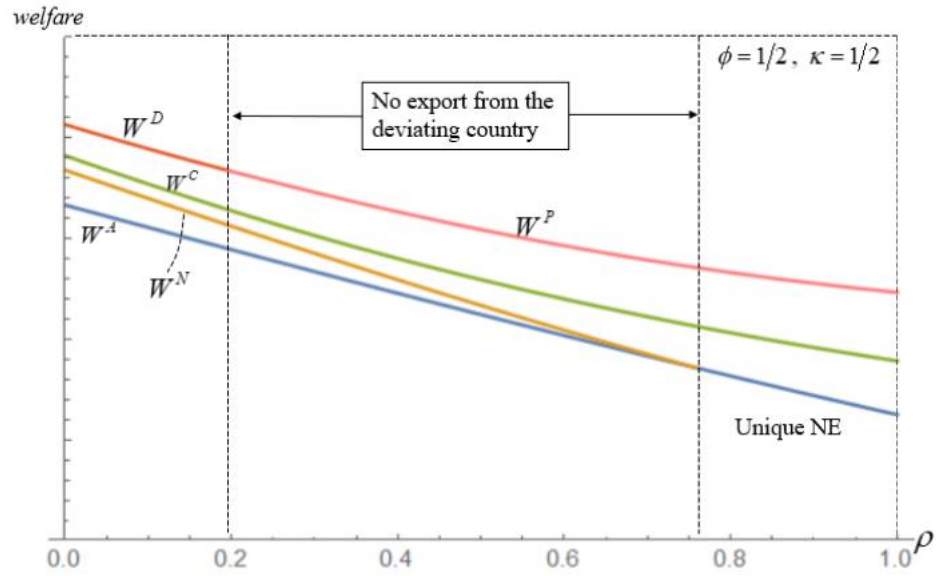


Figure 4.3 Welfare and the Environmental Effect

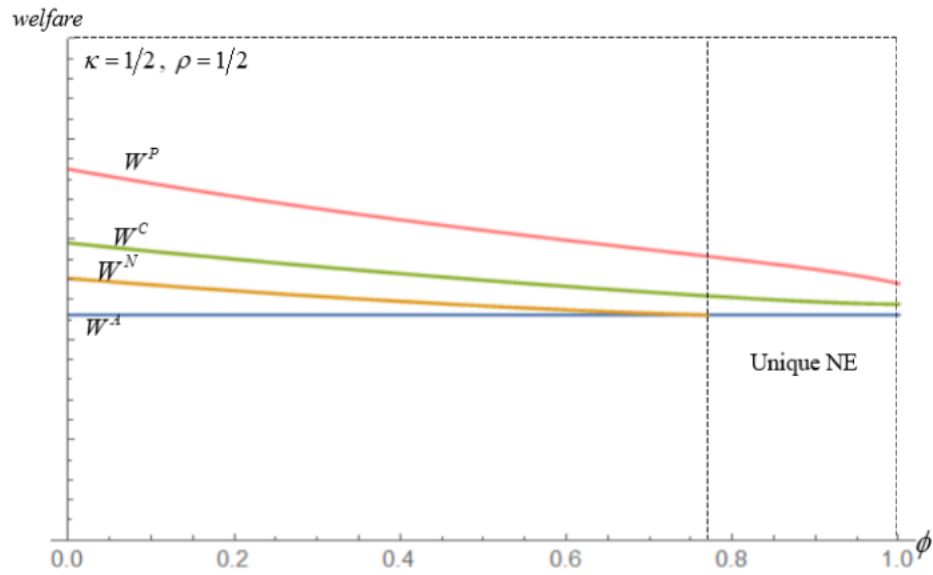


Figure 4.4 Welfare and the Degree of Product Differentiation

Welfare under different regimes is decreasing in all three variables except for the effect of product differentiation on welfare under autarky in Figure 4.4. This is because the product differentiation affects welfare through the effect of imports on prices. However, there is no trade under autarky. Only domestic production exists in domestic market. Therefore, whether products are differentiated or not does not affect the welfare level under autarky, and autarky welfare is a horizontal line when plotting against the degree of product differentiation.

When products are differentiated in some extents and pollution is transboundary as in Figure 4.2, by equalising the interior solution of welfare from deviation in (4.3.12) and welfare using prohibitive export tax in (4.3.14) or by equalising the interior solution of export tax in deviation case and its prohibitive level, one could obtain the threshold level of relative damage that $\bar{\kappa} = \left(\sqrt{231001} - 139 \right) / 882 \approx 0.39$. The threshold level of ρ in Figure 4.3 can be obtained using the same approach with the parameter value of $\phi = 1/2$ and $\kappa = 1/2$. The critical value of spillover effect obtains as $\bar{\rho} = 0.19$. If $\kappa \geq \bar{\kappa}$ in Figure 4.2, or if $\rho \geq \bar{\rho}$ in Figure 4.3, the optimum export tax from deviation becomes prohibitive, there is no export from the deviating country, and the country receives welfare W^P . In Figure 4.4 when parameter values are chosen at $\kappa = 1/2$, $\rho = 1/2$, it is always the case that the deviating country receives welfare W^P . In the case of $\kappa = 1/2$, $\rho = 1/2$, the interior solution of an export tax under deviation is always greater than the prohibitive level given any value of $\phi \in (0, 1)$. It suggests that a country always needs to impose a prohibitive export tax to keep export non-negative and to maximise individual welfare in this case.

$$\varepsilon^D - \varepsilon^P \Big|_{\rho=\kappa=1/2} = \frac{(\alpha - c)(\phi^2 - 4)(424 - 558\phi + 1113\phi^2 - 727\phi^3 - 120\phi^4 + 120\phi^5)}{(-86 + 45\phi + 24\phi^2)(344 - 56\phi - 225\phi^2 + 24\phi^3 + 31\phi^4)} > 0$$

It can also be concluded from the above figure that the gain from deviating from free trade and an IEA is increasing in relative damage, environmental spillover and the degree of product differentiation. When there is a greater environmental damage, a larger pollution leakage, and when products are more differentiated, a country gains more from cheating. However, if the other country deviates, the result of such a trade and environmental policy game is both countries receive welfare either in the interior Nash equilibrium or under autarky, which both make them worse off than stay in cooperation.

4.4 Sustaining Cooperation

The prisoners' dilemma situation in trade policy in which both countries receive a welfare below the cooperative level can be avoided in a repeated game. The WTO, that is established to regulate and facilitates international trade between nations, and IEAs could be modelled as the outcome of an infinitely repeated game. Countries sign up commitments for international trade and an IEA. If any of the members breaches the agreement, there is an enforcement mechanism in the WTO for the cheated member to retaliate and punish the cheating country. As a negotiating platform for trade partners to achieve a trade agreement and implement the prescribed punishment, the WTO sustains collusion by allowing retaliation if any deviation from agreement occurs. Given the fact that both countries become worse off in a tariff war, a country, with the fear of retaliation, may be willing to cooperate instead of triggering a trade war. The Folk Theorem by Friedman (1971) states that any outcome that Pareto dominates a Nash equilibrium can be sustained as a subgame perfect equilibrium in a repeated game with sufficiently patient players. It implies that countries may sustain the cooperative equilibrium as long as the discount rate for future periods is low enough by using trigger strategies, which typically prescribe adopting the cooperative solution unless a defection is observed. The policy game is modelled as an infinitely repeated game to analyse the sustainability of cooperation in this section.

In an infinitely repeated game where both countries have the same discount factor $\delta \in (0,1)$, the strategy of each country is to cooperate by using a free trade policy and an environmental optimal environmental policy until the other country deviates by unilaterally using its optimal trade and environmental policies that maximises its individual welfare. Defection by any country results in a permanent breakdown of cooperation in which case countries revert to the non-cooperative equilibrium.

The non-cooperative equilibrium is an interior Nash equilibrium that results in a trade and environmental policy war, and it is considered as a punishment to deviation. As pointed out by Dixit (1987) that both countries minimaxing each other with a prohibitive trade policy is also a Nash equilibrium that results in autarky welfare for both countries. Autarky is another Nash equilibrium in this model, because no country

would be better off departing from it if both countries used welfare-maximizing production policies and environmental policies. Under oligopoly market, a set of prohibitive trade policies and environmental policy are required to lock countries in autarky. However, it is worth mentioning that the autarky equilibrium in this chapter is not a minimax strategy as in Dixit (1987). Due to the existence of a spillover effect in environmental damage, each country is not essentially minimising its competitor's maximum welfare in such an autarky Nash equilibrium.

Once deviation occurs, both countries play the interior Nash equilibrium for the remainder of the game if countries use infinite Nash reversion trigger strategies. The cooperative equilibrium can then be sustained by the threat of infinite reversion to the interior Nash equilibrium. Using infinite autarky reversion trigger strategies, collusion is also sustainable by the threat of infinite reversion to the autarky Nash equilibrium. With infinite autarky reversion, countries play autarky Nash equilibrium and receive autarky welfare infinitely followed by any defection.

Any of the above strategies could potentially sustain cooperation if governments are patient enough. This is because countries in either the interior Nash equilibrium or an autarky state are bound to be worse off than in a cooperative situation. Assuming that both countries use infinite Nash-reversion trigger strategies, a country will play free trade and use environmental optimal policy if the discounted present value of welfare under cooperation exceeds the welfare from unilaterally deviating from free trade for one period, followed by a welfare level in the interior Nash equilibrium forever: $W^C / (1 - \delta) > W^D + \delta W^N / (1 - \delta)$.²⁰ The critical value of discount factor is obtained by setting both side equal:

$$\delta^{N\infty} = \frac{W^D - W^C}{W^D - W^N} \quad (4.4.1)$$

²⁰ In every period, each country weighs the current gain of deviating from cooperation against the future loss of the breakdown of cooperation. If the current gain of deviation is less than the discounted life-time loss for each country, no country has an incentive to deviate from the cooperative equilibrium and thus cooperation is sustainable.

Cooperation is sustainable if the discount factor is greater than the critical value $\delta > \delta^{N\infty}$. This is the case when countries are patient enough, and the potential loss of future welfare from a trade war weighs heavily in their decision-making process. If both countries use infinite autarky-reversion trigger strategies, the current benefit of deviation, which measures by $W^D - W^C$ must be less than the discounted life-time cost of deviation, which measures by $\delta(W^C - W^N)/(1 - \delta)$ in each country for cooperation to be sustainable. Setting benefit and cost equal, the critical value of discount factor using infinite autarky reversion obtains:

$$\delta^{A\infty} = \frac{W^D - W^C}{W^D - W^A} \quad (4.4.2)$$

The cooperative equilibrium with free trade and an IEA can be sustained as a subgame perfect Nash equilibrium if $\delta > \delta^{A\infty}$. The interior Nash equilibrium only exists under a certain condition, as stated in the previous section. There is a unique Nash equilibrium if $\kappa \geq 2(1 - \phi)/((\rho + \rho^2)(2 - \phi))$. When relative damage is large enough, both countries use prohibitive policies, resulting in autarky, and the critical discount factors under the two strategies are identical. Also, as discussed in the case of deviation, a relatively large environmental damage let a deviating country to use a prohibitive export tax that results in zero export. In this case, the current benefit from deviating is changed to $W^P - W^C$, while the pre period loss from deviating remains the same at $W^C - W^N$ for Nash reversion and $W^C - W^A$ for autarky reversion. Therefore, the critical discount factors when relative damage is sufficiently large is obtained by replacing the welfare W^D in (4.4.1) and (4.4.2) by welfare W^P :

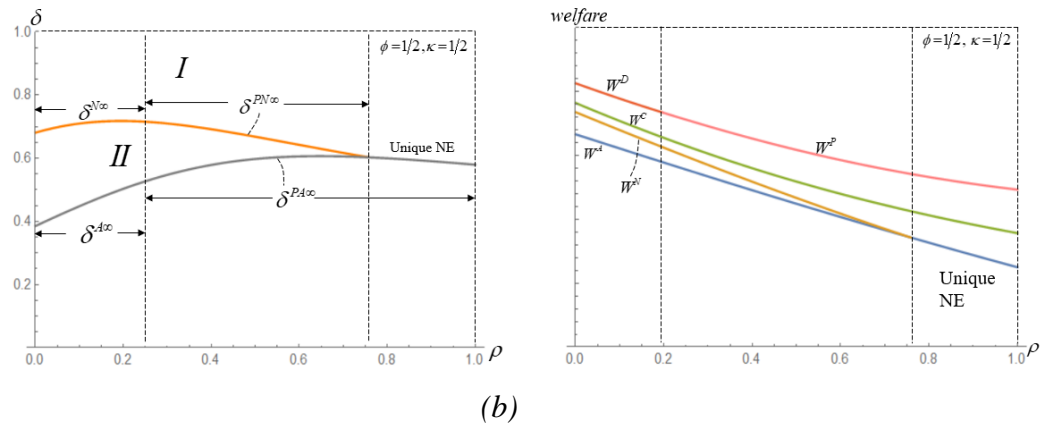
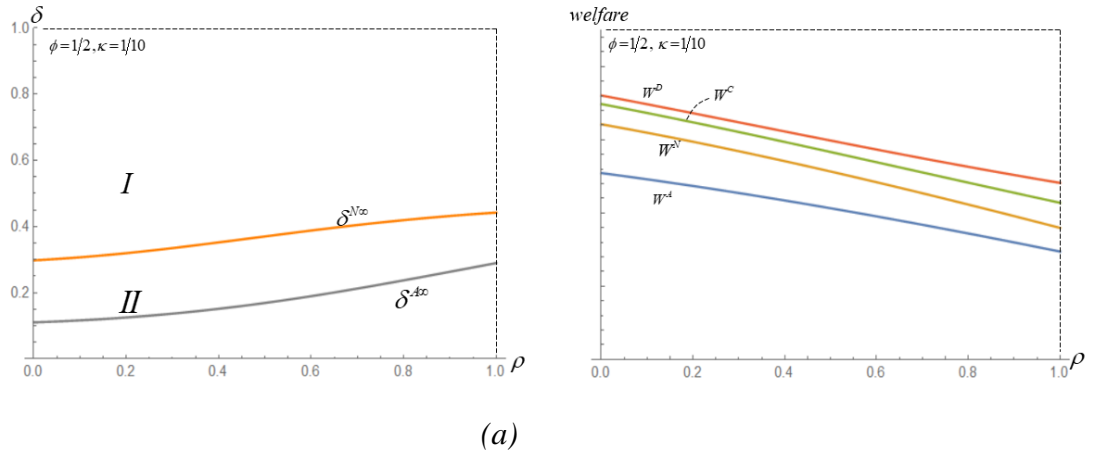
$$\delta^{PN\infty} = \frac{W^P - W^C}{W^P - W^N}, \quad \delta^{PA\infty} = \frac{W^P - W^C}{W^P - W^A} \quad (4.4.3)$$

For cooperation to be self-enforced, both countries discount factor should satisfy the constraint that $\delta > \text{Max}\{\delta^{N\infty}, \delta^{PN\infty}, \delta^{A\infty}, \delta^{PA\infty}\}$. Since free trade with an IEA is only sustainable if $\delta > \text{Max}\{\delta^{N\infty}, \delta^{PN\infty}\}$ for Nash reversion and $\delta > \text{Max}\{\delta^{A\infty}, \delta^{PA\infty}\}$ for autarky reversion, it will be sustainable in the region *I* above both curves in the following all figures. Clearly, it is easier to sustain free trade using infinite autarky

reversion trigger strategies given any value of ρ , κ , and ϕ . Although when relative damage is sufficiently large, there is a unique Nash equilibrium which results in autarky. This leads to the following result:

Result 4.3: *When the relative damage is not too great, i.e., $\kappa < 2(1-\phi)/((\rho+\rho^2)(2-\phi))$, cooperation is sustainable in an infinitely repeated game with sufficient large discount factors using both infinite autarky reversion and infinite Nash reversion. And it is easier to sustain cooperation using infinite autarky reversion than using infinite Nash reversion provided that $\delta^{N\infty} > \delta^{A\infty}$ and $\delta^{PN\infty} > \delta^{PA\infty}$.*

To evaluate the effect of environmental spillover, relative damage, and product differentiation on the sustainability of cooperation, the critical discount factors of the two countries are plotted against ρ , κ , and ϕ in the following figures for the different values of the other two parameters.



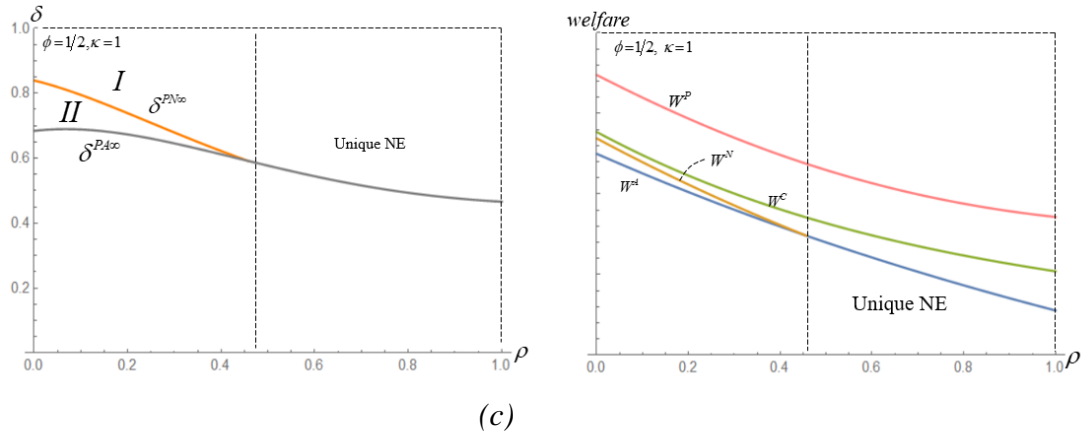


Figure 4.5 Critical Discount Factors and Environmental Spillover

Figure 4.5 shows the effect of environmental spillover on the sustainability with differentiated products and different values of relative environmental damage. Free trade with an IEA is always self-sustainable regardless the boundary effect of pollution (local, transboundary, or global). For a small environmental damage, i.e., $\kappa = 1/10$ in Figure 4.5(a), critical discount factors increase in environmental spillover, and it is easier to sustain cooperation when emission from output causes damage locally than a transboundary pollution. With a larger environmental damage as in Figure 4.5(b) and (c), spillover becomes less problematic in sustaining cooperation. Critical discount factors are decreasing in spillover if a country deviates using a prohibitive export tax and receives prohibitive deviating welfare W^P . As shown in Figure 4.5(c), when the relative environmental damage is large, i.e., $\kappa = 1$, a country always uses a prohibitive policy as the optimum policy to unilaterally improve its own welfare. In this case, a transboundary (or global) pollution appears more helpful in sustaining cooperation than a local pollution. This leads to the following result:

Result 4.4: *Free trade with an IEA is self-sustainable. Local pollution facilitate cooperation with a small environmental damage (in which case there are two NE) and global pollution facilitate cooperation with large environmental damage (in which case there might be an unique NE) if countries use optimum policies that are below the prohibitive level.*

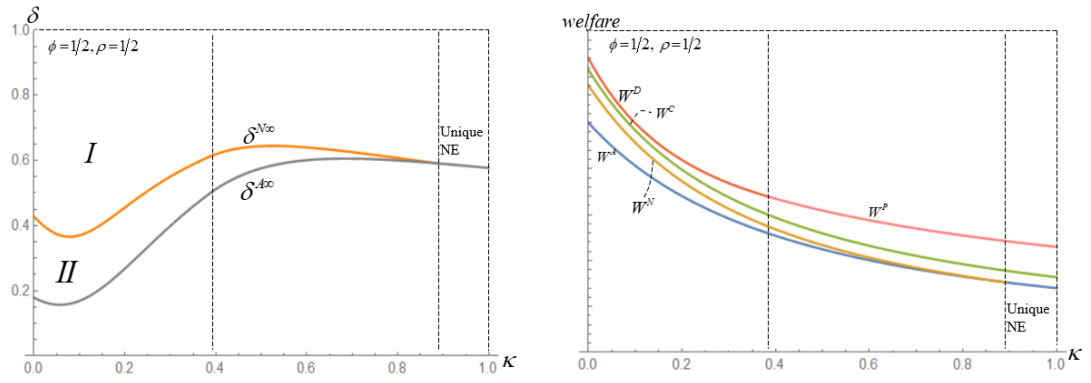


Figure 4.6 Critical Discount Factors and Environmental Damage

Figure 4.6 illustrates the effect of environmental damage on the enforceability. It can be seen that critical discount factors increase before the threshold of a prohibitive export tax in deviation case. Once the damage goes large and a country deviates by using a prohibitive policy, critical discount factors go down, in which case, the country receives a lower welfare as compared to the welfare received from unilaterally use an optimum non-prohibitive policies. If there is no export from the deviating country, the relative damage becomes less effective in sustaining cooperation as the total output that affects environmental damage and thus welfare is decreased.

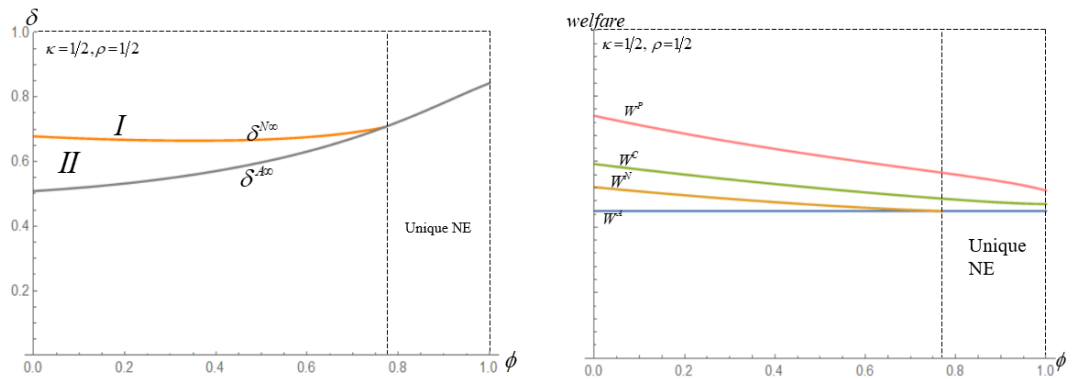


Figure 4.7 Critical Discount Factors and the Product Differentiation

Since the gain from cooperation is increasing in the degree of product differentiation, as in **Result 4.1**, the welfare level a country receives from cooperation is close to the welfare level under autarky when products are highly substitutes. Hence, the critical discount factor using infinite autarky reversion becomes larger with a

greater ϕ , and will eventually equals one when products are homogenous, and when environmental damage is purely local.

If both countries are penalised indefinitely, the chance that the cheated country will forgive the cheater and agree to return to cooperative equilibrium cannot be overlooked. Punishments that sustain cooperation in infinitely repeated games may be vulnerable to renegotiation, in which case cooperation is not an outcome of an infinitely repeated game. With the potential of renegotiation, the punishment in this chapter would no longer be credible, because each country knows that they may always renegotiate and improve their welfare at some point in the future. This problem could be addressed if the punishment phase is set for a few rounds followed by a return to cooperation. In this case, countries are punished for cheating for a definite time, which is a credible sanction. From the results of the previous two chapters, cooperation is expected to be sustained with a limited number of rounds of punishment. And since autarky is a more severe threat than being in a policy war when interior NE condition is satisfied, it would be the case that cooperation is easier to be sustain with an even fewer rounds of punishment when using autarky reversion strategy than using Nash reversion strategy. Therefore, the best way to sustain cooperative equilibrium might be to use autarky reversion for a few round and then allow countries to go back to free trade with an IEA afterwards.

4.5 Conclusions

This chapter has discussed trade policies and environmental policies in two countries under Cournot duopoly with differentiated products. Pollution leakages, including local, global, and transboundary environmental externalities were allowed. Trade policy was used to deal with the terms of trade externality and the environmental policy and production policy were used to affect output, which has an impact on addressing the environmental externalities and oligopolistic distortion. A static two-stage game was discussed first. In the static game, countries choose policy and firms then choose output and play as Cournot duopolies. Since free trade is a focal point, it was assumed that countries do not intervene in trade when cooperating. They cooperate by using a border tax to deal with environmental issues and a production tax that has two roles: one is to be used as a production policy to counteract the oligopolistic distortion, and the other is to be used as an environmental policy to address environmental externality. It was showed that there are always gains from multilateral free trade with an IEA, and such gains are greater with more differentiated products. Each country had incentives to deviate from cooperation by intervening in both trade and environmental issues. And a prohibitive export tax that results in zero export might be the best response when environmental damage is sufficiently large. Each country uses an optimum export tax, import tariff and production tax, were modelled as an interior Nash equilibrium in the trade and environmental policy game, and it led to a prisoners' dilemma situation in which both countries were worse off than in the cooperative equilibrium. Two non-cooperative equilibria (the interior NE and autarky NE) were considered, and it was shown that there is a unique NE that results in autarky welfare for both countries when variables (product differentiation, relative damage, and environmental spillover) satisfy some certain condition.

The static two-stage game was then considered as the stage game in an infinitely repeated game. The sustainability of cooperation was discussed with the use of trigger strategies. It was shown that an IEA under free trade can be self-enforced and sustained provided that environmental damage was not too great. The environmental spillover effect on the sustainability was affected by the severity of environmental damage, and it became less problematic with a more severe pollution. Local pollution facilitate

cooperation with small environmental damage whereas global pollution facilitates cooperation with large environmental damage.

In this chapter, an environmental policy is only imposed on imports in the cooperative equilibrium, which is a limitation of this research. Possible extension would be to consider the case of taxing emission from exports and explore the differences between taxing a firm's total output and using a border tax. Trade models with many countries, many firms, or with the adoption of trading blocs, as well as allowing abatement technologies to mitigate pollution can also be analysed in the future.

4.6 Appendix C

To show that the welfare function is strictly concave in its own production tax, export tax and import tariff.

A function $W_i(t_i, \tau_i, \varepsilon_i)$ is strictly concave if:

$$H = \begin{bmatrix} \frac{\partial^2 W_i}{\partial t_i^2} & \frac{\partial^2 W_i}{\partial t_i \partial \tau_i} & \frac{\partial^2 W_i}{\partial t_i \partial \varepsilon_i} \\ \frac{\partial^2 W_i}{\partial \tau_i \partial t_i} & \frac{\partial^2 W_i}{\partial \tau_i^2} & \frac{\partial^2 W_i}{\partial \tau_i \partial \varepsilon_i} \\ \frac{\partial^2 W_i}{\partial \varepsilon_i \partial t_i} & \frac{\partial^2 W_i}{\partial \varepsilon_i \partial \tau_i} & \frac{\partial^2 W_i}{\partial \varepsilon_i^2} \end{bmatrix} = \frac{1}{\beta(2+\phi)^2} \begin{bmatrix} 2\lambda_4 & \lambda_{16} & \lambda_7 \\ \lambda_{16} & 2\lambda_8 & \lambda_9 \\ \lambda_7 & \lambda_9 & 2\lambda_5 \end{bmatrix}$$

is negative definite for all $(t_i, \tau_i, \varepsilon_i)$. This is true if and only if:

$$D_1 = \left| \frac{\partial^2 W_i}{\partial t_i^2} \right| < 0, \quad D_2 = \begin{vmatrix} \frac{\partial^2 W_i}{\partial t_i^2} & \frac{\partial^2 W_i}{\partial t_i \partial \tau_i} \\ \frac{\partial^2 W_i}{\partial \tau_i \partial t_i} & \frac{\partial^2 W_i}{\partial \tau_i^2} \end{vmatrix} > 0, \quad \text{and} \quad D_3 = \begin{vmatrix} \frac{\partial^2 W_i}{\partial t_i^2} & \frac{\partial^2 W_i}{\partial t_i \partial \tau_i} & \frac{\partial^2 W_i}{\partial t_i \partial \varepsilon_i} \\ \frac{\partial^2 W_i}{\partial \tau_i \partial t_i} & \frac{\partial^2 W_i}{\partial \tau_i^2} & \frac{\partial^2 W_i}{\partial \tau_i \partial \varepsilon_i} \\ \frac{\partial^2 W_i}{\partial \varepsilon_i \partial t_i} & \frac{\partial^2 W_i}{\partial \varepsilon_i \partial \tau_i} & \frac{\partial^2 W_i}{\partial \varepsilon_i^2} \end{vmatrix} < 0$$

For any given $\kappa > 0$, $0 < \rho < 1$, and $0 < \phi < 1$, it can be derived that:

$$D_1 = \frac{\phi^2 - 4 - \kappa(\rho\phi - 2)^2}{\beta(\phi^2 - 4)^2} < 0$$

$$D_2 = \frac{3 - \phi^2 + \kappa(3 + \rho^2 - 2\rho\phi)}{\beta^2(\phi^2 - 4)^2} > 0$$

$$D_3 = \frac{\kappa(-36 + 16\phi^2 + 4\rho(7\phi - 3\phi^3) + \rho^2(\phi^2 + \phi^4 - 8)) - 4(6 - 5\phi^2 + \phi^4)}{\beta^3(\phi^2 - 4)^2} < 0$$

Therefore, the concavity of the welfare function is proved

Chapter 5 : Conclusions

This thesis has analysed trade wars under both perfect competition and oligopoly using the approach that Collie (2019) used for trade wars under oligopoly. A trade war occurred when all players used optimal policies to maximise welfare and it is modelled as the interior Nash equilibrium in a policy game. In the main context of this thesis, chapter two and three concentrated on trade policy in a perfectly competitive market. Chapter four allowed for environmental externalities and looked at both trade and environmental policies under oligopoly.

In chapter two, trade wars and trade agreements between two countries where each country used either an import tariff or an export tax were studied in a repeated game, with the stage game being the well-known model of Kennan and Riezman (1988). In their static two-country model, trade policy was analysed in a pure exchange model with Cobb-Douglas preferences and exogenous endowments. It was shown that a country could potentially win a trade war if its endowment size was significantly larger than the other countries, implying the effect of endowment asymmetries on the outcome of a trade war. Then, since free trade is efficient under perfect competition, the sustainability of free trade agreement in which there are zero import tariffs, zero export taxes, and zero transfers, was considered in an infinitely repeated game. It was shown that free trade was sustainable provided that the endowment asymmetries were not too great using both infinite Nash reversion (that results in the interior Nash equilibrium) and infinite minimax reversion (that results in autarky welfare for both countries). The critical discount factor was always significantly less than one for any endowment sets using infinite minimax reversion, however, only a limited set of endowments supported a critical discount factor below one. This implied that asymmetries were less problematic in the case of infinite minimax reversion. When the world's endowment was symmetrically distributed between two countries, chapter two further analysed the impact of trade volume (in terms of the volume of imports under free trade) on the sustainability of cooperation. It was demonstrated that a larger trade volume made free trade easier to be sustained using infinite Nash reversion, whereas made it more difficult using infinite Minimax reversion. Punishments that

sustain free trade agreement in an infinitely repeated game may be vulnerable to renegotiation, in which case both infinite Nash reversion and infinite minimax reversion are no longer credible. To address the issue of renegotiation, chapter two and three analysed the sustainability using a few rounds of the punishment phase. With sufficient large discount factors, free trade was sustainable using minimax reversion for one round, however, it could only be sustained using Nash reversion for more than two rounds. The critical discount factor turned out to be closer to that with infinite punishment when the punishment phase lasted longer. Free trade was also proved to be sustainable in a finitely repeated game when players are patient enough. It was shown that a country's incentives to deviate significantly affect the critical discount factor and it might desire to deviate as early as possible under a certain condition.

Chapter three extended the two countries case and looked at a symmetric trade model in which there were n countries trading n goods with the use of import tariffs. All the results in chapter three were qualitatively similar to those in chapter two despite the welfare effect of the number of countries, which was not considered in chapter two in which the number of countries was fixed at two. In a trade war, modelled as the interior Nash equilibrium in trade policies, all countries were worse off than they were under free trade in the symmetric structure. Therefore, multilateral free trade was sustainable using infinite Nash reversion in an infinitely repeated game. Since there are always gains from trade, multilateral free trade was also proved to be sustainable using infinite minimax reversion that results in autarky welfare for all the countries. In the case of symmetric endowment, the effect of the size of the world (in terms of the number of countries) and the degree of comparative advantage on sustainability was studied. Trade volume under free trade was determined by the degree of comparative advantage in chapter three, and it was shown in chapter three that a larger scale of comparative advantage made it easier to sustain free trade using infinite Nash reversion, whereas became more problematic using infinite minimax reversion. A larger number of countries made it more difficult to sustain free trade using infinite Nash reversion. However, surprisingly, in the case of infinite minimax reversion, free trade was easier to achieve and sustain when there were more countries. Infinite minimax reversion was proved to be a more severe punishment than infinite Nash reversion since the critical discount factor using infinite minimax reversion was always less than that using infinite Nash reversion. It was also demonstrated that

multilateral free trade was sustainable using a limited punishment phase, in which case the problem of renegotiation was avoided. In a finitely repeated game, multilateral free trade was sustainable for a definite number of rounds if there were no incentives for either country to deviate at that round. The critical discount factor increased in the degree of comparative advantages and decreased in the number of countries.

Chapter four discussed trade policies and environmental policies in two countries under Cournot duopoly with differentiated products and pollution leakages. Each country used a production policy, a trade policy, and an environmental policy. Since free trade is a focal point, the cooperative equilibrium referred to the case when countries did not intervene in trade policy (zero trade taxes) but used an environmental border tax at the Pigouvian level that equals the marginal environmental damage. It was shown that the interior Nash equilibrium of a trade and environmental policy game resulted in welfare losses as compared to the cooperative equilibrium in a constituent game. The interior Nash equilibrium only existed if the relative environmental damage was not too great, in which case, cooperation was sustainable using both infinite Nash reversion and infinite autarky reversion. And it was shown that the infinite Nash reversion results in a greater critical discount factor than that using infinite autarky reversion, meaning that infinite autarky reversion is a more severe punishment. With pollution leakages, the environmental spillover effect was analysed, and it was also affected by the severity of environmental damage. It was shown that environmental spillovers became less problematic in sustaining cooperation with more severe pollution. Both countries would use prohibitive policies if the relative environmental damage was sufficiently large, in which case there was only one equilibrium that resulted in autarky welfare, and free trade with IEAs was still sustainable provided that the discount factors were large enough. Also, production differentiation made it easier to sustain free trade using infinite autarky reversion as the gains from cooperation increase in the degree of product differentiation.

All three main chapters looked at international trade and environmental agreements between countries. Sustaining cooperation was studied in both cases of trade policy and environmental policy in a repeated game, and all the results were similar from both perfect competition and from oligopoly. Cooperation in trade policy and environmental policy could be self-enforced using either infinite Nash reversion

or infinite autarky reversion. The infinite autarky reversion punishment was always more severe than the infinite Nash reversion, and the more severe the punishment the easier it is to sustain cooperation.

One of the limitations of this analysis is that consumers' tastes in the case of the perfect competition were assumed to follow Cobb-Douglas preferences, which is a special case of the CES preferences when the elasticity of substitution is equal to one. The generality of those results could be demonstrated with the use of a CES preference. Considering the case of many firms, studying IEAs in international trade in a multi-country setting, evaluating the case of different forms of cooperation, and allowing for abatement technologies in the case of externality are all possible extensions for future research. One could also look at various forms of international cooperation, such as the harmful tax competition and the OECD's agreements on the cooperative tax rate.

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