Fighting Tax Havens and Climate Change

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Chapter 1

Introduction

The increasingly intertwined global relationships of goods, services, people and activities have rendered domestic legislation and policymaking which only extends to national borders insufficient. In fact, according to the OECD, the biggest challenges of the 21st century are of a global nature and demand a global approach.[1] A successful global strategy, however, can only be achieved by extensive and detailed multilateral coordination. Hence, an international initiative is needed to first identify the main challenges of a global approach and then introduce instruments that can be used for coordination. This thesis analyzes the consequences of policies and mechanisms introduced by multilateral initiatives using two examples, one in the field of international taxation and the other in the field of climate policy.

The need for an international initiative stems from the fact that activities are no longer necessarily bound by geographical or political borders. This phenomenon creates an externality which national legislators cannot take into account. The inefficiency arises due to the fact that, by definition of an externality, agents are unable

[1]The OECD's Future Programme report international terrorism, pandemic outbreaks, financial crises and climate change as the main challenges of the 21st century. See OECD (2003).

to fully internalize the costs or benefits of their actions. Consequently, due to such externalities, international cooperation is hampered by a reality wherein the strategic interactions between jurisdictions generate incentives to not cooperate.

In the era of globalization and stronger economic integration, the facilitation of cross-border investment has been achieved by a reduction of capital controls and restrictions.[2] In tax policy, this has introduced competitive pressure on jurisdictions wishing to attract mobile capital and investment. Accordingly, the theory of international competition depicts a scenario in which countries mutually undercut each other in their tax rates in a Bertrand like race to the bottom.[3] In this context, a fiscal externality exists as higher tax rates in one country drive capital out of this country and into other countries. These countries, then, benefit from this increase in tax rates by broadening their tax base and increasing their tax revenue. Trapped into this "race to the bottom", tax rates and tax revenues are inefficiently low.[4] Consequently, in order for countries to achieve a more efficient equilibrium they must coordinate to jointly increase their tax rates. In practice, the multilateral OECD's Harmful Tax Practices Initiative was started to provide a thorough analysis of the deleterious effect of tax competition and to provide a framework within which countries might work together in order to eliminate harmful tax practices. The OECD report developed a set of guidelines for member countries by which to identify, report and eliminate the harmful aspects of tax competition. Tax havens have been identified by the OECD report as serious drivers of tax competition. They are defined as jurisdictions which levy no or very low taxes on mobile capital and have strong bank secrecy rules, no transparency and no effective exchange of information on mobile

[2]See OECD (2002)

[3]See Wildasin (1988,1991), Wilson (1986) and Bucovetsky (1991).

[4]Oates (1972) identifies the harmful aspect of tax competition as springinh from the fact that due to inefficiently low tax rates and tax revenues an inefficiently low level of the public good is provided.

activities.[5] A major contribution of the initiative has been the development of a clear definition and criteria for the identification of tax havens and the proposal of a legal framework through which countries can deal with the tax haven phenomenon. Given that tax havens can be perceived as specializing in capital concealment activities, the introduction of a mechanism that facilitates the exchange of information can be a useful and effective tool to counteract their tax haven activities. Notice that by sharing information, a correct estimation of each individual's tax burden would be possible. In this thesis, we particularly study the implications of the implementation of the information exchange mechanism. The literature on tax havens has mainly concentrated on the welfare effects of the tax havens phenomenon and has disregarded the proposed initiatives put forward that deal with tax havens.[6] Thus, this thesis contributes to the literature on tax havens by providing a theoretically founded analysis of the proposed mechanism and its implementation. We use both non-cooperative game theory and empirical methods to understand the implications of the implementation of the proposed information exchange mechanism.

Climate policy, as the second topic which this thesis covers, presents a classic case of positive externalities as the benefits of climate mitigation efforts cannot be limited to one country. Given that climate protection is a global public good, countries have an incentive to free-ride on the contribution of others and, as a result, contributions to climate protection are inefficiently low. In order to increase the level of overall climate protection, international cooperation and coordination is needed. However, questions of climate policy adoption are further complicated by timing considerations. Countries are faced with the decision of when to adopt climate mitigation policies, given that the extent of the damage of climate change is unknown but waiting for more information might prove to be too costly. On the international policy agenda, climate policy has long been identified as a topic where international

[5] See OECD (1998) p.19.
[6] See Dharmapala (2008).

coordination is crucial. In 1992 the United Nations Framework Convention for Climate Change (UNFCCC), an international environmental treaty with the objective of stabilizing "greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system", was opened to signature. To achieve this type of stabilization, the UNFCCC identified two main dimensions of cooperation: first, the commitment to binding CO_2 emission reduction targets and, second, the support of green technology and technology transfer initiatives.[7] In this thesis, we focus on the technology dimension of the UNFCCC. The support for technology sharing and technology transfer initiatives has been clearly documented in Article 4.5 of the United Nations Convention for Climate Change.[8] While the commitment to a new binding CO_2 reduction agreement has remained an elusive goal, there have been both widespread national and international initiatives that support green technology and technology sharing mechanisms.[9] Literature in favour of national and international support of investments in climate protection normally does not take the strategic context of climate protection into account but allows for an investment in new markets argument.[10] In fact, in a strategic context, a particularly robust theoretical finding of the literature is that countries should strategically keep their costs of contributing high. The rationale is that a country with a higher contribution cost can free-ride on the other countries' contributions.[11]In this thesis, we contribute to this debate by analyzing a technology sharing scheme which takes into account the strategic context of climate protection effects and but also

[7]The Stern Review (2006) identified a technology-based scheme as indispensable for effectively tackling climate change.

[8]Article 4.5 of the United Nations Framework Convention on Climate Change states that countries "shall take all practical steps to promote, facilitate and finance, as appropriate, the transfer of, or access to environmentally sound technologies and know-how to other parties."

[9]See Moselle et al. (2010) for an overview.

[10] See Jaffe et al. (2003) for a survey and Ulph and Ulph (2006,2007).

[11]See the seminal work by Bergstrom et al. (1986) and Cornes and Sandler (1985). on private contribution to international public goods and see Bucholz and Konrad (1994,1995) for the strategic effect of technology on climate protection in the same framework.

includes the important timing considerations that countries' face when deciding over policy adoption.

This thesis uses non-cooperative methods to analyze existing structures and policies introduced via a multilateral initiative in the field of tax policy and climate policy. The second and third chapters study the OECD's strategy to counteracting tax havens. Specifically, the second chapter theoretically analyzes the OECD's strategy and process of closing down the tax havens' capital concealment activities, while the third chapter attempts to empirically analyze the main mechanisms driving the implementation process of the closure of tax haven activities of jurisdictions. The fourth chapter spurred on by the continuing success of the UNFCCC strategy to support technology transfer initiatives analyzes the effects of the technology sharing of unilateral investments in green technology on the timing of and contributions to climate protection. In the following, we present the main results from each chapter of the thesis. Each chapter is self-contained and can be read independently.

In Chapter 2, using a competition theory framework, we compare the sequential approach of closing down tax haven activities with a simultaneous and coordinated approach. The main argument presented in this chapter is that the 'deactivation' of some tax havens (in the sense of compliance with OECD information exchange rules) has implications for other tax havens' business opportunities. By closing down a majority of tax havens, the equilibrium payoffs of the tax havens that remain active increase, making it more attractive for them to continue their business. We show that this market concentration effect makes the process of closing down the tax haven business of one tax haven country after the other particularly costly, compared to a simultaneous and coordinated all-at-once approach. In reality, the implementation process of including tax information exchange articles to existing agreements or the signing of agreements has been rather slow and sequential in nature. Consequently, the analysis reveals a hidden cost to the sequential process that is not obvious from the outset. Furthermore, our analysis also incorporates asymmetric tax havens and shows that, given a sequential implementation pattern, and from the perspective of the overall cost, it is less costly to approach larger havens first; a finding which does not correspond to the pattern of recent Tax Information Exchange Agreement (TIEA) signings.

In Chapter 3 of this thesis, we provide a more detailed analysis of the legal vehicle proposed by the OECD Harmful Tax Practices Initiative; the signing of a TIEA or the inclusion of an information exchange clause to a Double Taxation Convention (DTC). We analyze the main factors determining the signing of an agreement: the outcome of a bargaining process between tax havens and high tax countries. Anecdotal evidence and analysis of different treaty forms show that a tax haven would rather sign an information exchange treaty which also facilitates cross-border investment (DTC) than sign a treaty which only regulates information exchange (TIEA). Taking this into account, we use a highly stylized bargaining model to develop testable hypotheses with regard to the type of agreement signed. The theoretical model identifies the general bargaining position of a tax haven versus a high tax country, the effectiveness of the defensive measures that can be used by the high tax country against a tax haven and the share of capital, which is evaded in the tax haven country, as the main drivers of the bargaining outcome. Taking these insights to the data, we argue that the countries' bargaining positions are a function of each country's respective economic position, while the effectiveness of the defensive measures is a function of the strength of the bilateral relationship. Using an ordered maximum likelihood regression model, our empirical analysis confirms the theoretically derived hypotheses. Specifically, a haven's bargaining position is significantly correlated with a lower number of signed agreements and the potential of defensive measures does have a positive impact on the compliance of tax havens, albeit to a smaller measure than the haven-specific characteristics. Consequently, these empirical findings can be used to give a deeper analysis of the progress of the fight against tax havens. The recent success in the fight against tax havens has been to a large degree buoyed by smaller tax havens complying with international tax and transparency standards. A particular challenge, which the study has put forward, is that the size of a haven's economic sector has a positive impact on its bargaining power. Taking into account that this effect is found when controlling for the bilateral financial relationship, this seems to suggest that stronger multilateral coordination and instruments are needed when dealing with larger havens.

Chapter 4 leaves the tax policy sphere and tackles the issues of the timing of contributions to climate protection and the effects of technology sharing initiatives on these timing considerations. In this chapter we show that investment in cost-reducing technologies, which can be shared and affect the costs of both countries identically, can influence the timing decision of the contribution to climate protection differently. Our contribution is twofold. First, we extend the framework of private provision to a public good game to a model that incorporates the important trade-off that countries face when deciding on climate policies; uncertainty versus irreversibility of damages. We derive the equilibrium contributions to climate protection and identify the main mechanisms driving the timing of the contribution decision. Second, we analyze, for the case of technology sharing, how an investment in cost-reducing technology by one country alters the timing decision of the contribution to climate protection game. We identify two scenarios wherein a country can invest in cost-reducing technology in order to free-ride on the other country's contribution. As countries can withstand different degrees of irreversibility of damages, we show that by a targeted use of cost-reducing technology, countries can switch from one equilibrium candidate to another. Specifically, countries can achieve an equilibrium candidate which allows them to free-ride on the other country's contribution.

Chapter 2

Fighting Multiple Tax Havens

This chapter is based on joint work with Kai A. Konrad.[1]

2.1 Introduction

The OECD report on Harmful Tax Competition (1998, p. 23) worked out a number of factors that may be used for identifying tax havens. One of these factors is existing national bank secrecy rules which have been utilized to support tax haven activities. Such rules protect investors "against scrutiny by tax authorities, thereby preventing the effective exchange of information on taxpayers benefiting from the low tax jurisdiction" and effectively enable investors to avoid paying the respective capital income taxes in their country of residence. Since the 1990s several initiatives have been launched against tax havens by the OECD, the G8, the United Nations Office for Drug Control and Crime Prevention and the European Union, in response.

Most prominent is the 1998 OECD initiative subsequently known as the Harmful

[1] See Elsayyad and Konrad (2012).

Tax Practices Initiative which was intended to discourage the use of preferential tax regimes for foreign investors and to encourage effective information exchange among the tax authorities of different countries. As part of the initiative, the OECD produced a list of countries and territories that it deemed to be tax havens. Over the years OECD attitudes with regards to tax havens shifted from confrontational to co-operative. OECD and non-OECD countries have worked together to develop mutual standards of transparency and exchange of information, which have come to serve as a model for a vast majority of the 3600 bilateral tax conventions entered into by the OECD and non-OECD countries and may now be considered as the international norm for tax cooperation (see, e.g., Kudrle 2008). If this information exchange is sufficiently effective, this would close down the respective country's activities as a tax haven. The dynamic process of implementation of these agreements, however, stretches over many years. Between 2000 and the London Summit Declaration in 2009, only 100 Tax Information Exchange Agreements (TIEAs) had been signed between OECD countries and the financial centers; furthermore, these signings for the most part have been limited to a small number of countries. Despite the surge in TIEA signings, which has taken place in the months after the London Summit, it is evident that not all agreements were made simultaneously, and the process is far from being complete. The fight against tax havens has been characterized by a sequential pattern, and agreements have not been conditioned on each other.

We compare the sequential approach taken with a simultaneous coordinated approach of effectively closing down tax haven activity (i.e., by enforcing appropriate information exchange institutions). 'Exit' by some tax havens (in the sense of complying with OECD information exchange rules) has implications for other tax havens' business opportunities. Tax havens compete with each other for customers and their capital. If the vast majority of competitors exits the tax haven business, the equilibrium payoffs of the tax havens that remain active increase, making it more attractive for them to continue their business. We show that this market concentration effect makes the process of closing down the tax haven business of one tax haven country after the other particularly costly, compared to a simultaneous and coordinated, all-in-one approach.

The OECD and other supranational entities engaged in the fight against tax havens may not have the option of an all-in-one approach. But for this case our analysis reveals a hidden cost of the sequential process that is not obvious from the outset.[2] Taking estimates of possible parameter values, we show that a sequential approach can be 1.5 times more costly than a simultaneous conditional approach. Furthermore, we show that given a sequential implementation pattern, from the perspective of the overall cost, it is less costly to approach larger havens first. A finding which does not correspond to the pattern of recent TIEA signings.

The public finance literature on tax havens has so far concentrated on the welfare implications of corporate tax planning and avoidance. The standard view underlying the OECD initiative is that tax havens may strengthen tax competition and erode the tax revenues of non-tax-haven countries.[3] Some of the literature also reveals possible countervailing effects suggesting that tax havens may actually provide benefits as well.[4] A diversity of views exists that is surveyed by Dharmapala (2008). However, this literature basically takes tax havens (typically one) as a given.[5] Slemrod and Wilson (2009) take a negative view on tax havens and account for the existence of multiple tax havens and tax haven fighting expenditures. To our knowledge this

[2]The problem entered into the policy discussion only very recently. An example is Rosenzweig (2012, p.729) who acknowledges: "It only takes one tax haven in the world to undermine a cooperative dynamic among other countries in the world."

[3]A formal analysis along these lines is provided by Slemrod and Wilson (2009). For an analysis focusing on the harmful effects for developing countries see Torvik (2009).

[4]See, e.g., Hong and Smart (2010), Desai et al. (2006) and Johannesen (2010).

[5]Slemrod (2008) provides an empirical analysis of the possible factors (including income, literacy, development aid, size or whether a country is an island) that make it more or less likely that a country engages in activities as a tax haven (following the OECD classification).

literature disregards the role of competition and market concentration between tax havens and the change in competition that emerges from the OECD policy that tries to change the set of tax havens. However, it is exactly this effect which needs to be taken into consideration in the process of closing down tax haven operations.[6]

For a description of competition between tax havens we adopt the formal structure of Bertrand markets with subsets of price sensitive and loyal or partially uninformed consumers, building on the fundamental insights of Varian (1980). More specifically, we rely on the competition model by Narasimhan (1988).[7] Tax competition is typically described as a variant of competition in tax rates (i.e., in "prices"). The Varian/Narasimhan framework is a natural generalization of such Bertrand competition, with the standard Bertrand type of competition as a special case. This more general structure is sufficient to map a continuum of competition regimes, ranging from local monopolies to standard Bertrand price competition (which is closest to the standard approach in the tax competition literature), and it is suitable to consider the competition and market concentration effects stemming from policies that deactivate tax-haven activities for a subset of tax havens.

The implications of these changes in market concentration for a simultaneous or sequential inactivation of tax havens are the main drivers of our results. Changes in market concentration play a major role in many other areas of international economics. Merger or exit by some competitors in a given market generates externalities to other competitors and also influences others' merger or exit decisions. These effects have been explored along a large variety of dimensions. Examples in contexts

[6] Considerable research has taken place to understand the economics of bilateral versus multilateral trade negotiations and agreements, see for example Bagwell and Staiger (2010). Research involving bilateral tax treaties has mainly focused on their investment effects between high-tax countries, see Chisik and Davies (2004).

[7] This competition model became a workhorse model in Industrial Organization. In the tax competition literature, this framework has been used by Wang (2004), Andersson and Konrad (2001), Konrad and Kovenock (2009) and Marceau et al. (2010).

such as strategic trade policy, outsourcing, and other policy areas are Dixit (1984), Horn and Levinsohn (2001), Lommerud et al. (2006) and Norbäck et al. (2009). In our framework the change in market concentration is caused by one player who is not a tax haven itself, but governs the possible exit or deactivation of some of the tax havens that compete among themselves, rather than by a merger. This difference is discussed in more detail in Section 2.6.

This chapter is structured as follows: Section 2.2 develops the model framework. In Sections 2.3 and 2.4 we solve for the equilibria of the multi-stage game. Section 2.5 discusses and compares the different deactivation regimes, their results and implications. Section 2.6 discusses the robustness of the results, in particular with respect to more than two tax havens and provides a numerical example. Section 2.7 concludes.

2.2 The structure of the problem

We consider a multi-stage game with three players: One player is the government in the country or group of countries that engage in fighting tax havens (or, for that purpose, the OECD).[8] We call this player S. Residents in S are the sole owners of financial capital. The other two players are tax havens, denoted H_1 and H_2. which seek to attract mobile capital by offering concealment services. Depending on the tax rate on capital income in S, whether the tax havens are active, and the terms which the tax havens offer for their services, financial capital can allocate between S, H_1 and H_2. Our analysis generalizes for more than two tax havens, as is shown in Section 2.6.

[8] There is a free-riding problem among the OECD countries. We disregard this problem in order to concentrate on the market effect. In some sense and particularly with regard to the fight against tax havens, the OECD is the institution that coordinates its members on a common anti-tax-haven policy.

In Phase 1 - the haven deactivation phase - actions by S, H_1 and H_2 determine whether no, one or two tax havens will be available for investors. Country S may offer to compensate the tax haven in exchange for its promise to enter into full information exchange and effectively discontinue its tax haven business. The assumption by which S compensates the tax havens to terminate their operation rather than threatening them with retaliatory actions, which are costly for the country that carries them out, is mainly for analytical simplicity and clarity.[9] We distinguish between two different types of offers made. One of these types is seen as a possible option that is currently not pursued. The other type maps more closely the current OECD initiative.

Simultaneous joint offer: Country S offers payments $b_1 \geq 0$ and $b_2 \geq 0$ to the two tax havens H_1 and H_2, respectively. S is able to commit to either pay both amounts or none, and to make this payment dependent on whether or not both havens agree. Tax havens then simultaneously and independently declare whether they would be willing to accept this offer or not. Each tax haven commits to close down in exchange for receiving the payment, but continues to operate if no payment is received. Accordingly, if both agree, then S makes both payments. If payments are made, both tax havens go out of business. If only one tax haven declares agreement or if none of the tax havens declares agreement, then no money is paid out and both tax havens remain active, and we move to Phase 2 of the game with two active tax havens.

Sequential offers: Country S may first offer a payment b_i to one of the tax havens H_i. This tax haven has to decide whether to accept this offer and to become inactive in Phase 2, or to remain active. Based on this observed outcome country S may (but need not) offer a payment b_{-i} to the other tax haven, H_{-i}. The choice of making

[9] An approach not using a "carrot" but a "stick" would yield results with a similar flavour. A punishment threat to a haven is costly for S as well, and causes a differential in payoff for the tax haven between compliance and non-compliance plus punishment. Unlike for the simple compensation that we consider, however, the cost and this differential need not be of equal size.

this offer, and the payment chosen, typically will depend on the outcome of the first offer made, and on whether it has been accepted or not. Also, whether the tax haven H_{-i} accepts or rejects this offer can generally be dependent on the first offer made and whether it has been accepted or not.

We assume that the havens accept the offer if they are indifferent between accepting or rejecting. This ends Phase 1.[10]

At the beginning of Phase 2 -the competition phase- the set of active tax havens is either $\{H_1, H_2\}$, $\{H_1\}$, $\{H_2\}$ or $\varnothing$. S first chooses a tax rate t that applies to financial capital invested in country S. This tax rate is from a closed interval $[0, r]$, where r may, for instance, be as large as a fully confiscatory rate of 100 percent. We consider the upper end of this interval as exogenously given here, but it could also be endogenized, together with making the total capital stock react to the anticipated tax rate. An option of "free disposal" of capital, for instance, would practically limit t to a maximum of 100 percent.[11] This tax has to be paid by each unit of financial capital that will locate in S. Tax havens that are active (that is, tax havens that have not accepted or received an offer by S in Phase 1) observe t and then choose user fees $p_1 \in [0, r]$ and $p_2 \in [0, r]$ per unit of financial capital that will be invested in the respective tax haven. In exchange for the fee the haven guarantees the investor full secrecy as regards his or her capital.[12] We assume that investors can fully rely

[10]We follow here a tradition which is common in the theory analysis of principal-agent problems and consider simple take-it-or-leave-it offers. Note that this makes the environment as favorable as possible for the OECD. Note also that more complex, possibly repeated concepts of non-cooperative Nash bargaining with complete and perfect information typically boil down to immediate agreement (Rubinstein 1982).

[11]From an analytic point of view, an upper limit of r is a necessary complement to the supply of capital being fixed exogenously here. The latter is a standard assumption in the tax competition literature, but is obviously a partial analytic simplification. For this assumption and a discussion of it, including further references, see Bucovetsky (2009).

[12]The government need not charge these fees directly to capital owners but may charge these fees to the local financial sector in the tax haven. If this sector faces perfect competition inside each tax haven and has only foreign customers, the fees chosen by the

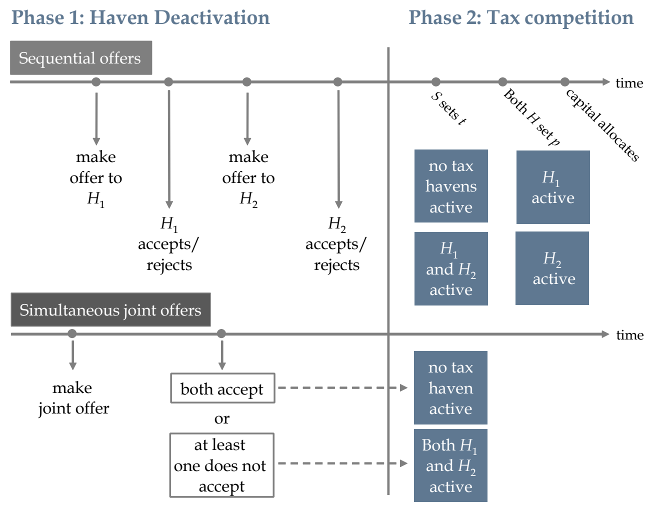

Figure 2.1: The upper panel and the lower panel show the structures of the game for the sequential and the simultaneous joint offer deactivation regime, respectively. The gray squares on the right-hand side represent the tax competition continuation games that may emerge from the deactivation phases.

on this promise. Hence, investors save the residence income tax t on this capital income. The partially sequential nature of this competition with S as a Stackelberg leader follows the consideration that tax havens are quicker and more flexible in their choices of fees than is the parliamentary process of tax legislation in the OECD. The two phases for the simultaneous offer regime and for the sequential offer regime are mapped in Figure 2.1.

Once the conditions for investment are known, financial capital is allocated between S, H_1 and H_2 as a function of the tax t and the user fees p_i for $i \in \{1, 2\}$ in

government and imposed on the local banking sector are fully passed through to their customers, just as if they would be charged to the capital owners directly. Perfect competition in the financial sector and the absence of local resident customers also removes possible considerations of strategic trade policy from the picture that would be relevant otherwise. With oligopoly in the financial sector and/or with local residents as customers, deactivating single tax havens would influence the incentives for strategic policy along lines that have been drawn in a more general setup by Krishna and Thursby (1991).

the active tax havens. The total amount of financial capital is normalized to 1, and is owned by residents of country S.[13] There are three different types of financial capital. A share s of this financial capital is fully immobile. This is the share of capital owned by residents who cannot, or would never like to invest their financial capital offshore and simply pay whatever is the tax rate in country S. Shares h_i of capital are mobile only between S and one of the respective tax haven H_i for $i \in \{1, 2\}$. For our analysis we assume $h_1 \geqslant h_2 > 0$, i.e., we allow for havens to have different market positions.[14] The share h_i of financial capital is invested in H_i if and only if $p_i \leq t$.[15] This assumption corresponds to the notion that some investors may have an affinity for particular tax haven countries. This affinity could, for instance, be based on geographical proximity, language, a convenient legal code etc. Finally, there is a remaining amount of financial capital that is perfectly mobile. This amount is denoted by $\beta = 1 - s - h_1 - h_2$. The share β stays in S if t is smaller than p_i for all tax havens that are active. It moves to a tax haven rather than staying in S if the user fee in one of the active tax havens is at least as low as the tax. If both tax havens are active and the user fees in both tax havens are not higher than t, this capital locates in the tax haven with the lower user fee, and if both tax havens are active and $p_1 = p_2 \leq t$, equal shares of this fully mobile capital locate in each of the two tax havens.[16] Capital yields the same gross return, independent of where it is located (which is a natural assumption in case of a well integrated international capital market). And it does not restrict generality if we normalize this return to

[13]Here tax havens do not have a genuine business other than sheltering foreign financial assets from resident taxes in their respective home countries. Hines (2010) provides empirical evidence about tax havens, showing that the overwhelming share of these indeed has a tiny national GDP. Our assumption is also appropriate if the tax havens have resident capital income, but can treat their own residents differently from foreign investors.

[14]The case $h_i = 0$ can be obtained for considering $\lim h_i \to 0$, but keeping $h_i > 0$ simplifies the formal exposition.

[15]For $p_i = t$ this is the natural tie-breaking assumption, given that S chooses t prior to the tax havens' choices of fees.

[16]Like in the workhorse model of tax competition, mobile capital simply flows to where the net return is highest.

zero, i.e., assume that one unit of financial investment turns into one unit of gross financial return, and -as is common in the tax competition literature- consider taxes and fees on capital, rather than on its returns.

The payoffs of S, H_1 and H_2 are as follows. Each tax haven maximizes the sum of user fees and payments b_i received from S. An active tax haven does not receive any payment from S and its payoff equals its user fees, which is equal to the product of p_i and the amount of financial capital x_i that is invested in this tax haven, where x_i is a function of t and p_i, and of whether the other tax haven is active. This is considered in more detail further below. The benevolent government in country S maximizes the following payoff:

$$\begin{aligned} \pi_S &= (1-t)(1-x_1-x_2)+(1-p_1)x_1+(1-p_2)x_2 \\ &\quad +(1+\lambda)t(1-x_1-x_2)-(1+\lambda)(\theta_1 b_1+\theta_2 b_2) \end{aligned} \tag{2.1}$$

The payoff (2.1) consists of several terms. The first term in (2.1) is the net-of-tax return on domestically invested capital. The second and third terms represent the capital incomes of residents net of user fees p_1x_1 and p_2x_2 paid on the amounts x_1 and x_2 that result from the financial assets shifted offshore to H_1 and H_2. The fourth term is the social valuation of the capital tax revenue. This is equal to the product of $(1+\lambda)$ and the tax revenue. The tax revenue is equal to t times the amount of financial capital that locates to S. The factor $(1+\lambda)$ accounts for the fact that government revenue has a shadow price of public funds $(1+\lambda)$. This shadow price is equal to the marginal social cost of an additional unit of tax revenue from other (distortionary) sources of taxation, measured in units of private consumption. A positive λ is the basis of the theory of optimal taxation, as these theories are based on the plausible assumption that the collection of tax revenue for financing desirable public expenditure generally causes an excess burden of taxation. And to assume that $(1+\lambda)$ is constant is generally justified as an approximation for the case in which the capital income tax is a small share of the total tax revenue generated in country S.[17] The last term is the social cost of possible payments b_1 and b_2 that are offered to the tax havens. These depend on whether the tax havens accept these payments (for becoming inactive). Here, θ_1 and θ_1 are indicator variables that are equal to 1 and 0 , depending on whether or not the payments are accepted and made.

To solve the different variants of this game we use the concept of subgame perfect equilibrium. We start with solving for the set of equilibria in phase 2 for different combinations of active tax havens.

2.3 Equilibrium in Phase 2

If both tax havens are active Country S chooses t prior to the tax havens' choices of p_1 and p_2. Consider the payoff of H_i for a given t and p_j:

$$\pi_{H_i} = p_i x_i = \begin{cases} 0 & \text{if } \; p_i > t \\ p_i h_i + p_i \beta & \text{if } p_i < p_{-i} \leq t \\ p_i h_i + \frac{1}{2} p_i \beta & \text{if } p_i = p_{-i} \leq t \\ p_i h_i & \text{if } t \geq p_i > p_{-i} \end{cases} \tag{2.2}$$

for $i, -i \in \{1, 2\}$. A choice of $p_i > t$ will render the haven zero profits. For $p_i \leq t$, if H_i offers lower user fees p_i than its haven competitor, it attracts its partially mobile capital segment h_i and the price sensitive segment β. If it offers its services for a fee p_i that is higher than its haven competitor, then it attracts only its partially mobile capital segment. If the two havens set the same level of user fees, then each gets

[17] For the assumption of constant $(1 + \lambda) > 1$ and its discussion see Bucovetsky (2009) in the tax competition context, and Laffont and Tirole (1986) in the context of procurement and regulation. Our justification for the assumption is the same as their's, which is outlined in more detail by Caillaud et al.(1988).

its partially mobile segment, while the price sensitive β segment is equally divided between the two havens.

The range of possible equilibrium choices of fees by the tax havens can be narrowed down. By (2.2) a choice $p_i > t$ for $t > 0$ yields zero payoff and is payoff-dominated by an appropriate choice $p_i \in (0, t)$. Also, a haven will never set a price which is lower than

$$\hat{p}_i = \frac{th_i}{h_i + \beta}, \tag{2.3}$$

as such low prices are payoff-dominated by a choice $p_i = t$ that yields a payoff that is higher or equal to th_i, irrespective of the other tax haven's choice. The maximum payoff obtainable from a $p_i < t$ is $p_i (h_i + \beta)$ and this maximum is obtained if, choosing this p_i, haven H_i captures the whole price-sensitive mobile segment β. Note further that $\hat{p}_1 > \hat{p}_2$ as $h_1 > h_2$. Given that $p_1 \geq \hat{p}_1$, this implies that $p_2 < \hat{p}_1$ is payoff-dominated by a price p_2 closer to $\hat{p}_1$. This narrows down the range of possible price chosen in an equilibrium to the interval $[\hat{p}_1, t]$. Note further that, for any given $t \in (0, r]$, there is no Nash equilibrium in pure strategies.[18] Intuitively, haven H_i has an incentive to undercut haven H_{-i}'s user fee by a very small amount in regions in which prices are above the floor $\hat{p}_1$, as this lures the whole mobile segment β to H_i. And $p_1 = p_2 = \hat{p}_1$ is also not an equilibrium, as, from there, deviations towards $p_i = t$ pay for at least one player.

The competition between tax havens, for a given t, is structurally equivalent to Bertrand competition between two firms with loyal customers as in Narasimhan

[18] To confirm this, suppose that $(p_1^*, p_2^*) \in [\hat{p}_1, r] \times [\hat{p}_1, r]$ is such an equilibrium. Note that p_1^* and p_2^* cannot be mutually optimal replies if $p_1^* > \hat{p}_1$ and $p_2^* > \hat{p}_1$. Suppose they are, and let $p_i^* \leq p_{-i}^*$. Then H_{-i} could increase its payoff by moving to $p_i^* - \epsilon$ for sufficiently small but positive ϵ. Note next that p_1^* and p_2^* cannot be mutually optimal replies if $\min\{p_1^*, p_2^*\} = \hat{p}_1$. Two cases need to be distinguished. If $p_1^* = p_2^* = \hat{p}_1$ then H_1 can do better by choosing $p_1 = r$. If $p_i^* > p_{-i}^* = \hat{p}_1$, then H_{-i} can do better by increasing its price by half the difference between p_i^* and p_{-i}^*. This shows that the claim of existence of a pure strategy equilibrium leads to a contradiction.

(1988), and we can use his results on existence and uniqueness of an equilibrium and its characterization.[19] A unique equilibrium exists and is in mixed strategies. In this equilibrium each haven picks its price independently and randomly according to a cumulative distribution function F_i for $i = (1, 2)$ with support $[\hat{p}_1, t]$, with haven H_1 having a mass point at t. The following lemma describes the havens' payoffs in this equilibrium.[20]

Lemma 2.1 *(Narasimhan (1988)) For $t > 0$ there exists a unique equilibrium of the subgame between two active havens.*[21] *The equilibrium has the expected payoffs*

$$E(\pi_1) = h_1 t \text{ for } H_1 \text{ and } E(\pi_2) = \frac{h_1 t}{h_1 + \beta}(h_2 + \beta) \text{ for } H_2. \tag{2.4}$$

In (2.4) H_1 with the larger partially mobile segment earns the same profit that it would earn if it were to set $p_1 = t$ with probability 1. The haven H_2 with the smaller h_i segment earns $h_1 t (h_2 + \beta) / (h_1 + \beta)$ which is higher than the profit $h_2 t$ that H_2 could make if it only focused on its partially mobile segment of capital. Hence, this tax haven's profit is positive even if it has no own partially mobile capital segment, i.e., if $\lim h_2 \to 0$.

The competition framework used here has several advantages. It is sufficiently general to have many standard cases as special cases. Suppose, for instance, that

[19] A generalization to n competitors is by Baye et al. (1992) for symmetric firms and by Kocas and Kiyak (2006) for asymmetric firms. We use their results to consider the case with more than two tax havens in Section 1.6.

[20] Equilibrium in mixed strategies for the choice of tax rates in tax competition has been used in number of recent papers, including Marceau et al. (2010), Wang (2004), and Konrad and Kovenock (2009). In our context only the tax havens use mixed strategies as regards the choice of fees, which are more like administratively chosen prices than law-based tax rates. Accordingly, the choice of such fees is similar to the choice of prices as in the standard literature that follows the tradition of Varian (1980) and the justification used for mixed strategies in this broad literature applies also here.

[21] For completeness we report the cumulative distribution functions characterizing the equilibrium. These are $F_1(p) = F_2(p) = 0$ for $p < h_1 t/(h_1 t + \beta)$, $F_1 = 1 + \frac{h_2}{\beta} - \frac{h_1 t(h_2+\beta)}{\beta p(h_1+\beta)}$ and $F_2 = 1 - \frac{h_1(t-p)}{\beta p}$ for $\frac{h_1 t}{h_1 t+\beta} \leq p \leq t$ and $F_1 = F_2 = 1$ for $p > t$.

$h_1 = h_2 \equiv h$. Then the equilibrium is symmetric. Both tax havens would earn the same expected payoff th. For $\lim h \to 0$ this payoff becomes equal to zero, as this is the case of Bertrand competition for a perfectly homogenous product and without loyal customers. Also, if the fully price-sensitive share β converges towards zero, then both tax havens simply charge the monopoly price as the pure equilibrium strategy. Furthermore, the payoffs in the competition subgame are uniquely determined in the equilibrium (Narasimhan (1988)). This allows us to consider a contracted game in which we can replace the subgame by the unique equilibrium payoffs of this last stage.

Assuming subgame perfect equilibrium play and using Lemma 2. 1, the payoff of country S is

$$1 - ts - h_1 t - \frac{h_1 t}{h_1 + \beta} (h_2 + \beta) + (1 + \lambda)\, ts. \tag{2.5}$$

For any $t > 0$ one or both of the tax havens can attract the mobile tax base. Hence, the welfare of country S consists of investors' expected net returns plus $(1+\lambda)$ times the tax revenue, minus $(1+\lambda)$ times the payments for closing down tax havens (zero in this case, as both tax havens are active). The immobile capital (quantity s) stays in country S. All other capital is invested in the equilibrium in one or the other tax haven for $t \in (0, r]$. The expected fees collected by the tax havens are equal to their expected payoffs, and are generally a function of t. Country S maximizes (2.5) with respect to t.

The two tax havens choose their equilibrium fees simultaneously once t is chosen and observed. Intuitively, for $t > 0$, they can always undercut S and attract all of the price-sensitive mobile capital. Country S, hence, anticipates that, for any $t > 0$, only the immobile capital remains in S, and this immobile tax base remains unaffected by changes in p_1 and p_2. Consequently, it is the shadow price of public funds, λ which determines whether the government is willing to set the tax rate equal to 0 or to the maximum rate. The threshold value for the shadow price will be shown to be

$$\hat{\lambda} = [1 + \frac{h_2 + \beta}{h_1 + \beta}](h_1/s). \tag{2.6}$$

This threshold value $\hat{\lambda}$ depends on the mobility composition of the financial capital. In particular, taking partial derivatives of (2.6) shows that an increase in any of the mobile capital segments results in an increase in $\hat{\lambda}$, while an increase in s decreases the size of the critical shadow price of public funds. Of course, none of h_1, h_2 , β or s can change in isolation, as they are connected through the budget constraint. More formally, we can state:

Proposition 2.1 *(i) Let $\lambda > \hat{\lambda}$. In the subgame perfect equilibrium of the continuation game with two active tax havens, S chooses $t = r$. The expected equilibrium profits of the tax havens and of S are :*

$$\begin{aligned} E(\pi_1) &= h_1 r \text{ and} \\ E(\pi_2) &= [h_2 + \beta]\tfrac{h_1 r}{h_1+\beta} \text{ and} \\ E(\pi_S) &= 1 + \lambda r s - h_1 r - \tfrac{h_1 r}{h_1+\beta}(h_2 + \beta) \end{aligned} \tag{2.7}$$

(ii) Let $\lambda < \hat{\lambda}$. Then the subgame perfect equilibrium of the continuation game with two active tax havens is described by $t = 0$, $E(\pi_1) = E(\pi_2) = 0$ and $E(\pi_S) = 1$.

Proof. Consider S's optimal choice t from the interval $[0, r]$ of feasible tax rates, anticipating equilibrium play in the continuation game for any given choice of t. The country's objective is to maximize (2.5). The gradient of the expression in (2.5) with respect to t is

$$\frac{\partial E(\pi_S)}{\partial t} = \lambda s - h_1 - \frac{h_1}{h_1 + \beta}(h_2 + \beta), \tag{2.8}$$

and is independent of t. (i) The gradient is positive if $\lambda > \left[1 + \frac{h_2+\beta}{h_1+\beta}\right]\frac{h_1}{s} \equiv \hat{\lambda}$. The payoff of S is maximal for the maximum feasible t which is $t = r$. The equilibrium payoffs in (2.7) follow from $t = r$, Lemma 2.1 and from inserting $t = r$ into the payoff function (2.5) for S. (ii) Note that (2.8) is independent of t and negative if $\lambda < \hat{\lambda}$. For λ smaller than this threshold, the optimal choice of the tax rate is, therefore, the smallest possible tax rate, $t = 0$. In this case any possible choice of p_1 and p_2 yields the same payoffs (of zero) for both tax havens, and $\pi_S = 1$ by (2.5). Note also that there is a multiplicity of (payoff-equivalent) equilibria with $t = 0$: all p_i and p_j yield the same payoffs. ■

If only one tax haven H_i is active. Consider the possible options for financial capital if only one tax haven H_i is active. For the capital h_i that either locates in the active tax haven H_i or in S, and for the immobile capital segment s the investment options do not change. The price-sensitive capital segment β can now locate only in S or in H_i. The capital share h_j that was mobile only between S and H_j, which is now inactive, becomes immobile: As H_j is no longer active, h_j remains in S.

As H_j but not H_i is deactivated, a payment b_j has been made, and no payment has been made to H_i. Hence, $\theta_j = 1$ and $\theta_i = 0$ hold. Note that, in the following section, the newly added superscripts to the payoff function refer to the haven which has been deactivated. To differentiate between the possible regimes, we use the following notation for the payoff of S: π_S^k denotes the payoff of S as a function of the regime, where superscript $k = 0$ refers to the default state regime (both tax havens active), $k = 1$, $k = 2$ and $k = 1, 2$ refer to the regimes with $i = 1$ or $i = 2$ or $i = 1$ and $i = 2$ deactivated.

Proposition 2.2 *Suppose that H_j has been deactivated due to a payment b_j. (i) If $\lambda > (h_i + \beta)/(s + h_j)$ then the subgame perfect equilibrium in Phase 2 is unique in payoffs and characterized by $p_i = t = r$ with payoffs:*

$$\begin{aligned} \pi_i^j = (h_i + \beta)r,\ \pi_j^j = b_j \ \textit{and} \\ \pi_S^j = 1 + (s + h_j)\lambda r - (h_i + \beta)r - (1 + \lambda)b_j. \end{aligned} \tag{2.9}$$

(ii) If $\lambda < (h_i + \beta)/(s + h_j)$ then the subgame perfect equilibrium in Phase 2 is unique and characterized by $p_i = t = 0$, with payoffs $\pi_S^j = 1 - (1 + \lambda)b_j$, $\pi_i^j = 0$ and $\pi_j^j = b_j$.

(iii) For $\lambda = (h_i + \beta)/(s + h_j)$ both equilibria exist.

Proof. Using backward induction, consider the last stage. The only active tax haven H_i chooses p_i for given $t \in [0, r]$ to maximize H_i's payoff $p_i x_i$, with $x_i = 0$ if $p_i > t$ and $x_i = 1 - s - h_j$ if $p_i \in [0, t]$. The solution of this maximization problem is $p_i = t$ for all $t \geq 0$ and yields a payoff of $(1 - s - h_j)t = (\beta + h_i)t$. For $t > 0$, the optimal p_i is unique. For $t = 0$, all possible p_i yield the same payoff of zero. Turn next to the optimal choice of t and take into consideration that at this stage b_j is exogenously given and that $p_i = t$ in the continuation game for $t > 0$. Country S maximizes

$$1 - (s + h_j)\, t - (h_i + \beta)\, t + (1 + \lambda)\left((s + h_j)\, t - b_j\right) \tag{2.10}$$

The gradient of this payoff with respect to t is $-(s + h_j) - (h_i + \beta) + (1+\lambda)(s+h_j)$ and independent of t. Accordingly, the optimal choice is a corner solution. S chooses $t = r$ (i.e., the largest feasible tax rate) if $(s+h_j)\lambda > h_i+\beta$ and $t = 0$ if $(s+h_j)\lambda < h_i+\beta$ which reduces to the condition for λ in the proposition. Finally, for $(s+h_j)\lambda = h_i+\beta$ both $t = r$ (with the respective equilibrium of the subgame as in (i)) and $t = 0$ (with the respective equilibrium as in (ii)) yield the same payoff for S and this payoff is higher than from any choice $t \in (0, r)$. ■

Intuitively, given the sequential structure of the tax decision, the fully mobile capital will always leave S for any $t > 0$. And for $t = 0$, whether the capital locates to S or H_1 (with $p_1 = 0$) is payoff-irrelevant. Due to the lack of competition for the mobile capital segment, the active tax haven earns the monopoly profit from the entire share of financial capital that is mobile between S and H_i. It chooses $p_i = t$ as this ensures maximum profit for the tax haven H_i which is active. With S's choice of t not affecting the final destination of the mobile capital segment, S

chooses $t = r$ only if λ is sufficiently high. The condition for λ to be sufficiently high is also intuitive. A high tax is more beneficial for the country if its equilibrium tax base is large (i.e., $s + h_j$ is large), and if $(h_i + \beta)$, which is the base on which the country as a whole loses the fees to the tax haven, is small.

If none of the tax havens is active. Suppose S has deactivated both havens and financial capital can only remain in S. Accordingly, all capital remains in country S, the country has to pay b_1 and b_2, and can charge any tax rate $t \in [0, r]$. The payoff function of S becomes $1 - t + (1 + \lambda)(t - b_1 - b_2)$ and this payoff reaches a maximum equal to $1 + \lambda r - (1 + \lambda)(b_1 + b_2)$ for $t = r$. Hence:

Proposition 2.3 *If both tax havens are deactivated, then S chooses $t = r$ and has a payoff $\pi_s^{1,2} = 1 + \lambda r - (1 + \lambda)(b_1 + b_2)$. The payoffs of the tax havens are $\pi_1^{1,2} = b_1$ and $\pi_2^{1,2} = b_2$.*

2.4 Equilibrium in Phase 1

In what follows we focus on the case in which the shadow price of public funds is sufficiently high to make a high tax strategy always preferable for S. We first show that S cannot expect to gain from deactivating just one tax haven, assuming subgame perfect equilibrium play in Phase 2. We then consider the cost and benefit of deactivating both tax havens for the sequential regime and the regime with simultaneous joint offers. This comparison leads to our main results: An equilibrium with simultaneous joint offers exists, whereas sequential offers are never profitable for S.

2.4.1 Deactivation of only one tax haven

For the active haven, deactivation of only one tax haven yields an increase in profits for the only remaining active tax haven for any given $t > 0$, due to reduced competition. If only H_1 remains active, an optimal reply for any given $t \in (0, r]$ is $p_1 = t$ and its payoff is $(h_1 + \beta)t$. Compared to both havens being active, the payoff increase is βt. If only H_2 remains active, its payoff is $(h_2 + \beta)t$. Compared to both havens being active, the payoff increases by $(h_2 + \beta)\beta t/(h_1 + \beta)$. Intuitively, a larger h_1 makes haven H_1 less aggressive in the competition. Hence, there is little to gain for H_2 from removing its competitor H_1 if h_1 is large. Note also that monopoly profits for a tax haven need not be larger than the aggregate profits in the case where both havens are active. Deactivation of a tax haven H_i shifts the share h_i of capital away from that tax haven. However, removal of competition between tax havens also increases equilibrium user fees in the remaining tax haven which increases the payoff of the active haven.

For S, deactivating one tax haven has several effects. First, if H_i is deactivated and H_{-i} remains active, the level of gross capital remaining in S and being taxed with $t = r$ increases from s to $s + h_i$. This increases the tax revenue in S. Second, there is a reduction in investors' rents. This is due to higher user fees that are charged on the mobile capital if only one tax haven is active, compared to a situation with several competing tax havens. Hence, with only one tax haven active, all capital (inside and outside S) is charged at the same, high rate r. Third, compared to both tax havens being active, S has to pay for the deactivation of one tax haven which reduces the payoff of country S.

We now confirm that the deactivation of only one tax haven is dominated by other choices for country S. We state this claim as a proposition.

Proposition 2.4 *Country S has a higher payoff if both tax havens are active than if it deactivates exactly one haven.*

Proof. Note that the effects of the deactivation of H_i on the payoff of S differ for $i \in \{1, 2\}$ if $h_1 \neq h_2$. Deactivating H_i only increases S's payoff if

$$\begin{aligned}\pi_S^i &= \underbrace{(1-r)(s+h_i)+(h_{-i}+\beta)-\underbrace{r(h_{-i}+\beta)}_{\text{active haven's profits}}}_{\text{net capital income}} + (1+\lambda)\underbrace{[r(s+h_i)-b_i]}_{\text{net tax revenue}} \\ &\geqslant \underbrace{1-rs-\underbrace{\left(h_1 r+\frac{h_1}{(h_1+\beta)}r(h_2+\beta)\right)}_{\text{aggregate haven's profits}}}_{\text{net capital income}} + (1+\lambda)\underbrace{rs}_{\text{net tax revenue}} = \pi_S^0 \end{aligned} \tag{2.11}$$

Rearranging (2.11) yields the *sole haven deactivation condition* (SHIC):

$$\underbrace{(1+\lambda)[rh_i-b_i]}_{\text{shadow value * increase in net tax revenue}} - \underbrace{\frac{\beta}{(h_1+\beta)}r(h_2+\beta)}_{\text{decrease in net capital income}} \geq 0 \tag{2.12}$$

The condition (2.12) shows: for the deactivation of one tax haven to be profitable for S, the decrease in net capital income has to be compensated by an increase in net tax revenue. As $\frac{\beta}{(h_1+\beta)}r(h_2+\beta)$ and λ are always positive, the level of compensation offered and paid to the deactivated haven plays an important role in this condition. The minimum possible compensation, which just compensates the tax haven for its loss in profits, as in Lemma 2.1 for $t=r$ can be inserted for b_i which transforms (SHIC) into

$$\begin{aligned} &-\frac{\beta}{(h_1+\beta)}r(h_2+\beta)\geq 0 && \text{when deactivating } H_1 \\ &\underbrace{(1+\lambda)\left[rh_2-\frac{h_1}{(h_1+\beta)}r(h_2+\beta)\right]}_{<0}-\frac{\beta}{(h_1+\beta)}r(h_2+\beta)\geq 0 && \text{when deactivating } H_2. \end{aligned}$$

Thus, the condition SHIC cannot be fulfilled. ■

Intuitively, deactivating one tax haven does not change total gross capital income here, but changes its decomposition in private income, tax revenue for S, and fees and compensation payments for the tax havens. Fees for the tax haven that remains active go up, due to the reduction in competition pressure between tax havens. This effect is the main driver of the result, as this effect in isolation reduces welfare in S.

A secondary effect is that tax revenue in S goes up. However, in order to achieve this, S needs to compensate the deactivated tax haven for its loss in fees and has to use public funds for this. For instance, if S deactivates the larger tax haven H_1, then the compensation for the loss in H_1's fees is just equal to the additional tax revenue in S. And, as this compensation is paid with public funds, the shadow price of this payment is higher than the money value taken from the capital owners in terms of fees.

2.4.2 Deactivation of all tax havens

The result in Proposition 2.4 reduces the problem to possible equilibria with deactivation of both, or none of the tax havens. We turn to this comparison now. Again, the problem is whether or not the compensations required are sufficiently low for making the deactivation of both tax havens attractive for S. We first derive a condition describing the maximum that S is willing to pay.

Proposition 2.5 *The country S is better-off than in the default state if it deactivates both tax havens provided that the sum of compensations fulfills the condition*

$$b_1 + b_2 < rh_1 + \frac{h_1}{(h_1+\beta)}(h_2+\beta)\,r + \frac{\lambda}{(1+\lambda)}\frac{\beta}{(h_1+\beta)}(h_2+\beta)\,r. \tag{2.13}$$

Proof. Country S makes deactivation offers only if its payoff $\pi_S^{1,2}$ after deactivation is at least as high as payoff π_S^0. This condition can be written explicitly as

$$\begin{aligned} \pi_S^{1,2} &= 1 - r + (1+\lambda)\left[r - b_1 - b_2\right] \\ &\geqslant 1 - rs - h_1 r - \frac{h_1}{(h_1+\beta)} r\,(h_2+\beta) + (1+\lambda)\,rs = \pi_S^0 \end{aligned} \tag{2.14}$$

Rearranging yields:

$$\underbrace{\frac{\beta}{(h_1+\beta)} r\,(h_2+\beta)}_{\text{decrease in net capital income}} \leq \underbrace{(1+\lambda)\left[r\,(h_1+h_2+\beta) - b_1 - b_2\right]}_{\text{increase in net tax revenue}} \tag{2.15}$$

This can be solved for b_1 and b_2 and yields (2.13). ■

Intuitively, deactivation of both tax havens has three main effects. First, it increases gross tax revenue in S, as all capital is taxed in S now, rather than invested in tax havens. Second, it reduces private capital income net of taxes, as in the equilibrium with two competing active tax havens, the fees on capital in the tax havens were, on average, lower than the equilibrium tax rate in S. Third, if deactivated, tax havens lose their income from fees, and country S uses public funds to pay them for this. The deactivation is beneficial for S if what needs to be paid to the tax havens for their deactivation is sufficiently small (see condition (2.13)).

A comparison of (2.7) and (2.13) shows that, for $\lambda = 0$, the maximum sum of bids that makes deactivation beneficial for S is equal to the equilibrium tax revenues of the two tax havens they have in the equilibrium if they stay active. The condition also highlights the role of the shadow price of public funds. Deactivation of the tax havens converts some private income of capital owners in country S into public funds. Hence, if $\lambda > 0$, then the willingness to pay of S for a deactivation is higher, as suggested by the third term on the right-hand side of (2.13).

2.5 Deactivation equilibrium

We have now shown that it is never an equilibrium for S to deactivate just one tax haven. Further, Proposition 2.5 characterizes S's maximum willingness to pay in order to deactivate both tax havens. The compensation that is needed in order to induce the two tax havens to close down is, however, a function of the deactivation regime. We show in this section that the compensation that would be needed with simultaneous joint offers for the deactivation of the tax havens is small enough, whereas the compensation that would be needed in total to deactivate both tax havens exceeds the willingness of S to pay in the sequential offer regime.

2.5.1 Simultaneous joint offers

First we consider a deactivation process in which S makes a simultaneous joint offer (b_1, b_2) to the two tax havens. The following result holds:

Proposition 2.6 *If S can make a simultaneous joint offer (b_1, b_2), then a subgame perfect equilibrium exists in which both tax havens become deactivated, with payoffs*

$$\pi_1^{1,2} = b_1 = h_1 r \tag{2.16}$$

$$\pi_2^{1,2} = b_2 = \frac{h_1}{(h_1 + \beta)} r (h_2 + \beta) \tag{2.17}$$

and

$$\pi_S^{1,2} = 1 - r + (1 + \lambda) \left(rs + \frac{\beta}{(h_1 + \beta)} r (h_2 + \beta) \right). \tag{2.18}$$

Proof. This regime's distinctive feature lies in the conditionality of the offers on the actions of the other haven, as each haven only receives a compensation when both accept the offers. Suppose S makes a simultaneous joint offer (b_1, b_2). Figure 2.2 summarizes the payoffs for the four subgames, assuming equilibrium play in the respective subgames that are reached, depending on the decision of the havens to either accept or reject the offer of S.

	Haven 2	
Haven 1	Accept	Reject
Accept	b_1, b_2	$h_1 r, \frac{h_1}{h_1+\beta} r (h_2 + \beta)$
Reject	$h_1 r, \frac{h_1}{h_1+\beta} r (h_2 + \beta)$	$h_1 r, \frac{h_1}{h_1+\beta} r (h_2 + \beta)$

Figure 2.2: Payoff matrix for the case of simultaneous joint offers

Figure 2.2 uses $t = r$ and the expected payoffs stated in Lemma 2.1 for the competition phase subgame with both tax havens being active. In each of the four cases, the first entry corresponds to the payoff of H_1 and the second to the payoff of H_2. The tax havens receive b_1 and b_2, respectively, if both accept the offer, and they receive the payoffs of the subgame with two active havens if one or both of them reject the offer. Joint acceptance is, hence, an equilibrium choice if $b_i \geq E(\pi_i^0)$ for both $i = 1, 2$. Moreover, the smallest amounts b_1 and b_2 for which joint acceptances are optimal mutual replies by the tax havens are $b_i = E(\pi_i^0)$ for both $i = 1, 2$. These bids fulfill conditions (2.16) and (2.17) in Proposition 2.6 and, together with the deactivation of both havens, yield (2.18). This payoff $\pi_S^{1,2}$ exceeds π_S^0, as can be seen from comparing $E(\pi_S)$ in (2.7) and (2.18). (The comparison boils down to $\frac{(h_1+\beta+\lambda\beta)}{(h_1+\beta)} > 1$ which is true.) ■

Proposition 2.6 shows that S can profitably deactivate all tax havens, provided that it can make a simultaneous joint offer to all tax havens. Intuitively, if S can make a simultaneous joint offer, the tax havens understand that they will never become the only active tax haven. Either both give up their tax haven business, or both stay active. Accordingly, it is optimal for them if they both accept the offer provided that the offer is at least as attractive for them as the situation in which both compete with each other, but they should reject any lower offer.

Note that the equilibrium in Proposition 2.6 is not unique, due to the coordination problem between the two tax havens. The simultaneous joint offers lead to payments and deactivation of both tax havens only if both tax havens accept the offer. Consider, for instance, offers (b_1, b_2) equal to, or even higher than (2.16) and (2.17). Although it would be beneficial for H_1 and H_2 to accept the offers, there is also an equilibrium in which both reject the offers: Given the expectation that the other tax haven H_{-i} will reject the offer, rejecting the offer is an optimal reply for H_i. Further, this coordination problem could be used by the tax havens to leverage up their equilibrium payoffs. For instance, if S expects the tax havens to end up in this rejection equilibrium for all offers (b_1, b_2) with $b_1 < h_1 r + \Delta$ and $b_2 < \frac{h_1}{h_1+\beta} r\left(h_2+\beta\right) + \Delta$, but with both accepting the offers for $b_1 \geq h_1 r + \Delta$ and $b_2 \geq \frac{h_1}{h_1+\beta} r\left(h_2+\beta\right) + \Delta$, this can support equilibria in which country S has to pay an additional 2Δ for positive and sufficiently low Δ, compared to the minimum offers that are accepted in the equilibrium in Proposition 2.6. These equilibria which are based on coordination failure are, however, not robust. They rely on H_i being indifferent regarding whether to accept or to reject if H_i thinks that H_j will reject. Country S can break this indifference if it can offer a menu that offers H_i also a very small payment for the case in which H_i accepts but H_j rejects the offer.

2.5.2 Independent sequential offers

Consider now the sequential deactivation regime, where S first approaches one haven H_i with a bid b_i for deactivation and then can make a bid b_j to the other tax haven H_j. The sequential process allows S to adjust its bid to H_j taking into consideration whether the previous bid to H_i was accepted or not.

Proposition 2.7 *If S makes sequential independent offers, the sum of compensations needed to deactivate both tax havens is smaller if the tax haven with more loyal capital (with higher h_i) is compensated first. Overall, the combination of $(b_i, b_j(.))$ that would make both havens accept the offers exceeds country S's willingness to pay.*

Proof. Using backward induction, we derive the subgame perfect equilibrium of this offer regime. Assume that S first makes an offer b_i to H_i, and then, depending on the outcome, possibly an offer $b_j(.)$ to H_j. Note that no offer b_j is made if b_i was not accepted, as this would lead to the deactivation of one tax haven only, and it was shown in Proposition 2.4 that it is not profitable for S to deactivate only one haven.

Suppose therefore that H_i has accepted the offer b_i, and consider the behavior of H_j for a given $b_j(.)$, given that H_i is deactivated. Given that H_j is the only haven that is possibly active, the offer is acceptable for H_j if and only if $b_j(.) \geq (h_j + \beta)r$. If S makes such an offer, it chooses the smallest acceptable offer, $b_j(.) = (h_j + \beta)r$.

Turn now to the compensation offer b_i. As a consequence of Proposition 2.4, H_i anticipates that S will never offer a deactivation bid to H_j if H_i rejects the offer b_i. Thus, the optimal strategy of H_i is to reject the offer if $b_i < \pi_i^0$ and to accept it if $b_i \geq \pi_i^0$. Accordingly, S will either deactivate H_i by a bid $b_i = \pi_i^0$ or not make an offer to H_i and pay nothing.

The lowest feasible sum of bids that deactivates both tax havens, hence, is $b_i + b_j(.) = \pi_i^0 + \pi_j^i$. Country S makes these sequential offers if the sum of these offers fulfills inequality (2.13) in Proposition 2.5.

Before we check whether (2.13) can be fulfilled for successful sequential offers, note that $\pi_1^0 + \pi_2^1 \leq \pi_2^0 + \pi_1^2$. This can be seen by inserting $\pi_2^1 = (h_2 r + \beta r)$, $\pi_1^2 = (h_1 r + \beta r)$ and π_1^0 and π_2^0 for $t = r$ as in Lemma 2.1 into this inequality which becomes equivalent to the condition $h_1 \geq h_2$. Accordingly, if S makes an offer in the sequential offer regime, the first offer is made to tax haven H_1.

For these sequential offers to be beneficial for S, the sum of offers $b_1 + b_2 = h_1 r + h_2 r + \beta r$ needs to be no greater than the right-hand side of (2.13) in Proposition 2.5. Inserting and reorganizing leads to the condition

$$1 \leq 1 - \frac{\beta}{(h_1 + \beta)(1 + \lambda)}, \tag{2.19}$$

and this condition can never be fulfilled for $\beta > 0$. ■

Intuitively, the sequential procedure has a major problem: once the first tax haven has been deactivated, this benefits the tax haven that remains active. This haven has a larger payoff than if both tax havens are active and compete, since it has lost its main competitor. Country S therefore would have to pay a high price for deactivating the remaining tax haven monopoly. This competition effect emerges only in the sequential regime, and is the main reason why the sequential regime is so unattractive. The result provides a potentially important lesson for the ongoing process by which the OECD tries to close down one tax haven after another. While initially the closing down of the first few tax havens is not very expensive, compensating further tax havens to close down their operation becomes increasingly costly: due to the reduced competition, the tax havens' business becomes more and more profitable, and this increases the compensation needed.

If -for whatever reason- the OECD initiative has to follow a sequential path, Proposition 2.7 also highlights an important second-best result: it is superior to start this sequential process by making an offer to the strongest tax haven(s) first (i.e., the one with the largest h_i) and then move on to the smaller tax havens later. This is also not necessarily in line with observed behavior in the Harmful Tax Practices Initiative.

2.5.3 Comparing offer regimes

We can also compare the equilibrium outcomes for the two offer regimes.

Proposition 2.8 *Comparing the least-cost offers in the two offer regimes by which S can deactivate all tax havens, the least-cost simultaneous joint offer is less costly for S than the least-costly sequential independent offers.*

The result in Proposition 2.8 follows directly from a comparison of Propositions 2.6 and 2.7: the necessary deactivation payments in the sequential offers regime exceed the benefits of deactivation, but the payments in the simultaneous joint offer regime do not. Hence, the sum of compensations is lower in the simultaneous joint offer regime than in the sequential regime.

Intuitively, in the case of simultaneous joint offers, none of the tax havens can hope to become the only active tax haven in the competition phase. When deciding about staying active, they compare the compensation offered to their payoff in a situation in which they compete with other tax havens. In the sequential regime, the possibility of becoming a monopoly tax haven plays an important role. The second tax haven that is approached is the monopoly tax haven in this case. Therefore, much more must be offered to this tax haven in order to make it attractive for the haven to become inactive.

To illustrate the potential magnitude of the effect, consider, for instance, $\lim h_1 = \lim h_2 = 0$. In this case, if both tax havens are active, they earn zero payoffs, as all existing mobile capital perceives the two havens as perfect substitutes in a Bertrand game. In the equilibrium in Proposition 2.6, the country S can close down both tax havens by making joint simultaneous offers that sum up to $b_1 + b_2 = 0 + 0 = 0$. In the sequential game, the equilibrium payment offers are $b_i + b_j(.) = 0 + r\beta$.

2.6 Robustness

We now illustrate why the results are qualitatively robust.

The case $n > 2$. First, let the number of havens H_i be $n \geq 2$, with an immobile capital segment s and a fully mobile segment β and with $h_1 > h_2 > ... > h_n$ the segments of capital that are mobile only between S and the respective tax haven. Turning to the competition phase of the game, suppose the government in S has chosen $t > 0$. Let there be a subset of m tax havens denoted as $\hat{H}_1$,..., $\hat{H}_m$ that are still active, with $\hat{h}_i$ the capital segment of $\hat{H}_i$ that is mobile only between S and $\hat{H}_i$, and let them be sorted such that $\hat{h}_1 > \hat{h}_2 > ... > \hat{h}_m$. These havens compete for the fully mobile capital share β by their choices of fees, with $\hat{p}_i$ chosen by each $\hat{H}_i$. The equilibrium choice is $\hat{p}_1 = t$ if $m = 1$ and the payoff is $t(\hat{h}_1 + s)$ for $m = 1$, i.e., if there is only one active haven. If there are more than 1 active havens, the equilibrium payoffs are described by

$$\begin{aligned} E(\hat{\pi}_i) &= \hat{h}_i t \text{ for } \hat{H}_i \text{ with } i = 1, ..., m-1, \text{ and} \\ E(\hat{\pi}_m) &= \frac{\hat{h}_{(m-1)} t}{\hat{h}_{(m-1)} + \beta} \left(\hat{h}_m + \beta \right) \text{ for } \hat{H}_m. \end{aligned} \tag{2.20}$$

Moreover, the tax havens $\hat{H}_1$,..., $\hat{H}_{m-2}$ choose a deterministic price $\hat{p}_i = t$ and the two havens with the smallest capital segments choose mixed strategies that are identical with the mixed strategies characterizing the equilibrium in the above analysis for $n = 2$, with $\hat{H}_{m-1}$ and $\hat{H}_m$ assuming the roles of H_1 and H_2 in Sections 2.3-2.5. This follows from Kocas and Kiyak (2006) who generalize Narasimhan (1988) to the case of n asymmetric competitors. Note that (2.20) also describes the equilibrium payoffs for $m = n$, in which case $\hat{H}_i = H_i$, and (2.20) reduces to (2.7) for $m = 2$. Given this result, it follows from similar arguments as in Section 2.3 that the optimal tax strategy of S also remains $t = r$, provided that the shadow price of public funds is sufficiently high.

This concludes a brief description of the possible equilibria that can emerge in the continuation game in the competition phase for the general case. Turn now to the deactivation phase. Consider the smallest simultaneous joint offer to all tax havens for which an equilibrium with complete deactivation of all tax havens exists. If S makes a bid to each haven that is equal to the haven's equilibrium payoff as in (2.20) for $m = n$, each haven will be just indifferent between accepting and rejecting this offer. Assuming again the same tie-breaking rule as in the previous sections, an equilibrium of the continuation game for this vector of bids is that all havens accept the bids. Hence, for $n > 2$, the amount of payments needed to deactivate all havens by a simultaneous joint offer is again the sum of the equilibrium payoffs that accrue to the havens if all havens stay active. For the sequential approach, there are more than two possible sequences of sequential offers. For any sequential offer choice, however, the deactivation of one haven will cause an increase in market power for the tax havens that remain, making the sum of necessary bids exceed the bids necessary for deactivating all tax havens in case of a simultaneous joint offer for any possible sequencing. It can be shown that S ideally makes offers first to the set of tax havens H_i for $i = 1, ..., (n-2)$ who have larger capital segments and then turns to the two remaining havens with the two smallest capital segments. It can also be shown that the sequencing within the group of havens H_1 to H_{n-2} is payoff-irrelevant. Finally, when turning to the last two havens H_{n-1} and H_n, it is less expensive for S to deactivate H_{n-1} prior to the last haven H_n. The offers made to the first $n-2$ tax havens are then equal to rh_i, and the offers to the remaining two tax havens are the same as in sections 2.3-2.5 for $n = 2$. If this sequencing is chosen, the deactivation of the first $(n-2)$ havens does not lead to a noticeable increase in market concentration. And for the last two remaining havens the results of the previous sections continues to hold one-to-one. If, instead, S chooses a different sequencing and deactivates one of the havens with the two smallest capital segments h_i early on, then this tends to increase the overall cost of complete deactivation compared to a sequencing where the deactivation of H_{n-1} is the penultimate deactivation followed by a deactivation of H_n.

A quantitative assessment. In this subsection we quantitatively assess the size of the difference in compensation levels needed for the deactivation of n tax havens in the sequential and in the simultaneous regime. We assume that a sequential approach uses the most efficient sequencing, i.e., closes down the tax havens $n-1$ and n with the smallest partially mobile capital segments last.

For the share of financial assets hidden in tax havens and the total level of world financial capital, we use estimates provided by Zucman (2011). According to his study, 8 percent of global household net financial wealth is held in tax havens, one third of which is located in Switzerland.[22] Accordingly, we take $(1-s) = \beta + \Sigma_{i=1}^{i=n} h_i = 0.08$. We abstract from the precise composition of $(h_1, ..., h_n)$ and simply assume that $h_i = h_{i+1} + \varepsilon$ for very small but positive ε for all $i = 1, 2..., (n-1)$.[23] For the ease of numerical calculations we use the approximation $h_i \approx h_j \equiv h$. Accordingly, we have $h_n + \beta = (1/3)(0.08) = \frac{2.6667}{100}$, and $(n-1)h = (2/3)(0.08)$, or $h = \frac{0.053333}{n-1}$. We also use a tax rate $t = 0.25$ for our calculation.[24] The OECD had 35 countries on its initial black list, hence we use $n = 35$.

This yields an estimation for the compensation for the simultaneous regime of $(n-1)htY + h_{(m-1)}t(h_m + \beta)/\left(h_{(m-1)} + \beta\right)Y = 0.014\ Y$. Similarly, the estimation for the total compensation in the sequential regime is $(n-1)htY + (h+\beta)tY = 0.02Y$. Using Zucman's estimate for total world financial wealth, which is $Y = 73.6$ trillion USD, these total compensations amount to 1.03 trillion USD and 1.48 trillion USD, respectively.[25] In the sequential regime, compensation required for each of the 34 first tax havens is 29 billion USD and 490.8 billion USD for the last haven - almost 17 times higher than the deactivation of one of the previous havens.

Other types of competition. Intuitively, the generalization of the structure of competition to $n > 2$ is a generalization of Bertrand competition for more than two

[22]We take these values at face value. A reliable estimation of the share of concealed financial capital is naturally difficult. Zucman's (2011) estimation relies on the systematic imbalance between global financial assets and liabilites.

[23]Note that this yields a conservative estimate. A more asymmetric distribution of partially mobile segments yields an even higher difference in compensation payments.

[24]This tax rate choice is, to some extent, arbitrary.

[25]Zucman (2011) bases his estimates on Lane and Milesi-Ferretti (2007) external wealth of nations extended database and the Coordinated Portfolio Investemnt Survey (2002) by the IMF.

competitors. For Bertrand price competition with perfect substitutes (i.e., $h_i = 0$ for all i), two competitors are sufficient to compete away all rents among the competitors, and a move from two to many competitors does not induce stronger competition. The main effect of increased concentration takes place in this case by moving from two suppliers (essentially with perfect competition) to just one supplier (who becomes a monopolist). The culmination of competition effects at the change from $m = 2$ to $m = 1$ is specific to this type of competition and should not be overemphasized. For many types of competition, such as Cournot competition or for Bertrand competition with imperfect substitutes, the increase in market concentration induces a smooth increase in the sum of suppliers' rents. Analyzing the problem of simultaneous versus sequential deactivation of many havens in other competition frameworks would result in a smoother result that is even more in line with the intuition: with the elimination of each additional haven the rent of each haven that remains active would increase by two effects: first a smaller number of havens would share the market remaining, attributing a larger market segment to each of them, and second, the equilibrium price would also typically increase as the number of competitors is reduced.

A comparison with mergers among tax havens. It is also interesting to compare the basic mechanism here with the merger paradox considered by Salant et al. (1983). They consider an oligopoly and show that a merger of a subset of firms is often not profitable for the firms merging, unless it leads to monopoly.[26] The intuition for the result is that a merger between two firms in an industry with n firms increases the profit of the whole industry due to the increased concentration, but the two firms merging suffer from the fact that their share in this industry profit drops from $2/n$ to $1/(n-1)$. This effect makes a merger profitable for two merging firms for $n = 2$, but typically not for $n > 2$, raising the issue of endogeneity of merger decisions that benefit non-merging firms by more than the firms that actually merge (see,

[26]For a survey on this literature see Huck et al. (2008).

e.g., Horn and Persson 2001).[27] The OECD problem of deactivating tax havens has a different structure. Not a merger among tax havens reduces competition between them, but the OECD deactivates single havens and increases concentration among those who stay in business. This typically increases the payoff that is obtained by the tax havens as a whole, and the share of this received by each single tax haven. And the deactivated tax haven does not simply merge with one of the others and shares payoff with this other haven: instead, it receives a compensation payment for its exit, and this payment is made not by the other tax havens, but by the OECD (or country S in the model). Accordingly, deactivation of one of n tax havens increases the payoff of all tax havens remaining in a twofold manner: Each of them receives a larger share in an increased group payoff.

2.7 Conclusions

This chapter considers the problem of how to deactivate tax havens in a world with multiple tax havens. The fight against tax havens has many aspects that we did not address here. For instance, we disregarded the problem of coordinated action among the non-tax-haven countries, and rather considered one big non-haven country or player such as the OECD that is able to internalize the benefits and cost of a deactivation initiative such as the Harmful Tax Practices Initiative. Our analysis highlights an important issue that is largely neglected in the current fight against tax havens: Once this fight shows some initial success, that is, once some of the tax havens have successfully been approached and convinced to close down their operations, this will change the nature of competition among the tax havens that remain active. Competition between these tax havens will relax, due to the exit of

[27] The Merger Paradox may actually explain why, in the absence of the OECD initiative, the tax havens fail to enact a merger process among the group of tax havens that yields an increase in industry concentration which they may consider desirable.

some of their competitors. The rents they earn from their "services" to financial capital, and other tax haven "services" more generally, increase as the number of tax havens is reduced. This effect has a number of relevant implications, which we argue are robust with respect to many modifications in the competition framework.

First, it reveals that a sequential fight against tax havens is easier in its initial phase. The initial series of successes in the fight against tax havens clouds the size of the true problem. It should not make us confident as regards the likelihood of final success. The more tax havens have been closed down, the harder it will be to convince the remaining tax havens to give up their tax haven business. It may actually become excessively expensive to close down the last few tax havens, as these tax havens will earn very high monopoly rents.

Second, closing down just a few tax havens leads to a situation that is potentially worse (from a welfare point of view of the OECD countries) than a situation with a large number of tax havens. If many tax havens offer their services and compete for capital, their fees will be low. Tax revenues will also be low, but at least the capital (and its returns) remains with its owners in the OECD countries. If a major share of tax havens have been closed down and only a limited number of tax havens are still active, competition between them will be reduced. Hence, fees for tax-sheltering services are high in the equilibrium outcome. Tax revenue in OECD countries may still be low, but a large share of the returns of capital is taken away from its owners and transferred to the tax havens (as fees).

Third, the analysis suggests that, if it comes to fighting tax havens, a coordinated and conditional "big-bang" policy initiative which tries to form a simultaneous multilateral agreement between all non-tax-haven countries and all tax-havens is superior (less expensive) compared to a sequential process of closing down one tax haven after another. If a "big-bang" policy is not feasible and only a sequential policy is possible, then also the order matters for the cost of a sequential policy.

Chapter 3

Bargaining over Tax Information Exchange

3.1 Introduction

Since the financial crisis, countries have shown a renewed interest in combatting international tax evasion. In fact, during the 2009 G20 Summit, countries renewed their commitments towards fighting secrecy jurisdictions by stating that the "era of bank secrecy is over" and that they "stand ready to deploy sanctions" against non-complying secrecy jurisdictions.[1] Countries classified as tax havens answered to the pressure increase with a surge in bilateral agreements which contain information exchange clauses. However, the mechanism driving the choice of treaty partner and type of bilateral information exchange agreement signed has remained unclear. This chapter studies recent treaty signings between tax havens and OECD countries. More specifically, it empirically analyzes the main factors determining the signing of an agreement as the outcome of a bargaining process between tax havens and high tax

[1] See G20 (2009) p.4.

countries.

There are two different types of agreements that can be signed between a tax haven and a high tax country: a Double Taxation Convention (DTC) and a Tax Information Exchange Agreement (TIEA). We use a highly stylized bargaining model to develop testable hypotheses with regards to the type of agreement signed. We show that the main determinants of the outcome of a bargaining framework are: the general bargaining position of a tax haven versus a high tax country, the effectiveness of the defensive measures that can be used by the high tax country against a tax haven, and the share of capital which is evaded in the tax haven country. We argue that the respective bargaining positions are a function of each country's respective economic position, while the effectiveness of the defensive measures are a function of the strength of the bilateral relationship. We show that a stronger bargaining position of the tax haven should lead to a more advantageous signing from the perspective of the haven, while an increase in the effectiveness of the defensive measures shifts the bargaining outcome more to the liking of the high tax country.

The empirical analysis, which uses an ordered maximum likelihood regression model, shows that the main drivers of treaty signing are haven-specific characteristics such as economic strength and good governance. Interestingly, bilateral similarity and geographical proximity characteristics seem to be unrelated to treaty outcomes, while bilateral financial relationship variables play a role albeit a weaker one compared to the haven-specific characteristics.

There are a few theoretical contributions on countries' incentives to exchange information that have focused on the question of the optimal use of an information exchange clause versus a withholding tax regime.[2] A main insight of these papers is that larger countries have a stronger incentive to pursue an information exchange

[2]The main contributions are Bacchetta and Espinosa (1995, 2000), Huizinga and Nielsen (2003) and Keen and Ligthart (2006,2007).

regime than smaller countries. Bacchetta and Espinosa (2000), for example, theoretically investigate under which circumstances countries are more likely to sign a tax treaty and when an information exchange clause will be included in the treaty. Most relevant to our study is that they show that an information exchange clause will not be used when there are one way capital flows. Consequently, a rationale for the reluctance of tax havens to sign any type of agreement is provided. Contrary to our approach, there is no explanation for the different types of agreements signed. We contribute to this literature by arguing that treaties and treaty types are outcomes of a bargaining process. A similar approach can be found in Chisik and Davies (2004). According to their paper, countries bargain over a withholding tax for foreign owned capital. The paper focuses on how bargaining can affect the agreed upon withholding taxes and shows that greater asymmetry in FDI activity increases the negotiated tax rates. Their empirical analysis, however, is driven by treaties already signed and disregards the cases where treaties have not been signed. In contrast, this study provides a more thorough investigation of treaty formation as it does not ignore the cases where no treaty was signed and in fact, attempts to provide an explanation for this empirical observation. Another relevant study on the economics of tax treaties is Ligthart et al. (2011), which empirically investigates the determinants of income tax treaty formations. In their study, they find that the main driver of DTC signing is the avoidance of double taxation and that information exchange plays a rather small role. Their paper, however, disregards the fact that the relationship between any two countries that are not tax havens, is an inherently different one than in the case of a country pair which consists of one high tax country and a tax haven. Specifically, while the signing of a tax treaty for two non-tax haven economies can be mutually advantageous, a treaty between a tax haven and a high tax country cannot be viewed in the same vein. Thus, by isolating country pair constellations that include a high tax country and a tax haven, we allow a more thorough investigation of the determination of these types of agreements.

Next to the literature on tax treaties and the inclusion of an information exchange clause, our study is also related to the general tax haven literature. This strand of literature has mainly concentrated on the welfare effects of the existence of tax havens.[3] A recent strand of this literature has particularly focused on the strategic implications of the fight against tax havens. In this literature we are more closely related to Elsayyad and Konrad (2012), who theoretically analyze the observed sequentiality of the fight against tax havens. The fight against tax havens has also been tackled in the empirical literature, mainly by Huizinga and Nicodéme (2004), Kudrle (2009) and most recently Johannessen and Zucman (2012) who attempt to evaluate how the signing of tax information exchange agreements and the blacklisting of tax havens have affected international deposits.[4] The previous papers present TIEA signings as a *fait accompli* and concentrate on their economic implications without explaining the mechanism behind their existence. Thus, our study contributes to this strand of literature by studying treaty formation as the endogenous outcome of a bargaining process which, in turn, is affected by the level of international deposits held in each tax haven country.

The chapter is structured as follows: Section 3.2 introduces the institutional set up of tax treaty signing, Section 3.3 presents the analytical framework and derives the theoretical hypotheses, Section 3.4 presents the estimation strategy and discusses the dependent and explanatory variables and Section 3.5 presents the regression results and provides a robustness analysis. Section 3.6 concludes.

[3]See Desai et al. (2006a) , Desai et al. (2006b) , Hong and Smart (2010) and Johannessen (2010) for notable examples of a positive view on tax havens and Slemrod and Wilson (2009) and Torvik (2009) for a negative view on tax havens. For a survey see Dharmapala (2008).

[4]The first two studies do not find a significant effect of the OECD's fight against tax havens. However, both studies use data that before the recent surge in signings starting in 2009. Johannessen and Zucman (2012) estimate a decline international deposits in reaction to a signing of a TIEA but also an increase in deposits to countries not complying to the international tax and transparency standards.

3.2 Institutional setting

Agreement form. In an effort to show commitment to tax transparency and exchange of information, tax havens can agree to sign one of two types of agreements: a Double Taxation Convention (DTC), also called income agreements, or a tax information exchange agreement (TIEA). Both agreements can include provisions that regulate tax-related information exchange. A signing of a tax treaty, which includes an information exchange clause, allows for the correct estimation of each individual's income and, consequently, the correct tax burden. The two agreements, however, differ in their scope. While a DTC is mainly signed to foster and alleviate the double taxation of cross-border investment and can include an article that regulates information exchange, a TIEA only regulates the flow of information between a tax haven and a high tax country and does not include other dimensions. The most widely accepted legal basis for bilateral exchange of information for tax purposes is Article 26 of the OECD Model Tax Convention. It creates an obligation to exchange information that is "foreseeably relevant to the correct application of a tax convention as well as for purposes of the administration and enforcement of the domestic tax laws of the contracting states." Article 26 can be added to a DTC. The TIEA is also based on Article 26 of the OECD Model Tax Convention, however, it includes stronger and more detailed regulations for information exchange. Thus, from the perspective of a tax haven, there is a natural preference ranking between the different outcomes. A tax haven would most prefer not to sign an agreement which complicates and impedes its capital concealment services. But if it would have to comply to one of the two agreements, the signing of a DTC would be preferable to the signing of a TIEA. This is due to the fact that there is a potential cross-border investment gain from signing a DTC, whereas a TIEA does not yield any such advantage. Anecdotal evidence supports this assumption. The Bahamas, for example, clearly state on their official website, with regard to treaty signing strategies, that they strictly prefer the signing of a DTC over a TIEA.[5] Notice that the EU Savings Tax Directive is another information exchange scheme used by EU countries. According to this scheme, countries either commit to an automatic exchange of information or a withholding tax regime on income of residents from other EU countries. This initiative is clearly multilateral and cannot be assumed to work in the same way as the bilateral agreements. For this reason, we only control for it in the robustness checks section.

Defensive measures. To induce tax havens to comply with international tax and transparency standards, the OECD report on Harmful Tax Practices also proposes a number of defensive measures that can be used against non-complying jurisdictions.[6] The defensive measures can be grouped into three categories: domestic tax measures, non-related tax measures and tax treaty measures. Domestic tax measures can be characterized by a punitive discrimination of foreign income originating from, or flowing to, a non-complying jurisdiction.[7] Non-tax treaty measures focus on the discouragement of financial institutions from investment in non-cooperative jurisdictions. An example for that is the tying of official development aid to compliance in tax transparency and information matters. Finally, tax treaty measures can take the form of the termination existing tax treaties with countries that are not prepared to engage in full exchange of information. Here, it becomes clear that such defensive measures can be used in order to pressure havens into complying and that the potential effectiveness of the defensive measures is a function of the strength and scope of the bilateral relationship.

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[5]See http://www.businessbarbados.com.

[6]See OECD (1998) p.40-50.

[7]A main example is the new French legislation, where dividends, service fees and royalties paid by a French entity to a beneficiary in a blacklisted country will face a 50% withholding tax.

3.3 A simple bargaining framework

In order to develop testable hypotheses, we develop a highly stylized model of bargaining over the type of agreement signed between a high tax country and a tax haven. We extend the driving mechanism first introduced in Bacchetta and Espinosa (2000) to include defensive measures which influence the tax haven's business negatively and allow for bargaining over the share of evaded income that can be taxed domestically due to information exchange.

We consider a world with two countries, a high tax country S and a tax haven H. Country S would like to tax the capital stock of its residents. We assume that due to lax regulation and strong bank secrecy rules, tax haven H provides capital concealment services that allow residents of the high tax country to evade taxes in their home country. However, H also suffers reputational and/or financial damages due to being classified as a tax haven. As in Elsayyad and Konrad (2012) capital $\bar{K}$ is solely owned by residents of S and is either invested in S and denoted by K^d or evaded in H and denoted by K^e;

$$\bar{K} = K^{d} + K^e. \tag{3.1}$$

Thus, the income of the tax haven amounts to

$$Y_H = pK^e - D, \tag{3.2}$$

which consists of the revenue from concealing the share of capital K^e at price p minus the defensive measures D that the high tax country employs in order to make a tax haven's concealment services less attractive.[8]

Due to the concealment services provided by the haven, S can only tax capital

[8]Note, that $pK^e - D \geq 0$. If not then, it would not make sense for the haven to remain active, as the damages that the haven has to suffer would be too high.

invested domestically. Country S's income amounts to

$$Y_S = tK^d. \tag{3.3}$$

While it is also possible to assume a different payoff function for the high tax country S, the main driver of the fight against tax havens is a revenue maximizing one, and thus, we abstract from other motives of taxation.

We assume that countries bargain over $\alpha \in [0, 1]$, which denotes the share of evaded capital which can, after the signing of the treaty, be taxed by S. For the tax haven H, signing a treaty means the reduction of its income from capital concealment services by α and no longer facing the defensive measures of S. For the high tax country S, signing a treaty means a higher amount of capital that it can tax domestically. Thus, $H's$ income after the signing of a treaty amounts to

$$Y_H^* = (1 - \alpha)\, pK^e, \tag{3.4}$$

and $S's$ income after the signing of a treaty amounts to

$$Y_S^* = t(K^d + \alpha K^e). \tag{3.5}$$

It is straightforward to see that a tax haven's income is decreasing in α and, thus, given the unconstrained choice, its optimal α would amount to zero. Furthermore, a high tax country would favor a high share of capital to be taxed domestically. Conversely, the high tax country's unconstrained choice of α would be $\alpha = 1$.

We use the generalized Nash bargaining solution to derive the results of the bargaining process.[9] Consequently, the solution can be found by choosing an α which maximizes a weighted product of the two countries' gains from treaty formation. Thus, α must satisfy:

$$\alpha(\gamma) \in \arg\max \left[(Y_H^* - Y_H)^{\gamma} (Y_S^* - Y_S)^{1-\gamma} \right] \tag{3.6}$$

[9]Given that the observed country pairs are inherently asymmetric, we abandon Nash's symmetry axiom.

where γ represents the relative bargaining power of the tax haven H.

Taking the first derivative with respect to α yields

$$\alpha = \frac{(1-\gamma)\,D}{pK^e}. \tag{3.7}$$

Note that when $\gamma = 0$, the high tax country has all the bargaining power and the chosen share will be as close to $\alpha = 1$ as possible. Analogously, when the tax haven enjoys all the bargaining power due to $\gamma = 1$, the optimal α is 0.

From equation (3.7), we can derive a set of comparative statics which helps us to determine the testable hypotheses.

Proposition 3.1 *Suppose H and S bargain over the share of formerly evaded capital to be taxed by S, then the negotiated share α is:*

(i) decreasing in γ,

(ii) decreasing in K^e and

(iii) increasing in D .

Proof. Differentiating (3.7) with respect to γ, D and K^e yields

$$\begin{aligned}
\frac{\partial\alpha}{\partial\gamma} &= -\frac{D}{pK^e} < 0 \\
\frac{\partial\alpha}{\partial K^e} &= -\frac{(1-\gamma)\,D}{p\,(K^e)^2} < 0 \\
\frac{\partial\alpha}{\partial D} &= \frac{(1-\gamma)}{pK^e} > 0.
\end{aligned}$$

■

The derived comparative statics allow for the identification of the main drivers of the bargaining outcome. It is straightforward that an increase in the bargaining power of the haven reduces the optimal share of α and shifts it more to the tax haven's liking. An increase in the share of evaded capital in the tax haven works in the same direction. This is quite intuitive as the gains from treaty formation increase for the high tax country and, thus, a tax haven can push a more favorable outcome. A ceteris paribus increase in the defensive measures also shifts α quite intuitively. In this case, an increase in the defensive measures is connected with an increase in the gains from treaty formation for the haven. Here, the tax haven is unable to profit from its tax haven business and is therefore more prone to accept a higher α to avoid the defensive measures.

Consequently, we are able to show that the main determinants of the outcome of a bargaining framework are the general bargaining position of a tax haven vs. a high tax country, the effectiveness of the defensive measures that can be used by the high tax country against a tax haven and the share of capital which is evaded in the tax haven. For the succeeding empirical analysis, we argue that the bargaining positions are a function of each country's respective countries' economic positions, while the effectiveness of the defensive measures is a function of the strength of the bilateral relationship.

In the following sections, we empirically analyze the effect of the different tax havens' specific economic characteristics and the bilateral relationship on the bargaining outcome.

3.4 Empirical analysis

3.4.1 Estimation strategy

While the optimal share of capital α_{ij} for tax haven i and high tax country j cannot be directly observed, what can be observed are three different outcomes: For a given haven-high tax country-country pair, one can either observe no agreement, a DTC or a TIEA. Notice that we include in our analysis only DTCs which have an information exchange clause to capture the focus on the tax haven activity dimension of treaty signings. DTCs signed that do not include the information exchange clause are treated as if no agreement was signed. We argue that α_{ij} is an underlying latent variable, that can be mapped into agreement form. We purport that low levels of α_{ij} correspond to no treaty, middle levels of α_{ij} correspond to a DTC and high levels of α_{ij} correspond to a TIEA. The ordinal character of the variable is based on the institutional set up presented in Section 3.2. The continuous latent response α_{ij}^* is related to the ordinal agreement form y_{ij} via the threshold model

$$y_{ij} = \begin{cases} \text{No agreement} & \text{if} \quad \alpha_{ij}^* \leq \kappa_1 \\ \text{DTC} & \text{if} \quad \kappa_1 < \alpha_{ij}^* \leq \kappa_2 \\ \text{TIEA} & \text{if} \quad \kappa_2 < \alpha_{ij}^*. \end{cases} \tag{3.8}$$

As developed in the previous section, the bargaining outcome is a function of the evaded capital, the general bargaining power of the tax haven and the effectiveness of the defensive measures. While it is inherently difficult to determine the share of the evaded income, our main explanatory variables run along the lines of determining the actual bargaining power of the tax havens and the possible effectiveness of the defensive measures. We argue that the actual bargaining power of a haven can be traced to its own position and characteristics, while the pressure that a high tax country can exert on it is determined by the strength of its bilateral relationship. Our empirical approach, thus, needs to encompass both unilateral and bilateral variables that explain treaty formation. In effect, we would like to regress agreement form on a tax haven's bargaining power and the strength of its bilateral relationship with the high tax country. For this, we specify a random intercept model for the latent response α_{ij}^* :

$$\alpha_{ij}^* = x_{ij}'\beta + u_i + \epsilon_{ij}. \tag{3.9}$$

x_{ij} is a column of exogenous variables that includes both haven specific and country pair specific variables, while β is a conformable vector of coefficients, u_i is a haven specific random effect and ϵ_{ij} is the usual independent and identically distributed error term. We assume that the haven specific random effect u_i and ϵ_{ij} have normal distributions and are independent. To fit the random effects ordered probit model, we use a generalized latent linear and mixture model (GLLAMM) procedure.[10] Notice that the need for a haven specific random effect stems from the fact that the observation unit is not an individual country but a country pair and, thus, one needs to correct for possible error term correlations between the country pair observations of each tax haven.

3.4.2 Agreement form

For the dependent variable, we consider all possible country pair constellations between OECD countries, which are not on the tax haven list themselves, and tax havens.[11] This amounts to (27 OECD*49TH)=1323 individual country pair observations. We combine the OECD's tax haven definition with the list of countries provided in Appendix 2 of Hines and Rice (1994).[12] For each generated pair, we check if either a DTC that incorporates a strong information exchange clause or a TIEA has been signed. The main sources of these agreements are the International Bureau for Fiscal Documentation Database and the OECD Global Forum for Transparency for Tax Purposes.

We restrict our dataset to this subset of countries for two reason: First, the main

[10]See Rabe-Hesketh and Skrondal (2008).

[11]Note, that Belgium, Luxembourg and Switzerland are OECD countries that have been found to fall under the tax haven definition. To ensure that our results are not driven by these countries, we have in some empirical specifications excluded them from the analysis.

[12]A list of countries and territories classified as tax havens under this definition are presented in the Appendix.

fight against tax havens has been initiated by OECD countries and main developments have always been spearheaded by the OECD Forum. Second, while the TIEA model framework and Article 26 can be introduced and signed between any two countries, they have been mainly developed to combat international tax evasion and the concealment services of haven jurisdictions.

Out of the 1323 possible country pair observations, 155 DTCs that include a strong information exchange clause and 323 TIEAs have been signed. The Bahamas, with 18 TIEAs, has the largest number of TIEAs signed, while Luxembourg tops the list for the highest number of DTCs with a strong information exchange clause signed. A quick look at the signings shows that the Nordic countries have been particularly active treaty partners. This is partly due to the fact that they adopted a multilateral approach of treaty signing very early.[13] Due to the fact that the bulk of the agreements have been signed in 2009/2010, there is no meaningful longitudinal variation in this measure and the analysis is restricted to a cross section.

3.4.3 Haven-specific characteristics

General characteristics of the haven have a strong impact on its bargaining position. As previously posited, an increase in a haven's bargaining power should decrease the latent variable α^*_{ij} and, thus, be correlated with a stronger share of country pair constellations where no agreements have been signed or where, at most, a DTC has been signed.

A haven's economic strength. A possible indicator of a country's relative economic strength is its GDP, and, for that reason, we have included the GDP of the

[13]In our estimation, one robustness check is to exclude country pair constellations of tax havens with Nordic countries, in order to insure that our results are not driven by the different multilateral approach of the Nordic countries.

havens in 2006 (in current USD). The use of GDP in our analysis is particularly advantageous, as it has the widest coverage. There are two possible explanation how the size of the economic sector of a tax haven can affect its bargaining position. On the one hand, a large economic sector might make a tax haven less reliant on its tax haven business and, thus, makes it less costly for the haven to comply with the new tax and information standard. Following this line of thought, a large economic sector should be correlated with a stronger bargaining position for the high tax country and, thus, a weaker bargaining position for the tax haven. On the other hand, one might also argue that if a tax haven has a strong economic sector then, the cost of closing down the tax haven business via a high tax country is much larger and the need for multilateral coordination in this regard is much stronger. Thus, due to the coordination problem, it might be that a larger economic sector is connected with a stronger position for the haven and, thus, less compliance with international tax standards. Notice that we already account for the possible bilateral pressure that can be exerted against a tax haven in our estimation of the bilateral defensive measures. Thus, our economic strength variable would pick up remaining variation that is not explained by the bilateral economic relationship.

In a robustness check, we add the share of foreign direct investment outflow from the tax haven, as a share of its GDP, as a variable to capture a haven's outward financial activity and disentangle it from its other economic activities. It is to be argued that there is a direct correlation between the financial importance of the country and its bargaining position. Due to the limited coverage of this variable, we analyze it separately.

A haven's bargaining power can be also interpreted as its ability to exert its financial independence. For this reason, we add a dummy variable which indicates whether a haven is eligible for official development aid or not. In this case, one can assume that countries eligible for aid are more reliant on the international community and international good will and will, thus, be more prone to comply to the international standards of transparency and information exchange. Consequently, we expect a positive correlation between the share of signed treaties and the types of treaties being signed.

A haven's good governance. Taking into account that the decision to comply with international tax information exchange standards is a function of a country's general good governance, we add a measure of countries' governance institutions developed for the World Bank by Kaufmann et al. (2010).[14] We have constructed an aggregated index of the world governance indicators for the year 2009 because it has significantly expanded coverage. In this case, we expect a positive correlation between a higher good governance index and agreement form which translates into a low share of country pair observations that have no treaty signed and a high share of country pair observations wherein a TIEA has been signed.

3.4.4 Country pair-specific characteristics

Taking into account that agreement form is the outcome of a bilateral process and, therefore cannot be solely explained by unilateral determinants, we include country-pair specific characteristics to determine the scope and strength of the bilateral relationship of each country pair. The bilateral relationship can be characterized by the relative bargaining position of the high tax country and the effectiveness of the defensive measures that can be used by the high tax country against the tax haven.

[14]They construct aggregate country-scores for six different elements of country-level governance: Voice and accountability, political stability, government effectiveness, regulatory quality, rule of law and control of corruption. Each of these measures takes values from approx. -2.5 to 2.5 with higher values indicating better governnce. The data is normalized so that the mean across all countries is 0 and the standard deviation is 1.

Relative bargaining power. To control for the fact that the relative strength of the high tax country also influences treaty formation and can positively correlate with the possible defensive measures, we include the difference in GDP per capita for each tax haven-OECD country pair. In this regard, we expect that a higher GDP per capita difference should correlate with a larger share of signed agreements.

Defensive measures. Next to the tax haven blacklist, which has also been used as an instrument to generally pressure all listed tax havens into compliance with OECD transparency standards, country-pair specific pressure should play a stronger role for agreement form outcome. As a guideline for possible bilateral defensive measures, we use the OECD's Harmful Tax Practices Initiative Report's recommendations highlighted in Section 3.2 of this chapter. While discriminatory measures can differ from one OECD country to another, it stands to reason that their scope is highly dependent on the importance of the bilateral relationship between a haven and a high tax country. To capture all possible types of financial flows between a tax haven and high tax country, we add bilateral portfolio outflows from OECD countries to tax havens and bilateral foreign direct investments to our analysis.[15] The third type of defensive measure pertains to the status of the haven as a treaty partner. The report proposes the scrapping of beneficial tax treaty arrangements in order to pressure non-complying jurisdictions. For this reason, we have added a dummy variable which records whether or not a treaty was in force before 1998 and, consequently, whether its potential termination could be used as method of pressuring tax havens into compliance. In our dataset, there have been 38 cases of treaty termination, of which 30 have resulted in new tax information exchange agreements; 8 country pairs have remained without a treaty. Furthermore, 147 treaties have been renegotiated to include the stronger information exchange clause. Taking our cue from the the-

[15]For non-tax treaty related flows, one could add bilateral trade and bilateral official development assistance to the analysis. However, both measures are only availabe for a very few number of countries.

oretical framework, we expect the defensive measures to positively correlate with treaty outcome and, thus, a higher share of country pairs should be complying with international standards and have either a DTC or a TIEA.

Control variables. We add bilateral control variables that should account for country pair similarity. Specifically, we have added a dummy variable for common language and a bilateral distance measure. For missing bilateral distance measures, we use the distance of the nearest country available. It is unclear how mobile capital should react to distance, given that most tax havens are islands and, thus, rather isolated. For the common language variable, if one assumes that evaded capital is more likely to flow to countries that share the same language due to an easier understanding of the environment and culture, one can assume a negative correlation between agreement form and common language.[16]

3.5 Results

3.5.1 Benchmark estimations

In the following, we present the results of our benchmark estimation which can be found in Table 3.1. All regression tables can be found in Section 3.7. Before interpreting the coefficients of the covariates there are two remarks to be made. First, we use the standard ceteris paribus interpretation for the coefficients. Second, the haven-specific random effect τ_i is shown to have a rather high standard deviation, this means that there is a strong correlation between the outcomes for each haven. This strong intra-class correlation already hints at the fact that haven-specific effects will have a strong impact on agreement form outcome.

[16] All variables and their sources are described in more detail in the Data Appendix.

The first specification of Table 3.1 empirically analyzes the relationship between the bargaining position of a tax haven and agreement form. Accordingly, we include all haven-specific characteristics while controlling for country pair similarity. This means we regress agreement form on the tax haven's GDP, average governance indicator, official development assistance eligibility and difference in GDP per capita between the country pair. In the subsequent specifications, we then add the defensive and bilateral relationship measures to the estimation to determine their correlation with agreement form. The defensive measures include a dummy variable for treaties signed before 1998 and the level of bilateral portfolio investment outflow from an OECD country to a tax haven (specification 2) or the sum of bilateral foreign direct investment between a tax haven and a high tax country (specification 3).[17] As is common in all maximum likelihood estimations, the estimated coefficients cannot be interpreted directly. Nevertheless, they are proportional to the marginal effects and, thus, one can determine the impact of each covariate in relation. Furthermore, the estimated coefficients identify the estimated effect of the variables on the first and last category unambiguously. In the following, we present and discuss the results of the conditional model. The marginal effects of the population averaged model can be found in Table 3.8.

Haven-specific characteristics. Both GDP and the average of the havens' governance index show highly significant and robust results. In all of the presented specifications, an increase in GDP by one standard deviation increases ceteris paribus the probability for the country pair observation to have no agreement signed and unambiguously decreases the probability of a TIEA being signed. This seems to favour the notion that economically stronger countries are less responsive to pressure and, thus, are more likely to choose not to comply to the international standards of information

[17] In order not to lose too many observations, we regress each of the bilateral measures separately. Regressing both bilateral FDI and bilateral portfolio investments simultaneously does not change the results of the benchmark estimation.

exchange. An increase in the governance indicator shows the opposite effect. Havens with a higher governance indicator ceteris paribus. show a smaller probability of not having any agreement and a larger probability of signing TIEAs. This implies that a high governance index is not only correlated with a strong regard for the rule of law and transparency domestically but also a stronger compliance with international standards. The benchmark estimations also show a positive impact of official development aid eligibility on the probability of complying to international tax and transparency standards and signing TIEAs. This supports the claim that havens that are eligible for official development aid are more dependent on international good will and, thus, respond more quickly to pressure.

Country-pair specific characteristics. Differences in GDP per capita, which is a country-pair specific variable, also show a robust and significant correlation with agreement form outcome that is in line with the derived hypotheses. In all specifications, an increase in the difference in GDP per capita of a country pair is correlated with an increase in the likelihood of signing a TIEA. Thus, one can argue that the higher the difference in wealth between a high tax country and a tax haven, the higher the probability of having an agreement and a treaty form which is more advantageous to the high tax country.

With regard to the defensive measures used in our estimation, it seems that the treaty dummy has the strongest impact on agreement form outcome. We observe a significant positive correlation between the signing of a treaty before 1998 and the inclusion of the strong information exchange clause through renegotiations. More so, a higher level of bilateral portfolio outflow from OECD countries to tax havens is also correlated with a higher, albeit small, probability of countries signing TIEAs. Notice that the pressure that can be exerted bilaterally does indeed work in the theoretically expected direction. Surprisingly, bilateral foreign direct investment between tax havens and the OECD countries seem to be uncorrelated with agreement form. The regressions imply that while treaty-related defensive measures have an impact on the outcome of the agreement, financial flows between the high tax country and the tax haven do not seem to drive the bargaining decision. This begs the question as to whether the defensive measures have been a successful mechanism of making tax havens comply to international tax information exchange standards or not.

Control variables. Interestingly, the variables added to control for cultural and geographic proximity show, only in the case of the common language dummy variable, a significant effect on agreement form. While distance seems to be unrelated to agreement form, sharing the same language is correlated with a lower probability for the tax haven to comply with international standards and to sign any form of an information exchange agreement. If one assumes that tax havens which share the same language as the high tax country are more attractive to tax evaders from the high tax country, then it seems that the estimated effect goes in line with the proposed bargaining model. This is due to the fact that an increase in the share of capital evaded in the tax haven reduces the optimal agreed upon share of evaded capital that can subsequently be taxed by the high tax country.

3.5.2 Robustness

In this section, we examine the robustness of the results of the benchmark estimation. The performed robustness checks first consider the ordered specification and then either include more control variables, which might be perceived as affecting the outcome, or exclude some countries from the dataset in order to determine if the results are driven by these countries. All regression tables follow the same specifications as in Table 3.1.

Robustness of the ordered specification. While the thorough analysis of the conditions of the treaties shows that tax havens should prefer a DTC over a TIEA, we can also analyze whether or not the main conditions needed to justify the use of an ordered model can be found in the data. The fact that all the estimated thresholds in the benchmark model are strongly significant supports the fit of the ordered model assumption. An important implication of the ordered model is that each category if treated separately should be driven by the same mechanism. Thus, the results of the benchmark estimations should hold if one performs separate probit regressions for each category. Table 3.2 and Table 3.3 show two separate probit regressions for the scenario no agreement versus the signing of a DTC or for the scenario of no agreement or the signing of a TIEA. For each of the regressions, we drop the country pairs, which have a different type of agreement, in order to focus on the determinants of the signing of each of the agreements. The maximum likelihood regression for the signing of a TIEA shows highly significant estimated results similar to the ordered probit regression. Interestingly, haven GDP is estimated to have a significantly stronger impact on treaty formation which seems to support the notion that smaller countries have been the main countries signing TIEAS. The results of the regression, which only focuses on the signing of a DTC versus no agreement, show similar results to the benchmark estimation, however the results are in most cases insignificant. These results, however, can be attributed to the fact that there have been not enough DTCs signed between country pairs. Nevertheless, this seems to suggest two things: first, that the signing of a DTC and the signing of a TIEA can be driven by the same independent variables and second, that the results of the ordered probit are more strongly influenced by TIEA signings.

Haven Foreign Direct Investment Outflow. In the benchmark estimation, the GDP of a tax haven seemed to have a significant impact on agreement form. The GDP variable can be thought of as capturing all economic sectors and not distinguishing between general economic sectors of the haven economy and the haven financial sector. Table 3.4 shows the results of the ordered probit regression for the same specifications as in Table 3.1 if one includes net foreign direct investment outflow of a haven as a share of its GDP. This variable is particularly interesting as it is a clearer indicator for the importance of foreign direct investment for the haven's economy. While the direction of the estimated coefficients of the benchmark estimations remain significant and unchanged, the regressions show that a higher foreign direct investment outflow, as a share of GDP, is correlated with lower agreement forms. More specifically, an increase in a haven's foreign direct investment net outflow, as a share of its GDP, decreases the probability of the signing of a TIEA as well as increases the probability of a haven not complying to international standards and, thus, not signing any type of information exchange agreement. Thus, it seems that the increased openness of the haven with regard to foreign direct investment outflow also increases a haven's bargaining power.

Savings Tax Directive. EU countries have a separate information exchange scheme that runs under the name of Savings Tax Directive. The directive is also upheld by tax havens which are dependencies of EU countries. Consequently, it is not far-fetched that such an information exchange scheme would have an effect on the information exchange agreement forms. In Table 3.5, we present the same specifications as in Table 3.1 but also control for the existence of the Savings Tax Directive between some tax havens and the EU countries in the sample. Interestingly, the inclusion of a dummy variable, which indicates if both countries comply to the Savings Tax Directive, does not seem to have an affect on agreement form and the estimated effects of the conditional model remained largely unchanged. This is a particularly interesting result as it shows that the Savings Tax Directive is considered to be a separate vehicle for information exchange. It also shows that the Savings Tax Directive has not acted as either a substitute for the bilateral agreements or encouraged the signing of such agreements.

Excluding OECD tax havens. In order to account for the fact that OECD countries that also bear tax haven characteristics might be treated differently, Table 3.6 provides the conditional effects for the dataset, excluding the OECD tax havens Luxembourg, Switzerland and Ireland. Our main variables of interest remain unchanged by the restriction of the dataset. The only change documented is the fact that the common language dummy no longer has a significant negative effect on agreement form, but becomes insignificant. This seems to suggest that the effect of the common language dummy is mainly driven by the OECD countries of Luxembourg, Switzerland and Ireland.

Excluding Nordic countries. In another robustness check, we exclude country pair constellations that include the Nordic countries: Denmark, Finland, Iceland, Norway and Sweden (Table 3.7). This is to account for the fact that Nordic countries have a distinctly different procedure of bilateral treaty signing which has shown particular success. The results of our estimation with regard to the dataset excluding the Nordic countries show some marked differences to the previous results. While haven GDP, difference in GDP per capita, haven good governance and bilateral portfolio outflow to the tax haven remain significant and robust to the exclusion of the Nordic countries from the dataset, both the treaty variable and the official development aid eligibility variable become insignificant. This seems to imply that the treaty measure has been largely used by the Nordic countries and has not been put under as much use by the other OECD countries. The fact that the official development aid eligibility dummy variable loses its significance when the Nordic countries are excluded implies that the bulk of the treaties signed by countries that are also eligible to receive official development aid have been signed with the Nordic countries.

3.6 Discussion and conclusion

A first glimpse at tax haven compliance after the G20 crackdown on tax havens, initiated by the G20 London Summit in 2009, shows a strong surge of bilateral agreements between tax havens and high tax countries implying the success of the initiative. However, the main mechanisms driving the process of treaty signing have remained unclear. In this chapter, we present a bargaining framework with which to analyze treaty formation, taking into account that TIEAs and DTCs, even if both include information exchange clauses, are not the same. Given that DTCs facilitate cross-border investments, they are clearly more favorable to a tax haven than a normal TIEA. Furthermore, it is clear that havens would not pursue the signing of agreements which include an information exchange clause without outside pressure. Thus, taking the natural ordering of the three possible agreement forms into account, we estimate a random intercept ordered probit model to analyze how the potential bilateral defensive measures and a haven's bargaining position and characteristics are correlated with agreement form. We show that the main drivers of the likelihood of a specific agreement are each haven's bargaining power and its average governance index while bilateral indicators seem to have a smaller impact on agreement form. More specifically, we show that havens with a higher GDP are more likely to not sign any agreements and havens with a high average governance index are more likely to have a TIEA. Official development assistance eligibility seems to also have a positive impact on agreement form, as countries, which are eligible for this type of assistance, are more likely to have signed TIEAs. The case that a haven's foreign direct investment net outflow, as a share of its GDP, is significantly correlated with a lower agreement form is also easily interpreted as it seems to be a good proxy for the haven's reliance on being a financial hub. Possible defensive measures that should have a stronger impact when the bilateral financial relationship is strong are only significant in the case of bilateral portfolio outflow, whereas, in the case of foreign direct investment, there does not seem to be any significant correlation. The defensive measure, which seems to have the strongest impact on agreement form outcome, are the tax treaty related measure. We show that if an OECD country and a haven had an agreement before 1998 in force, they are more likely to respond to pressure and accept a renegotiation that includes the stronger form of the information exchange clause.

A particularly interesting and strong result of our analysis is the fact that the size of the haven's economic sector has a highly significant negative effect on compliance. Notice that this result holds, when we hold the strength of the bilateral financial relationship constant. Thus, it seems that while in line with the theory that stronger bilateral financial ties make exerting more pressure on the haven and the haven's compliance more probable, the overall size of the economic sector has a positive impact on a haven's bargaining position. A possible reason is that potential bilateral pressure that can be exerted is already accounted for and in order to effectively "capture" the remaining economic sector by the high tax country multilateral coordination is needed.

Taking our results into account, it becomes clear that the perceived recent successes of the G20 crackdown have been mainly due to the active participation of smaller tax havens. Stronger tax havens remain non-compliant and it is their characteristics which mainly define the agreement outcome. The financial bilateral relationships in the case of bilateral portfolio investment seem to have a positive impact on agreement form, but the strongest impact has been on tax havens which had already entered into agreements.

3.7 Regression Tables

Table 3.1: Benchmark Estimation

	(1)	(2)	(3)
Dep. variable: agreement form			
Distance	-0.0735	-0.0710	-0.0305
	-0.0485	(0.0509)	(0.0539)
GDP	-0.4590**	-1.3340***	-0.8036***
	(0.1498)	(0.2764)	(0.2058)
Governance index	0.9080***	0.7209***	0.9451***
	(0.1645)	(0.1544)	(0.1643)
ODA eligibility	0.4257***	0.1628	0.3994**
	(0.1227)	(0.2286)	(0.1999)
GDP per capita difference	0.3597***	0.2813***	0.6315***
	(0.0470)	(0.0663)	(0.0812)
Common language	-0.1269	-0.2098*	-0.2679**
	(0.1005)	(0.1202)	(0.1274)
Treaty before 1998		.3917**	0.4373**
		(0.1502)	(0.1634)
Bilateral portfolio outflow		0.1020**	
		(0.0423)	
Bilateral FDI			-0.0082
			(0.0400)
κ_1	1.6864***	1.2762***	1.5431***
	(0.2097)	(0.2380)	(0.2269)
κ_2	2.0987***	1.7718***	2.0284***
	(0.2121)	(0.2399)	(0.2316)
τ_i	0.9889	0.7576	0.9765
Log Likelihood	-832.0007	-629.0557	-537.9602
N	1134	803	730

* p<0.1, ** p<0.05, *** p<0.001.
κ represent the estimated cut-off points.
τ_i is the estimated standard deviation of the haven-specific random intercept.
The data is standardized

Table 3.2: Probit Regression for DTC Decision

	(1)	(2)	(3)
Dep. variable: DTC=1			
Distance	0.0159	0.0282	-0.0154
	(0.0632)	(0.0717)	(0.0764)
GDP	-0.1853	-0.2004	-0.1717
	(0.1699)	(0.1925)	(0.1851)
Governance index	0.5879*	0.6731*	0.4361
	(0.3287)	(0.3562)	(0.2966)
ODA eligibility	-0.3865	-0.3557	-0.6578*
	(0.466)	(0.4301)	(0.3425)
GDP per capita difference	-0.1055	-0.1861*	-0.0781
	(0.0868)	(0.1026)	(0.1087)
Common language	-0.1456	-0.2184	-0.2164
	(0.1551)	(0.1768)	(0.1824)
Treaty before 1998		0.6764***	0.5928**
		(0.1969)	(0.2090)
Bilateral portfolio outflow		0.0925	
		(0.0698)	
Bilateral FDI			0.0568
			(0.0589)
Constant	-1.684***	-1.689***	-1.395***
	(0.4776)	(0.4958)	(0.3883)
τ_i	0.6412	0 .6136	0.5357
Log Likelihood	-288.7086	-224.2384	-196.2615
N	883	621	561

Subset of data with TIEA signings were dropped.
p<0.1, ** p<0.05, *** p<0.01.
The standard deviations are in brackets.
τ_i is the estimated standard deviation of the random intercept.
The data is standardized.

Table 3.3: Probit Regression for TIEA Decision

	(1)	(2)	(3)
Dep. variable:TIEA=1			
Distance	-0.1265**	-0.1603**	-0.07161
	(0.05496)	(0.0678)	(0.0735)
GDP	-35.3503***	-39.963***	-28.769***
	(5.999)	(9.336)	(7.106)
Governance index	0.6216***	0.5928***	1.015***
	(0.1221)	(0.1413)	(0.1969)
ODA eligibility	0.0036	-0.1155	-0.0698
	(0.1762)	(0.2436)	(0.2823)
GDP per capita difference	0.5262***	0.5123***	0.8438***
	(0.0620)	(0.0835)	(0.119)
Common language	-0.1819	-0.2752*	-0.3484**
	(0.1243)	(0.1532)	(0.1679)
Treaty before 1998		0.8897**	0.6895*
		(0.3095)	(0.366)
Bilateral portfolio outflow		0.2629**	
		(0.1251)	
Bilateral FDI			-0.3440
			(0.5972)
Constant	-11.3338***	-12.3634***	-9.5569***
	(1.6471)	(2.5451)	(1.849)
τ_i	1.4489***	1.316***	1.3097***
Log Likelihood	-419.0328	-290.4575	-248.9178
N	1012	697	643

Subset of data with DTC signings were dropped.
p<0.1, ** p<0.05, *** p<0.01.
The standard deviations are in brackets.
τ_i is the estimated standard deviation of the random intercept.
The data is standardized.

Table 3.4: Foreign Direct Investment net outflow (% of GDP)

	(1)	(2)	(3)
Dep. variable: Agreement form			
Distance	-0.0619	-0.0802	0.0024
	(0.0509)	(0.0550)	(0.0604)
GDP	-0.3537**	-0.4850**	-0.3250
	(0.1738)	(0.2018)	(0.2230)
FDI net outflow (%GDP)	-0.2798***	-0.2328***	-0.3444***
	(0.0552)	(0.0587)	(0.0754)
Governance index	1.4362***	0.7394***	1.1028***
	(0.2156)	(0.1496)	(0.2183)
ODA eligibility	0.2018	0.1454	0.4076*
	(0.1422)	(0.1813)	(0.2105)
GDP per capita difference	0.7062***	0.5213***	0.7790***
	(0.0701)	(0.0872)	(0.0909)
Common language	-0.2461**	-0.2833**	-0.3046**
	(0.1130)	(0.1297)	(0.1397)
Treaty before 1998		0.3774**	0.4434**
		(0.1563)	(0.1772)
Bilateral portfolio outflow		0.1139**	
		(0.0431)	
Bilateral FDI			0.0065
			(0.0450)
κ_1	1.7820***	1.0437***	1.4921***
	(0.2540)	(0.1940)	(0.2414)
κ_2	2.3235***	1.6586***	2.1064***
	(0.2581)	(0.1993)	(0.2484)
τ_i	0.9018	0.8697	0.9413
Log Likelihood	-622.3963	-498.9385	-422.9698
N	864	635	569

* p<0.1, ** p<0.05, *** p<0.001.
The standard deviations are in brackets.
κ represent the estimated cut-off points.
τ_i is the estimated standard deviation of the random intercept.
The data is standardized.

Table 3.5: Savings Tax Directive

	(1)	(2)	(3)
Dep. variable: agreement form			
Distance	-0.0705	-0.0756	-0.0293
	(0.0444)	(0.0507)	(0.0539)
GDP	-0.4485**	-0.7488***	-0.8046***
	(0.1472)	(0.2119)	(0.2063)
Governance index	0.8723***	0.6736***	0.9547***
	(0.1298)	(0.1470)	(0.1667)
ODA eligibility	0.4711***	0.3303*	0.3989**
	(0.1261)	(0.1879)	(0.1945)
GDP per capita difference	0.3636***	0.3138***	0.6304***
	(0.0461)	(0.0677)	(0.0793)
Common language	-0.1061	-0.2240*	-0.2763**
	(0.0998)	(0.1222)	(0.1292)
Common Savings Tax Directive	0.1489	0.0674	-0.0558
	(0.1162)	(0.1473)	(0.1546)
Treaty before 1998		0.4475**	0.4528**
		(0.1509)	(0.1679)
Bilateral portfolio outflow		0.1080**	
		(0.0418)	
Bilateral FDI			-0.0098
			(0.0399)
κ_1	1.722***	1.25***	1.533***
	(0.1813)	(0.2192)	(0.2281)
κ_2	2.135***	1.748***	2.018***
	(0.1841)	(0.222)	(0.2329)
τ_i	1.018***	0.7932***	0.9707***
	(0.1026)	(0.1080)	(0.1179)
Log Likelihood	-831.1884	-628.1058	-537.8952
N	1134	803	730

p<0.1, ** p<0.05, *** p<0.001.
The standard deviations are in brackets.
κ represent the estimated cut-off points.
τ_i is the estimated standard deviation of the random intercept.
The data is standardized.

Table 3.6: Excluding OECD tax haven countries.

	(1)	(2)	(3)
Dep. variable: agreement form			
Distance	-0.066	-0.0601	-0.0181
	(0.0511)	(0.0519)	(0.0571)
GDP	-2.51***	-0.77*	-1.22**
	(0.3564)	(0.4077)	(0.4374)
Governance index	0.946***	0.513***	0.970***
	(0.1888)	(0.1263)	(0.1713)
ODA eligibility	0.3621**	0.3772**	0.3689*
	(0.1278)	(0.1829)	(0.2165)
GDP per capita difference	0.3427***	0.1571**	0.6008***
	(0.0515)	(0.0636)	(0.0856)
Common language	-0.1010	-0.1383	-0.2217
	(0.1062)	(0.1267)	(0.1372)
Treaty before 1998		0.4954**	0.4678**
		(0.1602)	(0.1753)
Bilateral portfolio outflow		.0978**	
		(0.0443)	
Bilateral FDI			-0.0149
			(0.0401)
κ_1	2.227***	1.307***	1.644***
	(0.2612)	(0.2034)	(0.2466)
κ_2	2.6158***	1.7731***	2.0890***
	(0.2639)	(0.2067)	(0.2512)
τ_i	0.9432	0.9269	0.9498
Log Likelihood	-767.23	-568.60	-485.21
N	1053	730	668

* p<0.1, ** p<0.05, *** p<0.01.
The standard deviations are in brackets.
κ represent the estimated cut-off points.
τ_i is the estimated standard deviation of the random intercept.
The data is standardized.

Table 3.7: Excluding Nordic countries

	(1)	(2)	(3)
Dep. variable: agreement form			
Distance	-0.1116**	-0.0680	-0.0570
	(0.0500)	(0.05658)	(0.0635)
GDP	-0.4050**	-0.5415**	-0.5364*
	(0.1648)	(0.2685)	(0.3012)
Governance index	0.5130***	0.7675***	0.6486**
	(0.1280)	(0.1987)	(0.2402)
ODA eligibility	.1392	0.1547	0.1235
	(0.1340)	(0.2428)	(0.2979)
GDP per capita difference	0.2115***	0.1934**	0.4290***
	(0.0530)	(0.0872)	(0.1191)
Common language	-0.0635	-0.1527	-0.1346
	(0.1090)	(0.1295)	(0.1410)
Treaty before 1998		0.0481	0.1990
		(0.1921)	(0.2049)
Bilateral portfolio outflow		0.1362**	
		(0.0446)	
Bilateral FDI			0.0134
			(0.0429)
κ_1	1.1793***	1.2756***	1.2092***
	(0.1677)	(0.2781)	(0.3433)
κ_2	1.6279***	1.7655***	1.7315***
	(0.1705)	(0.2830)	(0.3470)
τ_i	0.8201	0.5943	0.7125
Log Likelihood	-642.9783	-508.8957	-407.1334
N	924	672	568

p<0.1, ** p<0.05, *** p<0.001.
The standard deviations are in brackets.
κ represent the estimated cut-off points.
τ_i is the estimated standard deviation of the random intercept.
The data is standardized.

Table 3.8: Population-averaged marginal effects

	(1)	(2)	(3)
Category: No Agreement			
GDP	**0.1078**	**0.3772**	**0.2045**
World Governance Average	**-0.2132**	**-0.2038**	**-0.2405**
ODA Eligibility	**-0.0988**	-0.0459	**-0.1007**
Distance	0.0173	0.0201	-0.0078
Difference in GDP	**-0.0845**	**-0.0795**	**-0.1607**
Common Language	**0.0292**	**0.0575**	**0.0657**
Treaty before 1998	-	**-0.1149**	**-0.1155**
Bilateral portfolio outflow	-	**-0.0288**	-
Bilateral foreign direct investment	-	-	0.0021
Category: DTC			
GDP	**-0.0216**	**-0.0891**	**-0.0415**
World Governance Average	**0.0427**	**0.0482**	**0.0488**
ODA Eligibility	**0.0200**	0.0109	**0.0207**
Distance	-0.0035	-0.0047	0.0016
Difference in GDP	**0.0169**	**0.0188**	**0.0326**
Common Language	**-0.0061**	**-0.0146**	**-0.0145**
Treaty before 1998	-	**0.0238**	**0.0202**
Bilateral portfolio outflow	-	**0.0068**	-
Bilateral foreign direct investment	-	-	-0.0004
Category: TIEA			
GDP	**-0.0862**	**-0.2881**	**-0.1630**
World Governance Average	**0.1705**	**0.1557**	**0.1917**
ODA Eligibility	**0.0788**	0.0351	**0.0801**
Distance	-0.0138	-0.0153	0.0062
Difference in GDP	0.0676	0.0607	0.1281
Common Language	**-0.0232**	**-0.0430**	**-0.0511**
Treaty before 1998	-	0.0911	0.0952
Bilateral portfolio outflow	-	0.0220	-
Bilateral foreign direct investment	-	-	-0.0017
N	1134	803	730

Bold characters signify significant results in the conditional model.

Chapter 4

Climate Uncertainty, Irreversibility and Technology Sharing

This chapter is based on joint work with Florian Morath.

4.1 Introduction

Getting countries to commit to new Post-Kyoto binding CO_2 emission reduction targets has hitherto remained an elusive goal. A continued success on an international scale, however, has been the support of renewable technology initiatives. For example, the Cancun Summit in 2011 declared the start of a 1$ Billion new initiative and fund for the exchange of climate change technology. Technology transfer mechanisms have always been a dimension of climate change agreements. Article 4.5 of the United Nations Framework Convention on Climate Change states that countries "shall take all practical steps to promote, facilitate, and finance, as appropriate, the transfer of, or access to environmentally sound technologies and know-how to other parties."[1] In fact, recent studies tracking the development of clean technologies show its steady and persistent rise.[2]

This development is not surprising, given the strong national policies in support of renewable technologies implemented by the US and the EU.[3] However, the support of renewable technology is often controversially debated. Investments in technology can be profitable if one perceives them as investments in new markets. But, in the public good framework of environmental protection, a particularly persistent argument has been that unilateral investments in technology hurt the investing country as other countries can reduce their effort on climate protection in return. Given the strong international support of technology sharing initiatives, this chapter provides an argument in favour of the sharing of cost-reducing technologies. A country may provide a new technology, because it can induce other countries not to delay their efforts but instead to contribute to climate protection today.

To develop our rationale, three distinctive features, which influence the decision of contributing to climate protection, are taken into consideration. Efforts to mitigate global warming are, to a large extent, private contributions to a global public good. As such the strategic interaction between countries causes strong incentives to delay one's own contribution since, in reaction to the high effort of one country, other countries can reduce their effort on climate protection. Furthermore, international coordination and the fight against climate change are further hampered by the fact that there is uncertainty with regard to the need for climate protection and a potential irreversibility of damages resulting from greenhouse gas emissions. The uncertainty connected with climate protection stems from the fact that the costs and

[1] For example, the Stern Review (2006) identified a technology based-scheme to tackle climate change as indispensible.

[2] See McCrone (2011).

[3] See Moselle et al. (2010) for an overview.

benefits of environmental damage and its reduction remain largely uncertain. Particularly difficult is the assessment of the impact of climate change which is highly reliant on different projections of the CO_2 impact on temperatures .[4] Consequently, such strong uncertainties should push policy-makers towards a later contribution to climate protection, i.e. after the resolve of the uncertainty. However, because CO_2 emissions are causing irreversible damages, delaying the fight against global warming may be expensive. For example, the accumulation of CO_2 emissions in the atmosphere is hard to reduce and the damage to the ecosystems from higher global temperatures, from acidified lakes and streams, or the clear-cutting of forests can be permanent. Thus, a large part of this chapter analyzes how uncertainty and irreversibility affect the timing of the contribution to climate protection, given that climate protection is a global public good.

Our contribution is twofold. First, we extend the framework of private provision to a public good game to a model that incorporates the important trade-off that countries face when deciding on climate policies: uncertainty versus irreversibility of damages. We derive the equilibrium contributions to climate protection and identify the main mechanisms driving the timing of the contribution decision. We show that for low degrees of irreversibility, both countries would like to wait until the resolve of the uncertainty, while for high degrees of irreversibility the opposite is the case. Our analysis, furthermore, shows that for intermediate ranges of irreversibility an alternating equilibrium endogenously emerges, where one country contributes early and the other country might contribute in the later stage of the game; a result strongly in line with empirical observations.

Second, we analyze, for the case of technology sharing, how an investment in cost-reducing technology by one country alters the timing decision of the contribution to climate protection game. We identify two scenarios, where a country can invest in

[4] See Allen et al. (2009) for a summary on CO_2 impact projections and their variability.

cost-reducing technology in order to free-ride on the other country's contribution. We show that by a targeted use of cost-reducing technology, countries can switch from one equilibrium candidate where they need to contribute to the public good to another where they can free-ride on the other country's contribution.

Thus, our model is related to the literature on the timing of environmental policy adoption. Mainly developed by Arrow and Fisher (1974) and Henry (1974) for the case of irreversible investment under uncertainty, they show that there is an option value to waiting until the resolve of the uncertainty in the one country framework.[5] Pindyck (2002), for example, argues that due to the uncertainty and irreversibility of damages that are often part of environmental protection considerations, environmental policy design can involve important problems of timing. Consequently, this study takes up the timing issue of policy adoption and introduces the notions of irreversibility and uncertainty in the simplest two country-framework. This allows us to isolate the effects of uncertainty and irreversibility in a context of strategic contribution considerations.[6]

Methodologically, our study is related to the standard literature on private provision to a public good. The standard static models of private provision to a public good literature highlight free-riding as the strongest effect in the private provision of the public good game.[7] In the simplest dynamic framework, our model exhibits a strong free-riding incentive, similar to Fershtman and Nitzan (1991) and Admati and Perry (1991), as countries would like to free-ride on the other players' future contributions. We contribute to this literature by exploring how uncertainty and

[5] See also Pindyck (1991) and Ulph and Ulph (1997) .

[6] Issues of timing have continued to play a role in the environmental literature with the recent struggles of international coordination in the post-Kyoto era. See Schmidt and Strausz (2011) and Beccherle and Tirole (2011) who analyse the impacts of delayed negotiations.

[7] See the seminal work by Bergstrom et al. (1986) and Cornes and Sandler (1985). Also see Varian (1994) on sequential contributions to a public good.

irreversibility affect the public good game equilibrium outcome.

Implementing a form of irreversibility in the dynamic public good game has first been introduced by Marx and Matthews (2000) and Lockwood and Thomas (2002). There, the term "irreversibility" is more in line with the irreversibility of investment notion where a contribution to the public good in a previous period cannot be taken back. In Marx and Matthews (2000), it is shown that contributions gradually rise to just above the efficient one-shot game levels. Furthermore, contributors alternate from one period to another, a feature which also endogenously arises in our analysis.

Bramoullé and Treich (2009) examine the effect of uncertainty on pollution emissions in a public good framework with risk averse countries. In the model the variance of damages increases with pollution and, thus, polluters can reduce risk by decreasing their own emissions. This result hinges on the risk aversion of the countries. In our model, given risk neutral countries, we show that the irreversibility of damages can induce similar behavior increasing the contributed level of the public good in the early stage of the game. While there have been studies, which have analyzed the effects of uncertainty or irreversibility in the context of public good provision in isolation, to our knowledge our study next to Morath (2010) is the first to analyze the effects simultaneously.[8]

There is a growing economic literature on the interaction between technology and the environment. For example, Bucholz et al. (2005), Buchholz and Konrad (1994,1995) show that the public good nature of environmental protection might induce countries to be "less green" in order to strengthen their bargaining position in the environmental policy coordination game. This argument has been further generalized by Beccherlé and Tirole (2011) and still holds true when introducing uncertainty or dynamics.[9] This robust result, however, stands in strong contrast to

[8] Morath (2010) introduces the trade-off of irreversibility vs. uncertainty in environmental policy,however, in the context of strategic information acquisition.

[9] See Harstad (2010) and Konrad and Thum (2011).

the steady rise of investments in renewable energy. Furthermore, the notion that such investments can be used to reduce the costs of the other countries, but not the country actually engaged in cost-reducing investments, is quite strong. Our model, while not modelling the investment in cost-reducing technology strategically and abstracting from bargaining over a cooperative outcome, identifies scenarios where a cost-reducing investment that is shared between both countries in the same way but generates an outcome similar to the argument by Buchholz and Konrad (1994).

The chapter is structured as follows: Section 4.2 introduces the model framework, Section 4.3 solves for the equilibrium contributions of the full model, Section 4.4 isolates the effects of uncertainty, irreversibility, and free-riding on the timing of the contribution. Section 4.5 analyzes the impact of the technology sharing of a cost-reducing investment on the timing of the contributions and Section 4.6 concludes.

4.2 Model framework

We consider a framework with two countries A and B and two periods t and $t+1$. In each period, countries simultaneously choose a contribution to a public good where $x_\tau^i \in \mathbb{R}_+$ denotes country i's contribution in period τ, $i \in \{A, B\}$ and $\tau \in \{t, t+1\}$. The marginal contribution cost in the two periods are assumed to be constant and identical for both countries and are denoted by $c_t(\kappa) > 0$ and $c_{t+1}(\kappa) > 0$; κ refers to the technology available to the countries, and c_t and c_{t+1} are assumed to be continuous and differentiable in κ (as explained below).

Individual contributions in the two periods sum up to the total amount contributed to the public good. Hence, country i's payoff is equal to

$$\pi_i = \theta^i f\left(\sum_{\tau=t,t+1}\sum_{i=A,B} x_\tau^i\right) - c_t x_t^i - c_{t+1}x_{t+1}^i,\ i \in \{A, B\}. \tag{4.1}$$

Here, function f translates climate protection effort into a mitigation outcome. As usual, f is assumed to be strictly increasing and concave, $f' > 0$, $f'' < 0$.[10]

Countries only differ in their valuation of the public good, denoted by θ^A and θ^B.[11] These country-specific valuations of the public good are independent draws from two commonly known continuous distribution functions Φ_A and Φ_B with support $\left[0, \bar{\theta}\right]$. The functions Φ_A and Φ_B are assumed to be continuously differentiable on $\left(0, \bar{\theta}\right)$.

In period t, there is uncertainty about the valuation of the public good θ that will be resolved in period $t+1$; consequently, both countries' valuations θ^A and θ^B become commonly known only between periods t and $t+1$. Overall, no country has private information about its benefit from climate policy: country-specific differences with respect to cost and benefit of climate protection are typically observed. The uncertainty in the model, thus, reflects the difficulty of assessing the cost-benefit ratio and valuation of climate protection.[12]

We will restrict the analysis to probability distributions with the following reverse hazard rate:

Assumption 1: $\frac{\Phi_i'(\theta)}{\Phi_i(\theta)} \leq \frac{1}{\theta}$ for all $\theta \in \left(0, \bar{\theta}\right], \ i = A, B.$

This assumption ensures that the countries' maximization problems in period t are well-behaved and that the objective function is concave.[13]

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[10]To simplify the exposition, we will assume that $\theta f'(0) - c_{t+1} > 0$ for all $\theta > 0$. Although not important for our results, this assumption will imply that all types $\theta > 0$ will prefer a strictly positive quantity of the public good, even if the contribution cost is c_{t+1}.

[11]The heterogeneity in θ captures all country differences in the cost-benefit ratio of climate protection efforts, including differences in the contribution technology.

[12]For example, in a review of impact estimates of climate change, Jamet and Corfee-Morlot (2009) identify five sources of uncertainty: greenhouse gas emissions projections, the accumulation of emissions in the atmosphere and how these emissions affect global temperatures, the physical impacts of a given increase in temperature, the valuation of physical impacts in terms of GDP and the risk of abrupt climate change.

[13]Note that, for instance, uniform or exponential probability distributions fulfill As-

The aspect of the irreversibility of foregone climate efforts is reflected in the contribution cost. A general increase in average world temperatures cannot be easily reduced, regardless of how advanced the abatement technology is. This is particularly the case as CO_2 stocks in the atmosphere very slowly dissipate. Furthermore, other environmental damages like acidified rain and lakes can have considerable irreversible damages. Thus, due to the irreversibility of damages, delaying mitigation efforts may make future climate policy more expensive. Therefore, we assume that the marginal contribution cost in $t+1$ is strictly larger than marginal contribution cost in t,

$$c_{t+1}(\kappa) > c_t(\kappa). \tag{4.2}$$

Our analysis considers the effects of an investment in cost-reducing technology on the equilibrium climate protection outcome. We focus on the notion that investments in climate abatement technology are shared. Generally, successful investments in R&D have strong spillover effects, for example, through trade magazines and reverse engineering by competitors. In addition, patent protection for new inventions and innovations only have a limited time frame. Furthermore, in the case of climate abatement technology, such spillovers are more strongly encouraged through large technology transfer initiatives. Thus, we consider investments in cost-reducing technology $\kappa \in [\kappa_0, \kappa_{\max}]$ in our model which affect the marginal costs of both countries in the same way. Notice that κ_0 denotes the initial technology in use and $\kappa_{\max}$ denotes the maximal technology to be used. Without explicitly modelling investments in technology, we analyze whether or not, at the beginning of period t, a country i, by improving the technology available to both countries, can alter the equilibrium reached. We consider the case where an improvement in technology reduces both periods' marginal contribution cost, that is,

$$\frac{\partial c_t(\kappa)}{\partial \kappa} < 0 \text{ and } \frac{\partial c_{t+1}(\kappa)}{\partial \kappa} < 0. \tag{4.3}$$

sumption 1. This assumption is sufficient but not necessary for obtaining our results, but it simplifies the analysis considerably.

Our analysis solves for the subgame-perfect Nash equilibrium of the following game. In stage 0, nature independently draws the country-specific valuations of the public good from the distribution functions Φ_A and Φ_B which are common knowledge. Then, countries might invest in a cost-decreasing technology. In stage 1 countries A and B simultaneously choose their contributions x_t^A and x_t^B. Then, both contributions and the country-specific valuations of the public good become publicly observable. Finally, in stage 2 countries again can simultaneously choose their contributions x_{t+1}^A and x_{t+1}^B, and payoffs are realized.

4.3 Contributions to Climate Protection

In this section, we characterize the countries' equilibrium contributions in the two periods when contributions to climate protection are voluntary contributions to a public good. In each period, the two countries A and B simultaneously decide over their contributions to the public good. The countries' contributions are strategic substitutes, and, as we will show, the countries' optimal contributions depend not only on incentives to free-ride on the other country's contribution but also on the trade-off between uncertainty and irreversibility of damages. We solve the game through backward induction.[14]

[14]In the game specified above, no player has private information about his type at any point in time, but each player's type is only revealed after period t. Hence, to be precise, a complete characterization of the equilibrium would require specification of the players' beliefs about their own and their co-player's type. In our equilibrium analysis, we implicitly assume that, in period t, each player $i = A, B$ believes that his and his co-player's type are drawn from the distributions Φ_A and Φ_B respectively, and we solve for the perfect Bayesian equilibrium under these beliefs. In period $t+1$, both types become common knowledge, and, thus, updating of beliefs does not play a role in our framework. For simplicity, we omit this more complex notation.

4.3.1 Preferred provision levels in period $t+1$

To solve for the equilibrium contributions, consider first period $t+1$. Here, the countries' valuations θ^A and θ^B are common knowledge and the game is strategically equivalent to a standard private provision game with a given contribution $X_t = x_t^A + x_t^B$.[15] We define a country i's *preferred provision level* of the public good in $t+1$ as the quantity $Q_{t+1}^i(\theta^i)$ that solves i's first order condition

$$\theta^i f'\left(Q_{t+1}^i\left(\theta^i\right)\right) - c_{t+1} = 0, \tag{4.4}$$

that is

$$Q_{t+1}^i\left(\theta^i\right) := \begin{cases} (f')^{-1}\left(c_{t+1}/\theta^i\right) & \text{if } \theta^i > 0 \\ 0 & \text{otherwise.} \end{cases} \tag{4.5}$$

$Q_{t+1}^i(\theta^i)$ denotes the level of contributions up to which i would like to increase total contributions. Notice that a country might only contribute a strictly positive amount in period $t+1$ if total period t contributions are $X_t < Q_{t+1}^i(\theta^i)$. Moreover, due to the quasi-linear payoff functions, in equilibrium one country at most will contribute in period $t+1$; this country will be the country i with the higher preferred provision level $Q_{t+1}^i(\theta^i)$ or, equivalently, the country i with the higher valuation θ^i for the public good. This country i raises the contribution level up to its desired quantity $Q_{t+1}^i(\theta^i)$, and country $j \neq i$ free-rides and contributes zero.[16] Hence, the equilibrium contributions are given by

$$\left(x_{t+1}^A, x_{t+1}^B\right)^* = \begin{cases} \left(\max\left\{Q_{t+1}^A\left(\theta^A\right) - X_t, 0\right\}\ ,\ 0\right) & \text{if} \quad \theta^A > \theta^B \\ \left(0\ ,\ \max\left\{Q_{t+1}^B\left(\theta^B\right) - X_t, 0\right\}\right) & \text{if} \quad \theta^A < \theta^B. \end{cases} \tag{4.6}$$

[15] Recall that the marginal contribution cost is constant.

[16] If $\theta^A = \theta^B$ and $Q_{t+1}^i > X_t$, in $t+1$ there is a continuum of equilibria with $\left(x_{t+1}^A\right)^* + \left(x_{t+1}^B\right)^* = Q_{t+1}^i$. For completeness, we assume that in this case the symmetric equilibrium is played, although $\theta^A = \theta^B$ occurs with probability zero (due to the assumption of continuous distribution functions Φ_A and Φ_B).

4.3.2 Preferred provision levels in period t

Inserting the optimal contributions in period $t+1$ into country i's decision problem in period t, country i chooses x_t^i to maximize its expected payoff $\pi_i\left(x_t^i\right)$ in t, given $\left(X_{t+1}\right)^* = \left(x_{t+1}^A\right)^* + \left(x_{t+1}^B\right)^*$ and given x_t^j. Hence, denoting this expected payoff by $\pi_i\left(x_t^i\right)$, we get

$$\begin{aligned}\pi_i\left(x_t^i\right) &= \int_0^{\bar{\theta}} \Phi_j\left(\theta^i\right)\left(\theta^i f\left(\max\{Q_{t+1}^i, X_t\}\right) - c_t x_t^i - c_{t+1}\left(Q_{t+1}^i - \left(X_t\right)\right)^+\right) d\Phi_i\left(\theta^i\right) \\ &\quad + \int_0^{\bar{\theta}} \left(1-\Phi_j\left(\theta^i\right)\right)\left(\theta^i f\left(\max\{Q_{t+1}^j, X_t\right) - c_t x_t^i\right) d\Phi_i\left(\theta^i\right). \end{aligned} \tag{4.7}$$

Taking contributions in period $t+1$ into account, country i weighs the expected probabilities of two scenarios: a scenario where it has the higher valuation in period $t+1$ than country j, which occurs with probability $\Phi_j\left(\theta^i\right)$, and a scenario where it has a lower valuation than country j, which occurs with probability $1-\Phi_j\left(\theta^i\right)$.

In both scenarios ($\theta^i > \theta^j$ and $\theta^i < \theta^j$), apart from the realization of the valuations θ^i and θ^j, potential contributions in period $t+1$ will depend on the amount X_t that has already been contributed in period t. Since country i might only contribute in period $t+1$ if its preferred provision level Q_{t+1}^i is strictly larger than X_t. Using (4.5) we can define by

$$\hat{\theta} := \frac{c_{t+1}}{f'\left(X_t\right)} \tag{4.8}$$

the *critical valuation* for which a country's preferred provision level in $t+1$ is exactly equal to X_t. Consequently, only countries with a realized valuation $\theta > \hat{\theta}$ may contribute in $t+1$.

Now consider country i's expected marginal payoff from an increase in x_t^i. Suppose, first, that the given total contribution X_t is smaller than $Q_{t+1}^i\left(\bar{\theta}\right)$ where $Q_{t+1}^i\left(\bar{\theta}\right)$ denotes the preferred provision level in $t+1$ of the type with the highest possible valuation $\bar{\theta}$. In this case, i's marginal expected payoff from an increase in x_t^i is equal to

$$\begin{aligned} \pi_i'\left(x_t^i; X_t\right) &= \int_0^{\hat{\theta}} \int_0^{\hat{\theta}} \left(\theta^i f'\left(X_t\right) - c_t\right) d\Phi_j\left(\theta^j\right) d\Phi_i\left(\theta^i\right) \\ &+ \int_{\hat{\theta}}^{\bar{\theta}} \int_0^{\theta^i} \left(c_{t+1} - c_t\right) d\Phi_j\left(\theta^j\right) d\Phi_i\left(\theta^i\right) \\ &+ \int_{\hat{\theta}}^{\bar{\theta}} \int_{\theta^i}^{\bar{\theta}} \left(-c_t\right) d\Phi_j\left(\theta^j\right) d\Phi_i\left(\theta^i\right). \end{aligned} \tag{4.9}$$

This marginal expected payoff in (4.9) consists of three terms representing three different scenarios: First, if both countries' realized valuations are smaller than the critical valuation $\hat{\theta}$, then no contribution will take place in $t+1$. Hence, with the probability that $\theta^i \leq \hat{\theta}$ and $\theta^j \leq \hat{\theta}$, the marginal payoff is the difference between the marginal benefit of public good consumption and the marginal contribution cost (the first term in (4.9)).

Otherwise, if i's valuation is greater than the critical valuation, i.e., $\theta^i > \hat{\theta}$, then i would, in principle, be willing to make a contribution in $t+1$, and its equilibrium contribution will depend on whether j has a lower or higher valuation for climate protection. Accordingly, the second term in (4.9) considers the case where $\theta^i > \theta^j$ and i's equilibrium contribution in $t+1$ is strictly positive. With the probability that $\theta^i > \hat{\theta}$ and $\theta^i > \theta^j$, the marginal payoff of increasing the period t contribution is equal to the difference in the contribution costs, $c_{t+1} - c_t$: by increasing the period t contribution, country i will save the higher contribution cost in $t+1$. The third term illustrates i's marginal payoff given that country j has a higher valuation (and $\theta^j > \hat{\theta}$); in this case, the marginal benefit for country i is zero because this contribution would have been made by j anyway, and a contribution only bears the marginal cost c_t.

Altogether, the three terms illustrate the trade-off between uncertainty (unknown realization of the valuation) and irreversibility (higher contribution cost in $t+1$) on the one hand and the incentives to free-ride on the other hand. While the effect of irreversibility in the second term in (4.9) is always positive and the free-riding effect in the third term is always negative, the sign of the first term depends on X_t. More precisely, the integrand in the first term in (4.9) will rather be negative for small realizations θ^i and positive for large realizations of θ^i.

If total contributions $X_t = x_t^A + x_t^B$ are sufficiently high, they will crowd out all potential contributions in period $t+1$: $X_t \geq Q_{t+1}^i\left(\bar{\theta}\right)$ implies $\hat{\theta} \geq \bar{\theta}$, and i's marginal payoff of an increase in x_t^i reduces to

$$\pi_i'\left(x_t^i; X_t\right) = \int_0^{\bar{\theta}} \int_0^{\bar{\theta}} \left(\theta^i f'\left(X_t\right) - c_t\right) d\Phi_j\left(\theta^j\right) d\Phi_i\left(\theta^i\right). \tag{4.10}$$

Regardless of which valuation is achieved in period $t+1$, no contribution will take place. Consequently, considerations with regard to a potential cost or saving of marginal contribution costs in period $t+1$ do not play a role. The expected marginal benefit of further increasing x_t^i is simply equal to $E\left(\theta^i\right) f'\left(X_t\right)$ and the expected marginal cost is c_t.

Optimizing over x_t^i yields a *preferred provision level* Q_t^i in period t for country i, provided that equilibrium contributions in $t+1$ are as in (4.6). Notice that $Q_t^i > 0$ does not imply that i's equilibrium contribution $\left(x_t^i\right)^*$ must necessarily be positive. Rather, Q_t^i is the quantity that i would contribute to the public good in period t if j does not contribute. Compared to $Q_{t+1}^i\left(\theta^i\right)$, country i's preferred contribution level in period $t+1$, which directly depends on θ^i, the preferred level Q_t^i of period t depends on i's expectations of the realizations of θ^i, θ^j, and the corresponding equilibrium contributions in $t+1$. The following Lemma characterizes each country's preferred period t provision level. It is assumed, as for all following statements, that **(Assumption 1)** holds

Lemma 4.1 *Consider the quantity of the public good that a country prefers to be provided in period t.*

(i) *Suppose that* $E\left(\theta^{i}\right)/\bar{\theta} \geq c_t/c_{t+1}$. *Then country i's preferred provision level in period t is equal to* $Q_t^i = (f')^{-1}\left(c_t/E\left(\theta^i\right)\right)$, $i \in \{A, B\}$.

(ii) *Suppose that* $E\left(\theta^{i}\right)/\bar{\theta} < c_t/c_{t+1}$.

(a) *If*

$$E\left(\Phi_j\left(\theta^i\right)\right) \leq \frac{c_t}{c_{t+1}}, \tag{4.11}$$

then country i's preferred provision level in period t is equal to $Q_t^i = 0$, $i \in \{A, B\}$.

(b) *If*

$$E\left(\Phi_j\left(\theta^i\right)\right) > \frac{c_t}{c_{t+1}}, \tag{4.12}$$

then country i's preferred provision level Q_t^i *in period t is uniquely determined with* $Q_t^i \in \left(0, (f')^{-1}\left(c_t/E\left(\theta^i\right)\right)\right)$, $i \in \{A, B\}$.

Proof. See Appendix. ■

The idea behind Lemma 4.1 is straightforward. In Lemma 4.1(i), if the expected to maximum valuation ratio $E\left(\theta^{i}\right)/\bar{\theta}$ is higher than the irreversibility ratio c_t/c_{t+1}, then country i prefers a provision level in t that is sufficiently high to crowd out all further contributions in $t+1$. In this case, Q_t^i is determined irrespective of period $t+1$ and, hence, country i equates marginal cost and benefit from contributing based on its expected valuation. We will refer to such a situation as the case of a "full" preferred provision level in period t, and it occurs if the expected valuation and/or the degree of irreversibility is high (where the degree of irreversibility can be measured as the inverse cost ratio c_{t+1}/c_t).

If, however, $E\left(\theta^{i}\right)/\bar{\theta}$ is lower than the cost ratio c_t/c_{t+1}, then country i will never want a full provision in period t already. In this case, $\pi_i'(0; X_t = 0) \leq 0$, or (4.11), is sufficient to ensure that country i does not want to contribute in t, independent of x_t^j.

This leads to Lemma 4.1(ii)a.[17] By the same argument, if instead $\pi_i'(0; X_t = 0) > 0$, or (4.12), then country i prefers a strictly positive provision level Q_t^i in period t. Here, country i prefers only a "partial" provision in period t, accepting that, depending on the true valuations, it might contribute again in $t+1$ (Lemma 4.1(ii)b).[18]

Which country prefers a higher provision level in period t? Due to the quasi-linear preferences, the mechanism of the standard private provision of a public good game persists in the contribution decision of period t. Positive contributions by either country are perfect substitutes. Thus, if both countries prefer a strictly positive contribution level in t, i.e., if $Q_t^A > 0$ and $Q_t^B > 0$, then, in equilibrium, only the country i with the higher preferred contribution level $Q_t^i > Q_t^j$ will contribute in t. Concretely, this country will contribute exactly $(x_t^i)^* = Q_t^i$, and the other country will contribute zero in period t.

Before turning to the characterization of the equilibrium, let us consider the determinants of whether $Q_t^i > Q_t^j$ that are implied by Lemma 4.1 in more detail.

If both countries prefer a full provision in period t, the country with the higher expected valuation will bear the contribution cost. Since this quantity is increasing in $E(\theta^i)$, i prefers a higher quantity if $E(\theta^i) > E(\theta^j)$. If one country prefers a full provision and the other country prefers a partial provision level in period t, this implies that $E(\theta^i)/\bar{\theta} > c_t/c_{t+1} > E(\theta^j)/\bar{\theta}$ and so, in this case, country i also is the country preferring the higher provision level.

[17]In Lemma 4.1(i), if (4.11) holds with equality and Assumption 1 holds with equality on some interval $[0, \theta']$, then i is indifferent between all $Q_t^i \in \left[0, (f')^{-1}(c_{t+1}/\theta')\right]$ (see Appendix). To simplify the exposition, Lemma 4.1(i) assumes that in this case $Q_t^i = 0$. If Assumption 1 holds with strict inequality, then $Q_t^i = 0$ if and only if (4.11) is fulfilled.

[18]Note that $E(\theta^i)/\bar{\theta} < c_t/c_{t+1}$ implies that $(f')^{-1}(c_t/E(\theta^i)) < Q_{t+1}^i(\bar{\theta})$. Hence, in Lemma 4.1(ii)b, $Q_t^i < Q_{t+1}^i(\bar{\theta})$ and there will be a positive contribution in $t+1$ with strictly positive probability.

In the case where the countries only prefer a "partial provision" in period t, the comparison of the expected valuations is no longer sufficient to determine which country has the higher preferred provision level in t. For any partial provision level $X_t < Q^i_{t+1}\left(\bar{\theta}\right)$, the difference between the countries' marginal payoffs of contributing in t, $\pi'_A\left(X_t\right) - \pi'_B\left(X_t\right)$, is equal to

$$\begin{aligned} &\Phi_A\left(\hat{\theta}\right)\Phi_B\left(\hat{\theta}\right)\left[E\left(\theta^A|\theta^A \leq \hat{\theta}\right) - E\left(\theta^B|\theta^B \leq \hat{\theta}\right)\right] f'\left(X_t\right) \\ &+c_{t+1}\left[\int_{\hat{\theta}}^{\bar{\theta}} \Phi_B\left(\theta^A\right) d\Phi_A\left(\theta^A\right) - \int_{\hat{\theta}}^{\bar{\theta}} \Phi_A\left(\theta^B\right) d\Phi_B\left(\theta^B\right)\right] \end{aligned} \tag{4.13}$$

where $\hat{\theta} = c_{t+1}/X_t$ is the critical valuation below which countries will not contribute in period $t+1$. Now, differences in the countries' preferred provision levels in period t are driven by two comparisons: first, by differences in the expected benefit from contributing, conditional on there being no further contributions in $t+1$ (the first term: conditional expected valuation multiplied by $f'\left(X_t\right)$), and second, by differences in the expected equilibrium contribution cost in period $t+1$ (the second term: c_{t+1} multiplied by the probability that this cost has to be paid).

In equilibrium, this comparison, evaluated at $X_t = Q^B_t$, yields

$$\begin{aligned} &\Phi_A\left(\hat{\theta}\right)\Phi_B\left(\hat{\theta}\right)\left[E\left(\theta^A|\theta^A \leq \hat{\theta}\right) - E\left(\theta^B|\theta^B \leq \hat{\theta}\right)\right] f'\left(Q^B_t\right) \\ &+c_{t+1}\left[\int_{\hat{\theta}}^{\bar{\theta}} \Phi_B\left(\theta^A\right) d\Phi_A\left(\theta^A\right) - \int_{\hat{\theta}}^{\bar{\theta}} \Phi_A\left(\theta^B\right) d\Phi_B\left(\theta^B\right)\right] > 0 \end{aligned} \tag{4.14}$$

where $\hat{\theta} = c_{t+1}/f'\left(Q^B_t\right)$. Without making further assumptions on the cumulative distribution functions, it is not straightforward when condition (4.14) holds. However, if the differences in the marginal payoff of contributing in t are always in favor of one country, it is clear that this country will have a higher preferred contribution level. This is the case, for instance, if the countries' distributions of the valuations can be ranked according to first-order stochastic dominance. In general, however, the first and the second term in (4.14) do not need to have the same sign, and whether or not $Q_t^A > Q_t^B$ will also depend on f' and c_{t+1}.

4.3.3 Equilibrium contributions

The equilibrium contributions in period t follow directly from the analysis above, which is summarized in the following proposition.

Proposition 4.1 *In the equilibrium of the two-country case, the contributions in period t are determined such that*

(i) *if* $Q_t^A = Q_t^B = 0$, *then* $\left(x_t^A\right)^* = \left(x_t^B\right)^* = 0$,

(ii) *if* $Q_t^A > Q_t^B \geq 0$, *then* $\left(x_t^A\right)^* = Q_t^A$ *and* $\left(x_t^B\right)^* = 0$,

(iii) *if* $Q_t^B > Q_t^A \geq 0$, *then* $\left(x_t^A\right)^* = 0$ *and* $\left(x_t^B\right)^* = Q_t^B$,

(iv) *if* $Q_t^A = Q_t^B > 0$, *then there is a continuum of equilibria with* $\left(x_t^A\right)^* + \left(x_t^B\right)^* = Q_t^A$

where country i's preferred contribution level Q_t^i *is given in Lemma 4.1.*

Proposition 4.1 results directly from Lemma 4.1; hence, a proof is omitted. If the irreversibility ratio c_t/c_{t+1} is close to 1 (to be precise, if it is larger than $\max\{E\left(\Phi_j\left(\theta^i\right)\right), E\left(\theta^i\right)/\bar{\theta}\}$; compare Lemma 4.1), then both countries prefer not to contribute in t but instead to wait until period $t+1$ (case (i)). Total expected contributions to the public good are then equal to

$$X_{t+1} = E_{\theta^A,\theta^B}\left[\max\left\{Q_{t+1}^A\left(\theta^A\right), Q_{t+1}^B\left(\theta^B\right)\right\}\right] \tag{4.15}$$

since, in $t + 1$, the country with the higher valuation will contribute its preferred provision level based on its contribution cost c_{t+1}.

For intermediate values of c_t/c_{t+1}, at least one country will prefer a positive provision level in t (cases (ii) and (iii)), and only one country will contribute in t. For such intermediate irreversibility ratios, it will be optimal to choose only a partial provision in period t, and there will be further contributions in $t + 1$. When c_{t+1} is high and, hence, the ratio c_t/c_{t+1} is low, contributing in t becomes even more attractive, and the country, which contributes in t, will choose a full provision in t that crowds out all possible contributions in $t + 1$.

Finally, if both countries prefer exactly the same contribution level in t (for instance, if $\Phi_A = \Phi_B$), then there is a continuum of equilibria where the countries' contributions in t sum up to this preferred level (case (iv)).

The derived equilibrium contributions have several implications. First, it becomes clear that if there is a positive contribution to the public good in any period, then it will only be borne by one country. Furthermore, the contribution decision is additionally affected by the free-riding possibility. Depending on the irreversibility ratio c_t/c_{t+1}, the optimal contribution level can be zero, a partial preferred provision level or a full provision level which crowds out all further $t + 1$ contributions.

4.4 Isolating the effects on timing

In the following, we isolate the different motivations that drive the timing of the countries' equilibrium contributions to climate protection.

The effects of uncertainty and irreversibility on the timing of the contribution. The countervailing effects of uncertainty vs. irreversibility have been already made clear in the previous section. Now consider the case where there is uncertainty about the valuations for climate protection but no irreversibility of forgone efforts to climate protection. When c_{t+1} converges to c_t, a contribution in t is strictly dominated, independent of the remaining parameters of the model (for instance, the probability distributions Φ_A and Φ_B). Both countries will prefer to wait until the resolve of the uncertainty. A standard private provision of a public good game, based on the realized valuations, will ensue in period $t+1$. Uncertainty is the predominant effect in case (i) of Proposition 4.1.

Now consider the case where there is no uncertainty but irreversibility; that is, where the variance of Φ_A and Φ_B goes to zero but where the structure of the model remains unchanged. In the limit where the valuations are already known in period t, delaying the contribution until $t+1$ is strictly dominated, as contributions in $t+1$ cause a strictly higher marginal cost. Accordingly, both countries will want to contribute in period t at the lower marginal costs c_t. This is comparable to cases (ii)-(iii) of Proposition 4.1, assuming that the equilibrium contribution $\left(x_t^i\right)^* = Q_t^i$ ensures a full provision of the public good in t.

In summary, while uncertainty pushes the timing of the contribution to climate protection towards a later date, irreversibility pushes the timing of the contribution to climate protection towards an earlier date.

The effect of free-riding on the timing of the contribution. To isolate the effect of free-riding on the optimal timing decision, consider the case in which there is only one country (here country i) that decides over its contribution to climate protection. The remaining structure of the model continues unchanged. Solving the model through backward induction, it is straightforward to see that the rationale driving the preferred provision level of period $t+1$ is identical to the two country case. The only difference is that the preferred provision level $Q_{t+1}^i\left(\theta_i\right)$ automatically constitutes the country's equilibrium contribution in $t+1$.

Now turn to country i's optimal decision in period t, taking into account that $\left(x_{t+1}^i\right)^* = Q_{t+1}^i(\theta_i)$. Suppose that i's contribution in t is smaller than $Q_{t+1}^i\left(\bar{\theta}\right)$ which ensures a positive contribution in $t+1$ with strictly positive probability. Again, $\hat{\theta} = c_{t+1}/f'(x_t)$ denotes the critical valuation below which there will be no contribution in $t+1$. In the one-country case, country i's marginal expected payoff from increasing the contribution in t is equal to

$$\pi_i^{'}\left(x_t^i\right) = \int_0^{\hat{\theta}} \left(\theta^i f'\left(x_t^i\right) - c_t\right) d\Phi_i\left(\theta^i\right) + \int_{\hat{\theta}}^{\bar{\theta}} \left(c_{t+1} - c_t\right) d\Phi_A(\theta). \tag{4.16}$$

Let us compare this marginal payoff to the marginal payoff in the two-country case, as derived in (4.9). Similar to (4.9), the first term in (4.16) describes the expected payoff if there is no contribution in $t+1$ (because $\theta^i \leq \hat{\theta}$). This marginal payoff also emerges in the two-country case (the first term in (4.9)), but, there, only with the probability that j also has a valuation below the critical valuation ($\theta^j \leq \hat{\theta}$).

The second term in (4.16) represents the savings in marginal contribution cost. In the one-country case, these savings are realized whenever $\theta^i > \hat{\theta}$, while in the two-country case, this positive effect on a period t contribution also depends on whether or not $\theta^j < \theta^i$. In the two-country case, even if country i has a valuation above the critical valuation ($\theta^i > \hat{\theta}$), this does not necessarily imply that it has to pay the high marginal cost c_{t+1} because j will bear the contribution cost if $\theta^j > \theta^i$.

Thus, the two-country case identifies an additional negative effect on the marginal payoff which corresponds to the possibility to free-ride and is not present in the one-country case (the third term in (4.16)). In the two-country case, if it turns out that the other country has a higher valuation, having increased the contribution in t would have caused an unnecessary cost.

While the benefits from an early contribution in the two-country case are realized only with lower probability, the free-riding possibilities add a cost to contribution in period t that does not play a role in the case where there is only one country present. Consequently, the existence of another country and the nature of the public good problem lower a country's marginal payoff from increasing the period t contribution and shift the timing of the contribution towards a later period.[19]

4.5 Investments in technology and the timing of contributions

Now consider the effect of an exogenous investment in cost-reducing technology κ on countries' timing of the contributions to climate protection. Recall that the cost-reducing technology κ is defined such that an increase in κ decreases the marginal contribution cost for both countries over both time periods. More specifically, the cost-reducing technology is denoted by κ, where $\kappa \in [\kappa_0, \kappa_{\max}]$ and κ_0 denotes the initial technology in use. We do not model the investment game explicitly but analyze its effects on the equilibrium outcome as regards the timing of contributions. The results will directly clarify which country will have an incentive to invest in cost-reducing technology, provided that the cost of investing is sufficiently low compared to the benefit of investing.

Our analysis will mainly focus on situations where the irreversibility ratio c_t/c_{t+1} is strictly decreasing over the interval $[\kappa_0, \kappa_{\max}]$ of possible technology levels. This is the case, when an investment in cost-reducing technology relatively reduces the marginal contribution cost of period t more strongly than the marginal contribution cost of period $t+1$. Intuitively, this can be interpreted as the notion that innovations in cost-reducing technology made today are more suited to tackle climate protection, given today's information, and that these technologies might be less effective with

[19] One can argue that the inclusion of a second country exhibits the same free-riding rationale as derived in Admati and Perry (1991) and Fershtman and Nitzan (1991).

altered conditions at a later date. For example, powerplants are characterized by large sunk costs when investing in generation units. Their efficiency is highly sensitive to a changing regulatory framework, environment, and fuel prices and as such it is likely that investments in such technology relatively reduce the costs, given a certain regulatory framework, environment, and fuel prices, in the early period more efficiently than in the later period.

In the next two sections, we will first analyze how an investment in cost-reducing technology affects the provision level and, then, we will identify cases where such changes in the provision level lead to a change in the equilibrium outcome.

4.5.1 Categorical changes in the preferred period t contributions

In the following, we identify how investments in cost-reducing technology can effect a "categorical change" in the preferred provision level Q_t^i. We consider "categorical changes" to be changes in the preferred provision levels in period t which are linked with a change in the potential equilibrium reached. While marginal reductions in the contribution costs c_t and c_{t+1} always (weakly) increase total contributions, we focus on "categorical changes" that affect one country's (or both countries') optimal timing of the contributions, i.e., that affect whether or not a country will choose a strictly positive contribution already in period t and which type of early contribution is preferred. The marginal effects on (already positive) contribution levels are analyzed in Appendix B.2.

Proposition 4.2 *Suppose that the irreversibility ratio $\gamma(\kappa) := c_t(\kappa)/c_{t+1}(\kappa)$ is strictly decreasing in κ. Then, there are two country-specific thresholds*

$$\kappa_i^p := \gamma^{-1}\left(E\left(\Phi_j\left(\theta^i\right)\right)\right) \text{ and } \kappa_i^f := \gamma^{-1}\left(E\left(\theta^i\right)/\bar{\theta}\right)$$

such that the following holds for the preferred provision level in period t:

(i) *If $\kappa < \min\left\{\kappa_i^p, \kappa_i^f\right\}$, then country i prefers a provision $Q_t^i = 0$ in period t, $i = A, B$.*

(ii) *If $\kappa \geq \kappa_i^f$, then country i prefers a full provision $Q_t^i = (f')^{-1}\left(c_t/E\left(\theta^i\right)\right)$ in period t, $i = A, B$.*

(iii) *If $E\left(\theta^i\right)/\bar{\theta} < E\left(\Phi_j\left(\theta^i\right)\right)$, then $\kappa_i^p < \kappa_i^f$ and country i prefers a partial provision $Q_t^i \in \left(0, (f')^{-1}\left(c_t/E\left(\theta^i\right)\right)\right)$ for all $\kappa \in (\kappa_i^p, \kappa_i^f)$, $i = A, B$.*

Proof. Notice that the irreversibility ratio $\gamma(\kappa) \in [0,1]$ is a strictly decreasing continuous function in κ. Lemma 4.1 identifies the irreversibility thresholds which determine when a positive provision level is preferred. As $\left(E\left(\theta^i\right)/\bar{\theta}\right) \in [0,1]$ and $E\left(\Phi_j\left(\theta^i\right)\right) \in [0,1]$ and using the inverse function of $\gamma(\kappa)$, then there exist two country-specific thresholds which are defined by

$$\kappa_i^p := \gamma^{-1}\left(E\left(\Phi_j\left(\theta^i\right)\right)\right) \text{ and } \kappa_i^f := \gamma^{-1}\left(E\left(\theta^i\right)/\bar{\theta}\right).$$

Consider first the case (i) where $\kappa < \min\left\{\kappa_i^p, \kappa_i^f\right\}$.

This means that $c_t(\kappa)/c_{t+1}(\kappa) > \left(E\left(\theta^i\right)/\bar{\theta}\right)$ and $c_t(\kappa)/c_{t+1}(\kappa) \geq E\left(\Phi_j\left(\theta^i\right)\right)$ are fulfilled simultaneously and according to Lemma 4.1(ii)b), country i strictly prefers a provision level of $Q_t^i = 0$ in period t.

Now consider case (ii) where $\kappa \geq \kappa_i^f$. Given that $\gamma(\kappa)$ is a strictly decreasing function in κ, this corresponds to a scenario where $\gamma(\kappa) := c_t/c_{t+1} < \left(E\left(\theta^i\right)/\bar{\theta}\right)$. Using Lemma 4.1(i), country i prefers a full provision in period t.

The same rationale can be employed for case (iii). As c_t/c_{t+1} is strictly decreasing in κ, it follows that $\kappa_i^p < \kappa_i^f$ for $E\left(\theta^i\right)/\bar{\theta} > E\left(\Phi_j\left(\theta^i\right)\right)$. Thus, for $\kappa \in (\kappa_i^p, \kappa_i^f)$ the irreversibility thresholds lie between $E\left(\Phi_j\left(\theta^i\right)\right) > c_t/c_{t+1} > \left(E\left(\theta^i\right)/\bar{\theta}\right)$

and Lemma 4.1(ii)a) holds. This means that country i prefers a partial provision $Q_t^i \in \left(0, (f')^{-1}\left(c_t/E\left(\theta^i\right)\right)\right)$. Notice that, as shown in Lemma 4.1, when $E\left(\theta^i\right)/\bar{\theta} > E\left(\Phi_j\left(\theta^i\right)\right)$ and consequently $\kappa_i^p > \kappa_i^f$, then $E\left(\Phi_j\left(\theta^i\right)\right)$ does not influence the contribution decision, and country i prefers a full provision for all $\kappa > \kappa_i^f$. ■

Whether or not a country wants to contribute to the public good in period t already crucially depends on the relation of the irreversibility ratio to the country's expected valuation and its expected probability of having the higher valuation. As Lemma 4.1 has revealed, the relation of irreversibility ratio c_t/c_{t+1} to this expected probability $E\left(\Phi_j\left(\theta^i\right)\right)$ determines whether a country prefers a partial provision in t, and the relation of c_t/c_{t+1} to the expected to maximum valuation ratio, $E\left(\theta^i\right)/\bar{\theta}$, determines whether a country prefers a full provision of the public good in t. Thus, investments in technology will have an effect on the timing of the countries' contributions if they change the irreversibility ratio c_t/c_{t+1}. Proposition 4.2 identifies the country-specific technology thresholds under which such investments in technology shift from no contribution to a positive provision level and from a partial provision level to a full provision level. Notice that we have added the superscript f and p, for illustrational purposes, to signal the type of period t provision preferred by country i: a **p**artial provision in period t or a **f**ull provision in period t.

Sufficient for a shift of the preferred provision level towards an earlier provision is that the irreversibility ratio c_t/c_{t+1} is strictly decreasing over the interval $[\kappa_0, \kappa_{\max}]$ of possible technology levels. This is the case if

$$\left|\frac{\partial c_t}{\partial \kappa}\right| > \frac{c_t}{c_{t+1}}\left|\frac{\partial c_{t+1}}{\partial \kappa}\right|. \tag{4.17}$$

As $c_t/c_{t+1} < 1$, even for the case when $\left|\partial c_{t+1}/\partial \kappa\right| > \left|\partial c_t/\partial \kappa\right|$, the relative costs of irreversibility can be perceived to increase which strengthens the incentive for an early contribution. In other words, an absolute reduction of period $t+1$ marginal costs can be stronger than the absolute reduction of period t marginal costs.

For investments $\kappa_i \geq \kappa_i^f$, country i prefers a full provision in period t as the irreversibility ratio becomes smaller than $E\left(\theta^i\right)/\bar{\theta}$. For low investment levels, where $\kappa < \min\left\{\kappa_i^p, \kappa_i^f\right\}$, the irreversibility ratio remains high and it is a strictly dominant strategy for country i to wait until the uncertainty is resolved. For intermediate investment levels, where $\kappa \in (\kappa_i^p, \kappa_i^f)$ and due to the fact that $E\left(\theta^i\right)/\bar{\theta}$ can be smaller or larger than $E\left(\Phi_j\left(\theta^i\right)\right)$, we need to distinguish between two cases which are illustrated in Figure 4.1. If $E\left(\Phi_j\left(\theta^i\right)\right) \leq E\left(\theta^i\right)/\bar{\theta}$ then $\kappa_i^f \leq \kappa_i^p$. In this case, $E\left(\Phi_j\left(\theta^i\right)\right)$ and the corresponding technology threshold κ_i^p is not relevant for the positive contribution decision, as country i's preferred provision level in t will either be zero or, based on its expected valuation, the full amount $Q_t^i = (f')^{-1}\left(c_t/E\left(\theta^i\right)\right)$. For $\kappa < \kappa_i^f$, Lemma 4.1(ii)a) holds and country i prefers not to contribute in period t. For $\kappa \geq \kappa_i^f$, country i prefers a full provision already in period t.

If $E\left(\Phi_j\left(\theta^i\right)\right) > E\left(\theta^i\right)/\bar{\theta}$, then $\kappa_i^f > \kappa_i^p$. For $\kappa \leq \kappa_i^p$, country i prefers not to contribute in period t, as the relative cost of waiting are not too high. Intermediate investments in technology $\kappa \in (\kappa_i^p, \kappa_i^f)$ then lead to a scenario where only a partial provision in period t is optimal for i. In this case, a positive period $t+1$ contribution occurs with a positive probability. A further decrease in the irreversibility ratio, due to a larger investment in cost-reducing technology κ, shifts the optimal decision towards a provision of the public good in t that crowds out any possible contribution in $t+1$. Thus, for a $\kappa \geq \kappa_i^f$ technology level country i prefers a full provision in period t.

Hence, one can distinguish between two occasions which constitute a categorical change in the preferred contribution levels. The first of which is an increase in cost-reducing technology which changes a country's preferred provision in period t from zero to a positive amount; a "categorical change" in the *equilibrium contribution* can take place when each country has a dominant strategy of not contributing in period t at the initial technology level.

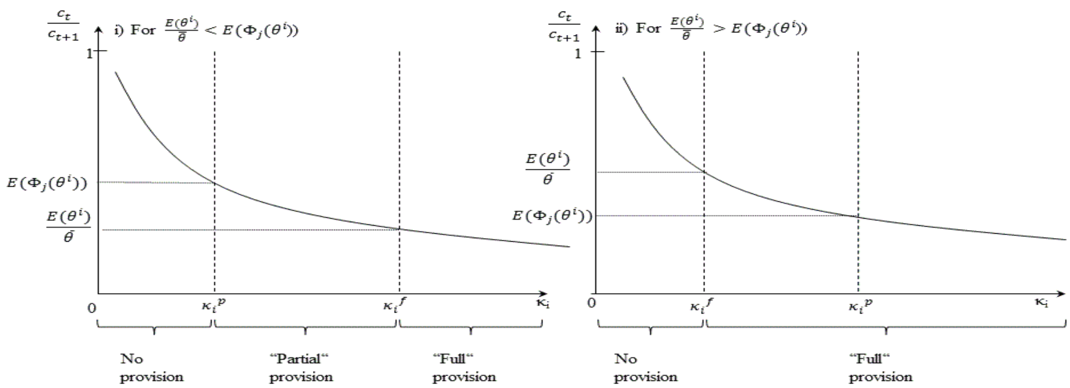

Figure 4.1: Categorical changes in the preferred provision level for country i with $i \in \{A, B\}$.

The second occasion is an investment in cost-reducing technology which changes countries' preferred provision levels in t from a partial provision to a full provision. In such a case, investments in technology can result in a situation where the contributions in t crowd out all future contributions in $t+1$; moreover, such investments in technology can have an impact on the determination of the country that, in equilibrium, has to pay the contribution cost of the early provision in t.

4.5.2 Technology sharing to free-ride

The assumption that all countries benefit from the cost reductions caused by investments in green technology adds an interesting layer to the analysis. Countries can choose a cost-reducing technology level that affects the equilibrium contributions such that the other country will bear the cost of an early provision of the public good. Specifically, countries can target a pre-determined technology range which allows one country to free-ride on the other country's contribution. We identify two cases where a free-riding opportunity exists: in a situation where otherwise no contributions take place in period t, and in a situation where, in the equilibrium without investments in

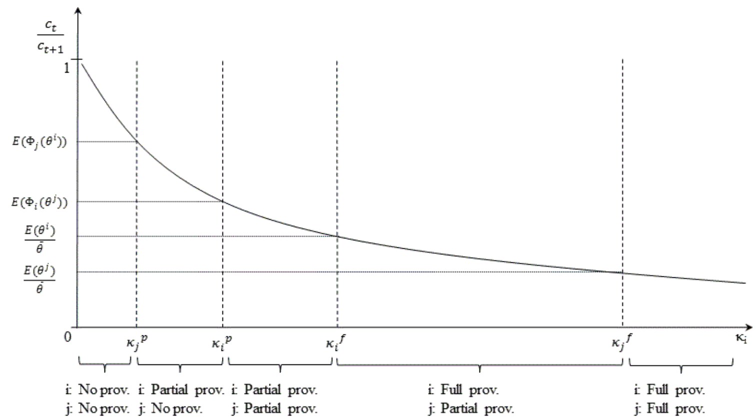

Figure 4.2: Categorical changes for the case where $E\left(\Phi_j\left(\theta^i\right)\right) > \left(E\left(\theta^i\right)/\bar{\theta}\right)$ is fulfilled for both countries.

technology, one country already contributes in period t. In this section, we derive the conditions for the existence of these "free-riding scenarios" by identifying the lowest technology threshold needed which ensures a shift from one equilibrium to another.

Given that, in our model, the country-specific valuations for climate protection can be asymmetrically distributed, it is clear that the thresholds κ_i^p and κ_i^f for $i = \{A, B\}$ will differ for each country. A merging of Figure 4.1 for the two countries, thus, allows us to identify the irreversibility ratios and corresponding technology ranges that are connected with the different equilibrium candidates introduced in Proposition 4.1. An example is illustrated in Figure 4.2.

Scenario 1: no contributions in period t. First, we consider the countries' incentive to invest in technology in a situation where, without cost-reducing technology, there would be no contributionto the public good in period t, but both countries prefer to delay their contributiona until period $t+1$. Lemma 4.1(ii) has revealed that this will be the equilibrium if

$$\frac{E\left(\theta^{i}\right)}{\bar{\theta}} < \frac{c_t\left(\kappa_0\right)}{c_{t+1}\left(\kappa_0\right)} \text{ and } E\left(\Phi_j\left(\theta^{i}\right)\right) \leq \frac{c_t\left(\kappa_0\right)}{c_{t+1}\left(\kappa_0\right)} \text{ for } i = A, B. \tag{4.18}$$

Proposition 4.3 *Suppose that $c_t\left(\kappa\right)/c_{t+1}\left(\kappa\right)$ is strictly decreasing in κ and*

$$\kappa_0 < \min\left\{\kappa_i^p, \kappa_i^f\right\} \text{ for } i = A, B$$

such that without investments in technology, equilibrium contributions in period t are zero. Define $i \in \{A, B\}$ and $j \neq i$ such that

$$\max\left\{E\left(\Phi_j\left(\theta^{i}\right)\right), \left(E\left(\theta^{i}\right)/\bar{\theta}\right)\right\} > \max\left\{E\left(\Phi_j\left(\theta^{i}\right)\right), \left(E\left(\theta^{i}\right)/\bar{\theta}\right)\right\}. \tag{4.19}$$

Then, for all investments in cost-reducing technology with

$$\kappa \in \left(\min\left\{\kappa_i^p, \kappa_i^f\right\}, \min\left\{\kappa_j^p, \kappa_j^f\right\}\right),$$

the equilibrium contributions in period t satisfy $\left(x_t^{i}\right)^* > 0$ and $\left(x_t^{j}\right)^* = 0$.

Proof. If $\kappa > \min\left\{\kappa_i^p, \kappa_i^f\right\}$, then i prefers at least a partial provision in t (i.e., $Q_t^i > 0$), while $\kappa < \min\left\{\kappa_j^p, \kappa_j^f\right\}$ implies that $Q_t^i = 0$. Since the cost ratio c_t/c_{t+1} is strictly decreasing and with $\gamma\left(\kappa\right) = c_t\left(\kappa\right)/c_{t+1}\left(\kappa\right)$,

$$\max\left\{E\left(\Phi_j\left(\theta^{i}\right)\right), \left(E\left(\theta^{i}\right)/\bar{\theta}\right)\right\} = \max\left\{\gamma\left(\kappa_i^p\right), \gamma\left(\kappa_i^f\right)\right\},$$

and (4.19) is equivalent to $\min\left\{\kappa_i^p, \kappa_i^f\right\} < \min\left\{\kappa_j^p, \kappa_j^f\right\}$. Hence, there is a non-empty interval for κ where $\left(x_t^{i}\right)^* > 0$ and $i \in \{A, B\}$ is defined such that (4.19) holds. ■

Proposition 4.3 addresses incentives to invest in cost-reducing technology in a situation where actually both countries prefer to delay their contribution to climate protection until period $t+1$. In this case, a targeted provision of cost-reducing technology κ by country j can raise country i's equilibrium contribution in period

t from zero up to a strictly positive amount, while country j free-rides. The intuition behind this incentive to invest in cost-reducing technology hinges on the fact that countries are willing to endure different levels of the irreversibility ratio c_t/c_{t+1} before they are willing to contribute in period t already. The early contribution of i strictly decreases the expected burden of contributing that both countries face in period $t+1$. Thus, there is a range $\left(\min\left\{\kappa_i^p, \kappa_i^f\right\}, \min\left\{\kappa_j^p, \kappa_j^f\right\}\right)$ of technology levels where the irreversibility ratio decreases for both countries, but the preferred provision level in t is raised only for one country from zero to a positive amount. Consequently, this opportunity to benefit from an early contribution of the other country exists for the country which needs a lower irreversibility ratio to start developing a positive preferred period t provision level. Depending of the constellation of $E\left(\Phi_j\left(\theta^i\right)\right)$ and $\left(E\left(\theta^i\right)/\bar{\theta}\right)$ of both countries, this will be the country that has the lower expected valuation or the lower probability of learning to have the highest valuation. Notice that it is unnecessary to distinguish between the type of positive contribution reached: country j benefits if i chooses a partial or a full provision of the public good in period t. Also, notice that for $\min\left\{\kappa_i^p, \kappa_i^f\right\} = \min\left\{\kappa_j^p, \kappa_j^f\right\}$, the interval that can achieve such a scenario is empty. The resulting scenario, where both country prefer a positive provision level in period t is analyzed in Scenario 2.

Scenario 2: positive equilibrium contribution in period t+1. Now consider a situation where, without investment in technology, the equilibrium contributions to the public good are such that in period t country j contributes a positive amount, while country i free-rides and contributes zero. Investments in technology, however, can cause a "categorical change" in the equilibrium and lead to the opposite scenario where, in equilibrium, the previously non-contributing country i is now contributing to climate protection.

Without investment in technology, $(x_t^i)^* = 0$ and $\left(x_t^j\right)^* > 0$ are assumed to hold.

This is fulfilled if

$$E\left(\theta^{i}\right)/\bar{\theta}<\frac{c_{t}\left(\kappa_{0}\right)}{c_{t+1}\left(\kappa_{0}\right)}\text{ and }E\left(\Phi_{j}\left(\theta^{i}\right)\right)\leq\frac{c_{t}\left(\kappa_{0}\right)}{c_{t+1}\left(\kappa_{0}\right)}\tag{4.20}$$

and

$$\max\left(E\left(\Phi_{i}\left(\theta^{j}\right)\right),\left(E\left(\theta^{j}\right)/\bar{\theta}\right)\right)>\frac{c_{t}\left(\kappa_{0}\right)}{c_{t+1}\left(\kappa_{0}\right)}\tag{4.21}$$

or, equivalently,

$$\min\left\{\kappa_{j}^{p},\kappa_{j}^{f}\right\}<\kappa_{0}<\min\left\{\kappa_{i}^{p},\kappa_{i}^{f}\right\},\ i\in\{A,B\},\ j\neq i.\tag{4.22}$$

Proposition 4.4 *Suppose that $c_t(\kappa)/c_{t+1}(\kappa)$ is strictly decreasing in κ and*

$$\min\left\{\kappa_{j}^{p},\kappa_{j}^{f}\right\}<\kappa_{0}<\min\left\{\kappa_{i}^{p},\kappa_{i}^{f}\right\},\ i\in\{A,B\},\ j\neq i,$$

such that without investment in technology, country j's equilibrium contribution in t is strictly positive. If

$$E\left(\theta^{i}\right)>E\left(\theta^{j}\right),$$

then for sufficiently high investments in cost-reducing technology, the equilibrium contributions in period t satisfy $(x_t^i)^*>0$ and $\left(x_t^j\right)^*=0$.

Proof. Note first that a technology level where i's equilibrium contribution in t is strictly positive can only exist if $\kappa_j^f\geq\min\left\{\kappa_i^p,\kappa_i^f\right\}$. To see why, suppose that $\kappa_j^f<\min\left\{\kappa_i^p,\kappa_i^f\right\}$. Then, for all κ where $Q_t^i>0$ (i.e., $\kappa\geq\min\left\{\kappa_i^p,\kappa_i^f\right\}$), j prefers a full provision of the public good in t; moreover, $Q_t^j>Q_t^i$ because $\kappa_j^f<\kappa_i^f$ is equivalent to $E\left(\theta^j\right)>E\left(\theta^i\right)$. But then, i's equilibrium contribution can never be strictly positive. The condition $\kappa_j^f\geq\min\left\{\kappa_i^p,\kappa_i^f\right\}$ directly implies that $\kappa_j^p<\kappa_i^p$ or $E\left(\Phi_j\left(\theta^i\right)\right)<E\left(\Phi_i\left(\theta^j\right)\right)$, that is, even if i has the higher *expected valuation*, i's *expected probability of having the lower valuation* than j must be higher, too. Hence,

it has to hold that $\kappa_j^f \geq \min\left\{\kappa_i^p, \kappa_i^f\right\}$ (which is guaranteed by the assumption of $E\left(\theta^i\right) > E\left(\theta^j\right)$). Now consider the case where $E\left(\theta^i\right) > E\left(\theta^j\right)$. This implies that $\kappa_j^f > \kappa_i^f$. Moreover, it implies that $(f')^{-1}\left(c_t/E\left(\theta^i\right)\right) > (f')^{-1}\left(c_t/E\left(\theta^j\right)\right)$, i.e., the full provision level preferred by i is strictly higher than the full provision level that j prefers. Consequently, if $\kappa \in \left[\kappa_i^f, \kappa_{\max}\right]$, then Q_t^i must be strictly higher than Q_t^j (independently of whether j prefers a full or a partial provision in t), and hence in equilibrium,

$$\left(x_t^i\right)^* = (f')^{-1}\left(c_t/E\left(\theta^i\right)\right). \tag{4.23}$$

If $E\left(\theta^i\right)/\bar{\theta} < E\left(\Phi_j\left(\theta^i\right)\right)$, then $\kappa_i^p < \kappa_i^f$ and there exists $\delta > 0$ sufficiently small such that for all $\kappa \in \left[\kappa_i^f - \delta, \kappa_{\max}\right]$, $Q_t^i > Q_t^j$ and $\left(x_t^i\right)^* > 0$, that is, the investment in technology only needs to bring i's preferred provision level sufficiently close to a full provision in t.

Finally, note that $E\left(\theta^i\right) > E\left(\theta^j\right)$ is sufficient but not necessary for obtaining the result on the "categorical" change in the equilibrium. If $\kappa_j^p < \kappa_0 < \kappa_i^p < \kappa_i^f < \kappa_j^f$, then $E\left(\theta^i\right) < E\left(\theta^j\right)$, and for $\kappa \in \left[\kappa_j^p, \kappa_i^f\right)$, both countries i and j prefer a partial provision of the public good in t. Even if $E\left(\theta^i\right) < E\left(\theta^j\right)$, condition (4.14) can, depending on the shape of the distribution functions, be positive which implies that $Q_t^i > Q_t^j$ and $\left(x_t^i\right)^* = Q_t^i > 0$. ■

The mechanism driving this proposition is straightforward: As above, an investment in cost-reducing technology that affects both countries can be used to alter the irreversibility ratio and so, illicit a different optimal response in the public good game. Country j might initially prefer a partial contribution in period t while i prefers to wait, but investments in technology can change the trade-off that both countries face. If country i has the higher expected valuation, this shifts the burden of contributing to country i, provided that both countries prefer an early contribution (based on their expected valuation).

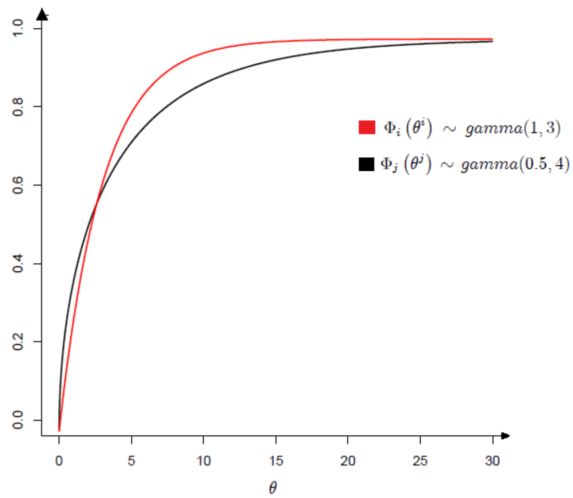

Figure 4.3: An example of two cumulative distribution functions, where the conditions for free-riding scenario 2 are fulfilled. Here, $E(\theta^i) = 3$ and $E(\theta^j) = 2$, while $E(\Phi_j(\theta^i)) = 0.44$ and $E(\Phi_i(\theta^j)) = 0.56$.

In this second scenario, we capture a situation where the country that initially expects a higher potential saving from an early contribution is actually the country with the lower expected valuation for the public good. However, when a country chooses a partial contribution in period t, it trades off the marginal benefit from an early contribution (depending on the expected valuation) and the expected marginal contribution cost in $t+1$ which depend on the probability that it turns out it has the higher valuation. As long as the country differences in the expected valuation for climate protection and the expected probability of having the higher valuation do not go in the same direction, a targeted reduction of the irreversibility rate via cost-reducing technology κ can cause a "categorical change" in the equilibrium contributions. An example for such probability distributions where $E(\theta^j) < E(\theta^i)$ but $E(\Phi_i(\theta^j)) > E(\Phi_j(\theta^i))$ is illustrated in Figure *4.3* using gamma distributions.

4.6 Conclusion

In this chapter we have shown how the timing of the contribution to climate protection is affected by uncertainty, irreversibility, and the possibility to free ride. Uncertainty about the country-specific benefit of climate protection creates an incentive to delay the contribution decision towards a later contribution date where the uncertainty is resolved, while the irreversibility of damages makes an earlier contribution more desirable. Furthermore, the fact that mitigation efforts are an international public good shifts the contribution more strongly towards a later contribution date. Specifically, in anticipation of a free-riding possibility, countries prefer to shift their contribution to a later date. Investments in cost-reducing technology have an important impact on the trade-off that countries face and, hence, on the timing of the contributions.

In the game of private contributions to the public good with potentially asymmetric but known valuations for climate protection, the country with the highest valuation for climate protection will face the burden of contributing. The fact that countries have different expected probabilities of having the higher valuation in the later period of the game makes them react differently to changes in the degree of irreversibility following investments in cost-reducing technology. The degree of irreversibility refers to the cost ratio of early and late contributions that are necessary to provide a marginal unit of the public good, and the expected probability of having the higher valuation in the later period can be interpreted as the potential saving from an early contribution. Thus the country, which expects a higher potential saving from early contribution, will have a stronger incentive to contribute early and will first react to changes in the irreversibility rate. Consequently, a targeted investment in cost-reducing technology can achieve a new equilibrium where one country can free-ride on the early contribution of the other country. We have identified two such scenarios, where such a potential for free-riding exists and investments in technology affect the countries' timing of contributions. In the first scenario, the current degree of irreversibility would lead to a situation where the countries have a dominant strategy of not contributing before the resolve of the uncertainty, and in the second scenario, one country j would contribute already in period t. In both cases, an investment in cost-reducing technology by country j, which changes the irreversibility rate, can lead to a situation where the other country i prefers an early provision of the public good at a quantity which is higher than what country j prefers, and thus in equilibrium country i free rides on country j's early contribution. Notice that different assumptions on the type of technology provided and hence on the effect of cost-reducing technology on the irreversibility rate can create an opposite situation where investments in technology that most likely lead to much lower *future* contribution cost shift the equilibrium contributions towards a later date. In this model, we have chosen investments in green technologies that already affect current contribution costs and, thus, modelling the argument that, by strengthening the other countries' incentive to contribute early, providing such technologies may be beneficial, due to the public good nature of climate protection.

In our model framework, investments in technology can achieve a discrete jump in the countries' equilibrium contributions and hence a discrete change in the investing country's payoff. Moreover, in the two scenarios considered, the cost-reducing technology strictly increases the quantity of the public good provided early and hence the overall amount contributed to climate protection: First, for a given valuation, optimal early contributions are strictly higher than late contributions because of the lower contribution cost, and second, early contributions also occur in situations where a country's valuation turns out to be low. (If the valuation turns out to be high, the country can still increase its contribution in the late period.) Both effects make the equilibrium quantity of the public good higher the higher the provision in the early period. From a welfare perspective, such increases in the total quantity provided are desirable, due to the underprovision of the public good in the equilibrium of private contributions. Since the countries' marginal contribution cost within a given period are assumed to be the same and our analysis abstracts from income effects, it does not matter for welfare which country contributes in equilibrium. Even if, ex post, a country has over-contributed from an individual perspective because its early contribution has been higher than what would have been optimal based on the true valuation, such overcontributions from an individual perspective are typically welfare-increasing, due to the underprovision of the public good. A complete welfare analysis would of course also have to take into account the cost of providing cost-reducing technologies, but the shift of the countries' equilibrium contributions towards early contributions will typically have a positive effect on welfare.

Appendix A

Appendix to Chapter 3

A.1 Data Appendix

Tax Haven list.

Source: Hines and Rice (1994) and OECD (2000).

Andorra, Anguilla, Antigua and Barbuda, Aruba*, Bahamas, Bahrain, Barbados, Belize, Bermuda, British Virgin Islands, Cayman Islands, Cook Islands, Cyprus, Dominica, Gibraltar, Grenada, Guernsey, Hong Kong**, Ireland**, Isle of Man, Jersey, Jordan*, Lebanon*, Liberia, Liechtenstein, Luxembourg**, Macao**, Maldives, Malta, Marshall Islands, Mauritius*, Monaco, Montserrat, Nauru*, Netherlands Antilles, Niue*, Panama, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Samoa*, San Marino*, Seychelles*, Singapore**, Switzerland**, Tonga*, Turks and Caicos Islands, Vanuatu, Virgin Islands (U.S).*

* : Appears only in the OECD (2000) list.

**: Appears only in the Hines and Rice (1994) list.

OECD countries.

Source: OECD.

Available at www.oecd.org

Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Italy, Japan, Korea, Mexico, Netherlads, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Turkey, United Kingdom, United States.

Agreement form.

Source: International Bureau of Fiscal Documentation Database and OECD Global Forum for Transparency and Exchange of Information for Tax Purposes.

Available at http://eoi-tax.org/

Bilateral categorical variable indicating 0 if no agreement has been signed between a tax haven and a OECD country, 1 if a DTC which meets the international standards and has the strong information exchange article (Paragraph 4 and 5 of Article 26) and 2 if a TIEA has been signed.

GDP.

Source: the World Bank's Development Indicators (WDI).

Available at http://data.worldbank.org/

Data are in current U.S. dollars, for 2006. Dollar figures for GDP are converted from domestic currencies using single year official exchange rates. For a few countries where the official exchange rate does not reflect the rate effectively applied to actual foreign exchange transactions, an alternative conversion factor is used. For countries and territories for which GDP data are missing in WDI, Data from the UN's National Accounts Main Aggregates Database is used http://data.un.org/

Governance Index.

Source: Kaufmann, Kraay and Mastruzzi (2005).

This index is obtained by the taking the unweighted mean of the 6 available governance measures constructed by Kaufmann et al. (2005) for the year 2009. It is a continuous variable over the approximate interval (-2.5, 2.5), normalized to have mean 0 and standard deviation 1, with higher values indicating better governance. Data is available for only 42 tax haven jurisdictions.

Official Development Aid Eligibility.

Source: OECD Development Cooperation Directorate.

Indicator variable (=1 if a country is on the 2006 DAC List of ODA Recipients).The DAC List of ODA Recipients shows all countries and territories eligible to receive official development assistance (ODA). These consist of all low and middle income countries based on gross national income (GNI) per capita as published by the World Bank, with the exception of G8 members, EU members, and countries with a firm date for entry into the EU. The list also includes all of the Least Developed Countries (LDCs) as defined by the United Nations (UN).

Foreign Direct Investment, net outflow (% of GDP).

Source: the World Bank's Development Indicators (WDI)

Available at http://data.worldbank.org/

This variable shows net outflows of investment from the reporting economy to the rest of the world and is divided by GDP for the year 2006. Foreign direct investment are the net inflows of investment to acquire a lasting management interest (10 percent or more of voting stock) in an enterprise operating in an economy other than that of the investor. It is the sum of equity capital, reinvestment of earnings, other long-term capital, and short-term capital as shown in the balance of payments.

Difference in GDP per capita.

Source: the World Bank's Development Indicators (WDI).

Available at http://data.worldbank.org/

Variable is constructed using the absolute value of the difference between a given country pair's GDP per capita.

Data are in current U.S. dollars, for 2006. Dollar figures for GDP are converted from domestic currencies using single year official exchange rates. For a few countries where the official exchange rate does not reflect the rate effectively applied to actual foreign exchange transactions, an alternative conversion factor is used. For countries and territories for which GDP per capita data are missing in WDI, Data from the UN's National Accounts Main Aggregates Database is used http://data.un.org/

Bilateral Portfolio Outflow.

Source: IMF's Coordinated Portfolio Investment Survey (CPIS).

Available at http://www.imf.org/external/np/sta/pi/cpis.htm.

Geographic breakdown of total portfolio investment assets from OECD countries to tax havens in current million U.S dollars, for 2006.

Bilateral FDI.

Source: OECD International direct investment database.

Available at http://stats.oecd.org.

The sum of inward and outward foreign direct investment flows from OECD countries to tax havens. Data is measured in millions U.S dollars, for year 2006.

Treaty before 1998.

Source: International Bureau of Fiscal Documentation Database.

Indicator variable (=1 if a country pair had a tax treaty in force before 1998).

Distance.

Source: GEODist Database (CEPII) available at http://www.cepii.fr.

Variable measures simple distances in km which uses the latitudes and longitudes of the most important cities/agglomerations.

Common language.

Source: GEODist Database (CEPII) available at http://www.cepii.fr.

Indicator variable (=1 if more than 9% of population of each country pair speak the same language).

A.2 Summary Statistics

Table A.1: Summary Statistics

Unilateral Variable	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**
ODA Eligibility	76	0.342105	0.4775669	0	1
World Goverance Index Average	69	0.78164	0.6446449	-0.8911266	1.81754
FDI net outflow (%GDP)	61	1.95E+10	4.15E+10	-7.E+09	2.E+11
GDP	76	5.34E+11	1.67E+12	2.E+07	1.E+13
GDP per capita	76	27704.07	25229.52	185	132234
Bilateral Variable	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**
Difference in GDP per capita	1323	25589.26	21243.53	71	124547
Bilateral Portfolio Outflow	942	7637.43	38508.35	-20	543887
Bilateral FDI	848	1563.651	12508	-4591.076	214303
Treaty before 1998	1323	0.139834	0.346	0	1
Distance	1323	4243752	31262	7932	9985533
Common Language	1323	0.270597	0.44443	0	1
Common Savings Tax Directive	1323	0.256991	0.43714	0	1

Table A.2: Haven DTCs And TIEAs signed

Tax Haven	No Agreement	DTC	TIEA	Tax Haven	No Agreement	DTC	TIEA
Andorra	15	0	12	Luxembourg	10	17	0
Anguila	13	0	14	Macao	21	0	6
Antigua & Barbuda	14	1	12	Maldives	27	0	0
Aruba	18	3	6	Malta	21	6	0
Bahamas	9	0	18	Marshall Islands	18	2	7
Bahrain	14	8	5	Mauritius	23	3	1
Barbados	19	7	1	Monaco	15	1	11
Belize	16	1	10	Montserrat	17	1	9
Bermuda	10	7	10	Nauru	27	0	0
British Virgin Islands	13	7	7	Netherlands Antilles	14	4	9
Cayman Islands	11	5	11	Niue	27	0	0
Cook Islands	15	1	11	Panama	19	7	1
Cyprus	26	1	0	St. Kitt & Nevis	13	1	13
Dominica	13	0	14	St. Lucia	15	0	12
Gibraltar	12	0	15	St. Vincent & Grenadines	13	0	14
Grenada	15	1	11	Samoa	19	2	6
Guernsey	10	7	10	San Marino	11	4	12
Hong Kong	17	10	0	Seychelles	25	2	0
Ireland	24	3	0	Singapore	14	13	0
Isle of Man	8	9	10	Switzerland	15	12	0
Jersey	10	9	8	Tonga	27	0	0
Jordan	27	0	0	Turks & Caicos Islands	14	0	13
Lebanon	27	0	0	Vanuatu	19	0	8
Liberia	23	0	4	Virgin Islands (U.S.)	27	0	0
Liechtenstein	15	0	12	Average Haven	17.24	3.16	6.59

Appendix B

Appendix to Chapter 4

B.1 Proof of Lemma 4.1

By an envelope theorem, $\pi_i'\left(x_t^i, \hat{\theta}\left(x_i^t\right)\right) = \partial\pi_i/\partial x_i^t$, which yields

$$\pi_i'\left(x_t^i\right) = \begin{cases} \int_{\hat{\theta}}^{\bar{\theta}} \Phi_j\left(\theta^i\right) c_{t+1} d\Phi_i\left(\theta^i\right) \\ + \int_0^{\hat{\theta}} \int_0^{\hat{\theta}} \theta^i f'\left(X_t\right) d\Phi_j\left(\theta^j\right) d\Phi_i\left(\theta^i\right) - c_t & \text{if} \quad 0 \leq X_t < Q_{t+1}\left(\bar{\theta}\right) \\ E\left(\theta^i\right) f'\left(X_t\right) - c_t & \text{if} \quad X_t \geq Q_{t+1}\left(\bar{\theta}\right) \end{cases}$$

where $\hat{\theta} = c_{t+1}/f'\left(X_t\right)$. Moreover,

$$\pi_i''\left(x_t^i\right) = \begin{cases} \left[\Phi_j\left(\hat{\theta}\right) - \hat{\theta}\Phi_j'\left(\hat{\theta}\right)\right] \int_0^{\hat{\theta}} \theta^i f''\left(X_t\right) d\Phi_i\left(\theta^i\right) & \text{if} \quad 0 \leq X_t < Q_{t+1}\left(\bar{\theta}\right) \\ E\left(\theta^i\right) f''\left(X_t\right) & \text{if} \quad X_t \geq Q_{t+1}\left(\bar{\theta}\right) \end{cases}.$$

Hence, if Assumption 1 holds, then $\pi_i''\left(x_t^i\right) \leq 0$ for all X_t.

Case (i): Suppose $\left(E\left(\theta^i\right)/\bar{\theta}\right) \geq \frac{c_t}{c_{t+1}}$. This implies that

$$\begin{aligned} \pi_i'\left(Q_{t+1}^i\left(\bar{\theta}\right)\right) &= E\left(\theta^A\right) f'\left(Q_{t+1}^A\left(\bar{\theta}\right)\right) - c_t \\ &= E\left(\theta^A\right) f'\left(\left(f'\right)^{-1}\left(c_{t+1}/\bar{\theta}\right)\right) - c_t > 0. \end{aligned}$$

and $Q_t^i \geq Q_{t+1}\left(\bar{\theta}\right)$.

Hence, $\pi'_A\left(Q_t^i\right) = 0$ is uniquely solved for $\left(Q_t^i\right)^* = \left(f'\right)^{-1}\left(c_t/E\left(\theta^i\right)\right)$. Since $Q_t^i \geq Q_{t+1}\left(\bar{\theta}\right)$, there will be no contribution in $t+1$.

Case (ii):$\left(E\left(\theta^i\right)/\bar{\theta}\right) < \frac{c_t}{c_{t+1}}\bar{\theta}$. This implies that

$$\begin{aligned}\pi'_A\left(Q_{t+1}^i\left(\bar{\theta}\right)\right) &= E\left(\theta^i\right)f'\left(Q_{t+1}^i\left(\bar{\theta}\right)\right) - c_t \\ &= E\left(\theta^i\right)f'\left(\left(f'\right)^{-1}\left(c_{t+1}/\bar{\theta}\right)\right) - c_t < 0.\end{aligned}$$

Hence, $Q_t^i < Q_{t+1}\left(\bar{\theta}\right)$. In turn, since $Q_{t+1}\left(\bar{\theta}\right)$ is the highest type's preferred contribution level in $t+1$, there is strictly positive probability that there will be a contribution in $t+1$.

Thus,

$$\pi'_i\left(0\right) = \int_0^{\bar{\theta}} \Phi_j\left(\theta^i\right)c_{t+1}d\Phi_i\left(\theta^i\right) - c_t > 0$$

is sufficient for $Q_t^i > 0$ (part (ii)b).

If instead either (1) $\pi'_i\left(0\right) < 0$ or (2) $\pi'_i\left(0\right) = 0$ and $\pi''_i\left(0\right) < 0$, then $Q_t^i = 0$ (part (ii)a). If, however, $\pi'_i\left(0\right) = 0$ and Assumption 1 holds with equality for $\theta \in [0, \theta']$, $\theta' > 0$, then $\pi'_i\left(x\right) = 0$ for all $x \in [0, Q_{t+1}\left(\theta'\right)]$, and i is indifferent between all period *t contribution levels* $Q_t^i \in [0, Q_{t+1}\left(\theta'\right)]$. (Note that this does not necessarily imply that i is indifferent between all contributions $x_t^i \in [0, Q_{t+1}\left(\theta'\right)]$, but $x_t^i = 0$ is at least weakly preferred to all contributions x_t^i.) To include this special case in part (i), we assume that in this latter case $Q_t^i = 0$.

B.2 Effect of technology on (positive) contribution levels

An analysis of the effect of a cost-reducing technology κ on the optimal contribution levels concentrates on an initial positive preferred contribution level.

Consider the effect of a marginal improvement of technology κ in the two-country scenario. Let $i, j = A, B$ and $i \neq j$ and suppose that $Q_t^i > 0$, then a marginal increase in cost-reducing technology κ strictly increases Q_t^i if

$$\left|\frac{\partial c_t}{\partial \kappa}\right| > \left(\int_{\hat{\theta}}^{\bar{\theta}} \left(\Phi_j\left(\theta^i\right)\right) d\Phi_i\left(\theta^i\right) + \Phi_j'\left(\hat{\theta}\right) \Phi_i\left(\hat{\theta}\right) E\left(\theta^i | \theta^i \leq \hat{\theta}\right)\right) \left|\frac{\partial c_{t+1}}{\partial \kappa}\right|. \quad \text{(B.1)}$$

Proof.

Consider first the case of $\left(E\left(\theta^i\right)/\bar{\theta}\right) \geq (c_t/c_{t+1})$. Here, $Q_t^i = (f')^{-1}\left(c_t/\left(E\left(\theta^i\right)\right)\right)$ and

$$\frac{\partial}{\partial \kappa} Q_t^i = \frac{1}{E\left(\theta^i\right) f''\left(Q_t^i\right)} \frac{\partial c_t}{\partial \kappa} > 0$$

if and only if $\partial c_t / \partial \kappa < 0$, which holds by assumption.

Second, if $\left(E\left(\theta^i\right)/\bar{\theta}\right) < (c_t/c_{t+1})$, then Q_t^i is determined as in Lemma 4.1(i). Totally differentiating yields

$$\frac{\partial Q_t^i}{\partial \kappa} = -\frac{\frac{\partial c_t}{\partial \kappa} - \left(\int_{\hat{\theta}}^{\bar{\theta}} \left(\Phi_j\left(\theta^i\right)\right) d\Phi_i\left(\theta^i\right) + \Phi_j'\left(\hat{\theta}\right) \Phi_i\left(\hat{\theta}\right) E\left(\theta^i | \theta^i \leq \hat{\theta}\right)\right) \frac{\partial c_{t+1}}{\partial \kappa}}{\pi_i''\left(Q_t^i\right)} \quad \text{(B.2)}$$

and hence (B.1) is necessary and sufficient for $\partial\left(Q_t^i\right)/\partial \kappa > 0$ if $\left(E\left(\theta^i\right)/\bar{\theta}\right) < (c_t/c_{t+1})$.

Hence, (B.1) is sufficient for $\partial\left(Q_t^i\right)/\partial \kappa > 0$. ■

Moving on to the contribution level decision in period $t+1$. Differentiating the expected optimal contribution in t+1 with respect to κ yields

$$\frac{\partial E\left(\left(x_{t+1}^{i}\right)^{*}\right)}{\partial\kappa}=\int_{\hat{\theta}}^{\bar{\theta}}\int_{0}^{\theta i}\left(\left(\frac{1}{\theta^{i}f''\left(f'^{-1}\left(\frac{c_{t+1}}{\theta^{i}}\right)\right)}\frac{\partial c_{t+1}}{\partial\kappa}\right)-\frac{\partial X_{t}^{*}}{\partial\kappa}\right)d\Phi_{j}\left(\theta^{j}\right)d\Phi_{i}\left(\theta^{i}\right),$$

where a decrease in marginal contribution costs c_{t+1} through an increase in κ is fully passed on to the optimal contribution level but where an increase in κ that first affected the equilibrium contributions X_t^* in period t crowds out such contributions. Consequently, the effect of a marginal increase in κ on the expected contribution in period $t+1$ is ambiguous.

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