Does Endogenous Timing Matter in Implementing Partial Tax Harmonization? *

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Abstract

The endogenous timing of moves is analyzed in a repeated game setting of capital tax competition, where a subgroup of countries implementing partial tax harmonization and outside countries choose whether to set capital taxes sequentially or simultaneously. It is shown that the simultaneous-move outcome prevails in every stage game of the infinitely repeated tax-competition game as its subgame perfect Nash equilibrium (SPNE) if a tax-union consists of similar countries, whereas both the simultaneous-move and (Stackelberg) sequential-move outcomes can be sustained as SPNEs when a tax-union consists of dissimilar countries. This makes a sharp contrast with the finding of Ogawa (2013) in which when asymmetric countries in terms of productivity have opposite incentives towards the terms of trade in order to manipulate the price of capital in their favor, there exists only a simultaneous-move Nash equilibrium in his two-stage game. This difference arises from the fact that infinite repetition is able to support a wider range of behavior that is not a Nash equilibrium of the one-shot stage game of the repeated tax-competition game, such as a Stackelberg follower’s strategy.

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1 Introduction

This paper examines under what conditions partial tax coordination (i.e., tax coordination implemented by a subset of the existing countries) is sustained in a repeated tax-competition model in the presence of endogenous timing in the orders of plays. The coordination of tax policies among sovereign jurisdictions has often been considered as a remedy against inefficiently low taxes on mobile tax bases or production inefficiency induced by asymmetric tax rates in the literature on tax competition. Although tax coordination among all the countries in the economy is desirable, generally, it is difficult to achieve full tax coordination among all existing countries because some countries may prefer a lower tax status for commercial reasons (i.e., the so-called tax haven) and because the differences in social, cultural, and historical factors or economic fundamentals such as endowments and technologies may prevent the countries from accepting a common tax rate. Therefore, partial tax harmonization, rather than global or full tax harmonization, is politically more acceptable, and thus one could be compelled to resort to partial tax coordination.

Various papers have studied partial tax harmonization from different perspectives (see, e.g., Keen and Konrad, 2013 for a useful survey). In particular, there are substantial literatures to examine how the formation of a partial tax union which harmonizes capital taxation affects the welfare of countries inside and outside a tax union. Konrad and Schjelderup (1999) demonstrate that in the standard static tax-competition framework with symmetric countries, based on the assumption of strategic complementarity between the tax rates of a tax union and outside countries, partial harmonization can improve not only the welfare of the union but also that of the outside countries. Bucovetsky (2009) considers an economy consisting of heterogenous population-sized jurisdictions and presents a sufficient condition under which the grand coalition Pareto-dominates all other coalition structure. Vrijburg (2009) sets up a three-country model with heterogenous population size, and shows that partial harmonization unambiguously increases welfare for outside countries, but the welfare of inside countries might either increase or decrease, although their coordinated taxes unambiguously increase. More recently, Vrijburg and de Mooij (2010) compare between the case of fully non-cooperative Nash
competition and the case where a subset of countries that implement partial tax harmonization behaves as a Stackelberg leader in the same three-country model, and shows that when the tax rates of a larger outside country and a tax union consisting of two smaller countries are strategic substitutes, partial harmonization increases the welfare of the outside country and decreases the welfare of the tax union under Nash competition, and vice versa under Stackelberg competition. This line of research agenda would provide one possible answer to the question as to whether or not the countries such as the ECA (Enhance Cooperation Agreement) in the EU or the EU in the world economy have a motivation to form a coalition group of countries which implements tax harmonization.

The analysis of Vrijburg and de Mooij (2010) is not only quite interesting from a theoretical point of view, but also the first attempt is to introduce the Stackelberg competition in the literature on tax coordination among a subset of countries, since most studies have exclusively employed simultaneous tax competition between a tax union and the rest of individual countries. The sequential-move game has been quite frequently used in the field of international policy coordination such as international environmental agreements (e.g., Kyoto protocol). Indeed, the literature on self-forcing IEAs examines both of the cases where all countries (signatories and non-signatories) make their decisions simultaneously (Carraro and Siniscalco 1993), and where the countries that have ratified the IEAs (signatories) act as a leader, whose decisions proceed the decision of the countries that remain outside the IEA (Barrett 1994, Rubio and Ulph 2006, Diamantoudi and Sartzetakis 2006). These two different timing models not only have become something of a workhouse tool to study IEAs, but also offer significantly important policy implications for implementing a stable IEA. Given this background, it is quite natural and especially relevant to investigate a tax competition model in which a tax union behaves as a Stackelberg leader or follower. Nevertheless, there is a usual criticism of Stackelberg equilibrium in that the order of moves of the players is exogenously given ex-ante. The present paper is to incorporate an endogenous determination of the timing of moves between a tax union and outside countries in the setting of repeated tax-competition games.

Our research is also closely related to the recent contribution of Kempf and Rota-Graziosi
(2010) which questions the assumption that the governments compete for mobile capital in a simultaneous-move Nash equilibrium in which competing governments simultaneously and independently select their tax rates, and shows that Stackelberg equilibria are subgame perfect Nash equilibria (hereafter, SPNE’s) in a two-stage timing game involving a pre-play stage in which the governments commit themselves to move early or late before they choose their capital tax rates, while simultaneous-move Nash equilibria are not commitment robust (i.e., not SPNEs). More recently, Ogawa (2013) demonstrates that if capital is owned by the residents of the countries, the only simultaneous-move Nash equilibrium emerges as a SPNE of the above two-stage game. Although those authors did not consider the interaction between tax coalition groups and outside countries, the extension we consider could be not only justified by the above-mentioned literature on IEAs, but also the fact that the timing of decision making is an essential strategic variable pertaining to competing governments that affects the consequences of fiscal competition involving a coalition group of countries which harmonizes their fiscal policies.

The purpose of the present paper is to investigate the tax competition between a tax union (such as the ECA in the EU or the EU in the world economy) which implements tax harmonization and the rest of individual countries. The noteworthy feature of the present analysis is to employ a heterogenous three-country version of the repeated tax-competition model developed by Itaya et al. (2015). The repeated model would be a more relevant and satisfactory workhouse to explain voluntary and self-enforcing cooperation in tax competition [see, e.g., Cardarelli et al. (2002), Catenaro and Vidal (2006), and Itaya et al. (2008, 2015) in more details]. In particular, it should be stressed the fact that national tax authorities always have a strong incentive to unilaterally deviate from even a Pareto-improving coordinated tax rate in the hope of reaping gains such as more tax revenues or higher welfare levels; hence, the countries generally end up in failure in implementing such implicit collusion or an explicit agreement for tax coordination without supranational agency that could enforce it. The maintenance of collusive agreements, explicitly or implicitly, needs repeated interaction that allows union-members to punish a deviator from an implicit agreement or a tax union in the future. Another notable feature of our model is to allow for the pre-play (or communication)
stage of the subsequent repeated tax-competition game in order to *endogenously* determine the order of moves of a tax union and an outside country. More precisely, the timing of moves in every stage game of the repeated tax-competition game will be endogenously determined at its outset.

This paper demonstrates the following. First, the capital-exporting (-importing) tax union is willing to raise (lower) the price of capital to increase (decrease) the income (payment) from capital trade. Their opposed incentives to manipulate the price of capital in its favor result in the simultaneous-move equilibrium of every stage game of the repeated tax-competition game. In other words, the simultaneous-move outcome prevails in every stage game of the repeated tax-competition game as its SPNE if a tax union consists of *similar* countries. Secondly, both the Stackelberg sequential-move and simultaneous-move outcomes can be sustained as a SPNE of every stage game when a tax-union consists of *dissimilar* countries. The reason for this difference is that the tax union comprised of *dissimilar* countries is willing to choose a *moderate* common tax rate relative to that in the simultaneous-move equilibrium, because it has to take care of the well-being of a disadvantaged partner in order to sustain the tax union. Thirdly, the Stackelberg sequential-move equilibrium can be sustained as a SPNE of the repeated tax-competition game in a wider range of productivity difference between member countries compared to the simultaneous-move equilibrium, because the *moderate* common tax rate set by the tax union ameliorates the loss of a disadvantaged partner, thereby enlarging the degree of productivity asymmetry between member countries which allows for the coexistence of the two equilibria.

The remainder of the paper is organized as follows. Section 2 presents an analytical model and characterizes its one-shot Nash solution. Section 3 investigates the equilibrium outcomes when a tax union implementing partial tax harmonization and an outside country move simultaneously, when a tax union behaves as the Stackelberg leader, or when it behaves as the Stackelberg follower. In section 4, we investigate the likelihood of sustaining tax harmonization among a subset of countries in a repeated tax-competition game. Section 5 concludes the paper with a brief discussion on extending our model.
2 The model

There are three countries which are indexed by $i = H, M, L$. We consider an infinite horizon model with repeated interactions between a tax union comprised of any two countries and an outside country (i.e., a remaining country). To make the problem tractable, we assume that the environment is stationary, so that our dynamic game (or supergame) is reduced to an infinitely repetition of the one-shot (stage) game. In other words, this stationary assumption eliminates the saving made by households and investment decisions made by firms.\(^1\) In each country there are a continuum of homogeneous households which are normalized to be 1; they are immobile across the countries, while their capital endowments, denoted by $k$, are identical, fixed through time and perfectly mobile across the countries. These factors are required in the production of a single private good. For analytical simplicity, we employ the quadratic production function: $f_i(k_i) \equiv (A_i - k_i)k_i$, where $A_i$ represents the level of productivity and $k_i$ is the per capita amount of capital used in country $i$.\(^2\) Without any loss of generality, we further assume that country $H$, $M$ and $L$, respectively, use the different technologies whose productivities are ordered such as $A_H \geq A_M \geq A_L$, and that $A_i > 2k_i$, $i = H, M, L$, in order to ensure a positive but diminishing marginal productivity of capital. Since the government of country $i$ levies a unit tax on capital at rate $\tau_i$, the after-tax profit of firms located in country $i$ is given by $\pi_i = f_i(k_i) - (r + \tau_i)k_i$ in each period, where $r$ is the net return on capital. The firm’s first-order conditions for profit maximization in country $i$ are

\[ r = f_i'(k_i) - \tau_i, \quad i = H, M, L. \] (1)

\(^1\)If the investment and saving decisions made by economic agents are explicitly introduced into the model, capital accumulation takes place over time so that the stationary assumption is no longer valid. To eliminate the saving decision made by households, we may implicitly assume that they live in only two periods. When young, the household receives wage income. Nevertheless, since it is assumed that the household consumes only when old, she transfers her whole income from the first to the second period of her life by investing in either the home or the foreign country. We further assume that firms do not incur any adjustment costs when undertaking investment activity, their intertemporal profit maximization problems simplify to an infinitely repetition of a static profit maximization one.

\(^2\)This specification has been commonly adopted by Bucovetsky (1991, 2009), Grazzini and van Ypersele (2003), Kempf and Rota-Graziosi (2010), Ogawa (2013) and Wildasin (1989).
Since the entire amount of capital in the economy is fixed at \(3 \bar{k}\) through time, the market for capital is perfectly competitive and hence capital flows across the countries until the net returns on capital, \(f_i'(k_i) - \tau_i\), are equalized. The market clearing conditions in each period are characterized by

\[
3 \bar{k} = k_H(r + \tau_H) + k_M(r + \tau_M) + k_L(r + \tau_L),
\]

(2)

where the capital demand function \(k_i(r + \tau_i) = (1/2)(A_i - r - \tau_i)\) is obtained by solving (1) for \(k_i\). Further, solving (2) for \(r\), together with \(k_i(r + \tau_i)\) derived above for \(i = H, M, L\), yields the equilibrium net return \(r^*\) and the equilibrium amount of capital employed by country \(i\), \(k_i^*\):

\[
r^* = \bar{A} - 2\bar{k} - \tau,
\]

(3)

\[
k_i^* = \bar{k} - \frac{(\bar{A} - A_i) - (\tau - \tau_i)}{2},
\]

(4)

where \(\bar{A} \equiv (\sum A_i)/3\) and \(\bar{\tau} \equiv (\sum \tau_i)/3\) are the average productivity level and the average tax rate over all existing countries, respectively. By differentiating (3) and (4), we have

\[
\frac{\partial r^*}{\partial \tau_i} = \frac{\partial k_i^*}{\partial \tau_i} = -\frac{1}{3} < 0 \quad \text{and} \quad \frac{\partial k_i^*}{\partial \tau_j} = \frac{1}{6} > 0, \ i \neq j.
\]

(5)

Each household inelastically supplies one unit of labor to the domestic firms and invests its own fixed capital holdings in the home and foreign countries. Since there are no opportunities of savings, they spend their entire income on the consumption of the numéraire good \(c_i\) every period. Accordingly, the period’s budget constraint of the household resided in country \(i\) is expressed by \(c_i = w_i + r^* \bar{k}\). To get closed-form expressions for the tax reaction functions of the respective countries, we need to assume that the period’s utility function of country \(i\)’s residents is linear in \(c_i\) and \(g_i\), i.e., \(u_i(c_i, g_i) \equiv c_i + g_i = f_i(k_i^*) + r^* (\bar{k} - k_i^*)\), where \(g_i\) can be viewed as either a publicly provided good or lump-sum transfer from the production sector.

\[\text{3 The assumption of a linear utility function has been commonly used in the literature on tax competition. See Bucovetsky (1991, 2009) and Peralta and van Ypersele (2005).}\]
to the households, and the government’s budget constraint of country i is balanced period by period; i.e., \( g_i = \tau_i k_i^* \).

The government chooses an optimal tax rate so as to maximize the discounted present value of total utilities of country i’s residents over an infinite horizon, given the expectation regarding the behavior of the other governments. Under the stationarity assumption, the government ends up simply playing an infinitely repetition of the following one-shot stage game. In the fully noncooperative Nash equilibrium of each stage game, therefore, taking (3), (4), and the tax rates chosen by the other countries as given, the government of country i independently and individually chooses \( \tau_i \) to maximize the one-period’s utility of country i’s residents. The first-order condition of country i is as follows:

\[
\frac{\partial u_i}{\partial \tau_i} = [f_i'(k_i^*) - r^*] \frac{\partial k_i^*}{\partial \tau_i} + (k - k_i^*) \frac{\partial r^*}{\partial \tau_i} = 0. \tag{6}
\]

By substituting (3), (4) and (5) into (6) and rearranging, we obtain the following best-response function of country i:

\[
\tau_i = \tau_j + \tau_h + \frac{(2A_i - A_j - A_h)}{8}, \tag{7}
\]

which reveals that the tax rates of different countries are strategic complement (i.e., \( \partial \tau_i / \partial \tau_j > 0 \) for \( i \neq j \)). By simultaneously solving (7) for the tax rates set by the respective countries, and then substituting the resulting tax rates into (3) and (4), we obtain the one-shot, fully noncooperative Nash equilibrium tax rate \( \tau_i^N \), the price of capital \( r^N \), and the amount of capital demand \( k_i^N \), respectively:

\[
\tau_i^N = \frac{2A_i - A_j - A_h}{9} = \frac{(A_i - A_j) + (A_i - A_h)}{9}, \tag{8}
\]

\[
r^N = \frac{A}{2k}; \tag{9}
\]

\[
k_i^N = \frac{2A_i - A_j - A_h}{9} = k + \tau_i^N. \tag{10}
\]

It follows from (8) and (10) that a country with the most productive technology (i.e., country

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\( ^4 \)In what follows, we restrict the equilibrium to be an interior solution.
imports capital with taxation \( \tau_H^N > 0 \) (since \((A_H - A_M) + (A_H - A_L) > 0\)), while a country with the least productive technology (i.e., country \( L \)) exports capital with subsidies \( \tau_L^N < 0 \) (since \((A_L - A_H) + (A_L - A_M) < 0\)). This is the terms of trade effect; i.e., capital importers (exporters) are willing to levy positive (negative) tax rates on capital in order to lower (raise) the capital remuneration \( r^* \) in (3). As a result, every country engages in manipulating the price of capital in its favor thus leading to the zero average tax rate in the Nash equilibrium, i.e., \( \overline{\tau}^N = 0 \) (which is confirmed by summing (8) over all \( i \)). By making use of (8), (9), and (10), we show that country \( i \) (\( i = H, M, L \)) can achieve the following one-period’s utility level in every stage game:

\[
u_i^N = (A_i - \bar{k})k + \frac{2(A_i - A_j - A_h)^2}{81}.
\]

\[
\text{(11)}
\]

3 Partial coordination in a stage game

Let \( G \subset \{H, M, L\} \) represent a subset of the existing countries; we consider three possible subsets forming a tax union which implements partial tax harmonization which lasts over an infinite horizon period, such as \( G \in \\{\{H, M\}, \{M, L\}, \{H, L\}\} \).

Since the repeated game we consider can be viewed simply as an infinitely repetition of an identical stage game, in order to endogenize the order of moves chosen by competing governments we simply add to the repeated tax-competition game an initial stage (which we may call a “pre-play stage game” or a “timing game”) in which every government simultaneously decides whether to move early or later in every stage game of the subsequent repeated game.\(^5\) More precisely, following Kempf and Rota-Graziosi (2010), the tax union \( G \) and the outside country \( h \) both simultaneously determine their timings for the choice of tax rates at the pre-play stage; hence the strategy set for each country is given by \( \{\text{lead, follow}\} \). If their announced timings coincide with each other; i.e., either the strategy profile \( \text{(lead, lead)} \), or \( \text{(follow, follow)} \) is announced, a simultaneous-move game between the tax union \( G \) and the outside country \( h \) will be played in every stage game, while a sequential-move stage game will be played if their announced timings are different; i.e., either the strategy profile \( \text{(lead, follow)} \)

\(^5\)The Nash equilibrium of this stage game is called as "a subgroup Nash equilibrium" analyzed by Konrad and Schjelderup (1999).
or (follow, lead) is announced. The structure of the extended repeated tax-competition game is summarized as follows:

- **Pre-play stage:** A tax union and an outside country simultaneously announce at the pre-play stage whether to set tax rates early or later in every stage game of the subsequent repeated tax-competition game.

- **Every stage of the repeated game:** A tax union and an outside country repeatedly set taxes in every stage game of the repeated game according to the moves predetermined at the pre-play stage.

Their announced timings must be credibly committed. In other words, in every stage game of the subsequent repeated tax-competition game, a tax union and an outside country find it to be in their best interest to select their strategies according to their announced moves or knowing when the other chooses its tax rate, which should constitute of a SPNE of the repeated tax-competition game.

### 3.1 Simultaneous-move stage game

Let us begin with the case where each stage game is a simultaneous-move one between a partial tax union $G$ consisting of countries $i$ and $j$. Those member countries have agreed to jointly choose their tax rates in order to maximize the sum of their one-period’s utilities represented by $W(G) \equiv u_i + u_j = f_i(k_i^*) + f_j(k_j^*) + r^* (k_h^* - \overline{k})$, while the outside country $h$ independently chooses its tax rate in order to maximize $u_h$ period by period.\(^6\) \(^7\) The first-order conditions of the tax union $G$ with respect to $\tau_i$ and $\tau_j$ for $i, j \in G; h \notin G$ are given by

\[
\frac{\partial W(G)}{\partial \tau_i} = f_i'(k_i^*) \frac{\partial k_i^*}{\partial \tau_i} + f_j'(k_j^*) \frac{\partial k_j^*}{\partial \tau_i} + r^* \frac{\partial k_h^*}{\partial \tau_i} + (k_h^* - \overline{k}) \frac{\partial r^*}{\partial \tau_i} = 0,
\]

\(^6\) It is assumed throughout the paper that country $j$ is a member of the tax union, but country $h$ is not whenever country $i$ is a member of that tax union.

\(^7\) Since this equilibrium is also a Nash equilibrium, it is often referred to as a subgroup Nash equilibrium in order to distinguish from the fully noncooperative Nash equilibrium which we have characterized so far (see Konrad and Schjelderup, 1999).
and $\partial W(G)/\partial \tau_j = 0$, respectively. By substituting (3), (4), and (5) into the above conditions, the best-response functions of the tax union members are derived as follows:

$$
\tau_i = \frac{2\tau_j + 2\tau_h + (A_i + A_j - 2A_h)}{7}, \quad i, j \in G; \ h \notin G,
$$

(12)

while $\tau_j$ is obtained by switching $i$ and $j$ in (12). Those symmetry forms lead to $\tau_i = \tau_j \equiv \tau^C$; namely, the tax union $G$ optimally chooses a common coordinated tax rate. The reason is that the equalization of the tax rates internalizes the externalities arising from the tax asymmetries among union-member countries, thereby achieving production efficiency within the tax union.

As a result, the best-response function of the tax union can be expressed by

$$
\tau^C = \frac{2\tau_h + (A_i + A_j - 2A_h)}{5}.
$$

(13)

On the other hand, the outside country $h$ individually and independently chooses its best-responded tax rate according to (7) with $i$ being exchanged for $h$ and setting $\tau_i = \tau_j \equiv \tau^C$. By solving these best-response functions, we obtain the harmonized tax rate for the tax union, $\tau^C(G^S)$, and $\tau^C_h(G^S)$ for the outside country (the superscript $S$ of $G$ stands for a case where the tax union $G$ takes a simultaneous-move), the equilibrium net return, $r^C(G^S)$ (using (3)), the amount of capital demanded for each union-member, $k^C_i(G^S)$ for $\forall i \in G$, and $k^C_h(G^S)$ for the outside country $h$ (using (4)), respectively:

$$
\tau^C(G^S) = \frac{A_i + A_j - 2A_h}{6}, \quad \tau^C_h(G^S) = -\frac{A_i + A_j - 2A_h}{12},
$$

(14)

$$
r^C(G^S) = \frac{A_i + A_j + 2A_h}{4} - 2\bar{k},
$$

(15)

$$
k^C_i(G^S) = \bar{k} + \frac{7A_i - 5A_j - 2A_h}{24}, \quad k^C_h(G^S) = \bar{k} - \frac{A_i + A_j - 2A_h}{12},
$$

(16)

It follows from (14) and (16) that the tax union $G$ imports (exports) capital with taxes (subsidies); i.e., $\tau^C(G^S) > 0$ ($< 0$), while the outside country exports (imports) with subsidies (taxes) $\tau^C_h(G^S) < 0$ ($> 0$). In particular, if there are no productivity asymmetries; i.e., $A_i = A_j = A_h$, all countries have no incentive to trade capital and thus $\tau^C(G^S) = \tau^C_h(G^S) = 0$ obtains (see (14)); consequently, the overall production efficiency in the economy is always.
attained without tax harmonization. However, when their production technologies are heterogeneous (i.e., $A_i \neq A_j \neq A_h$), the tax union and the outside country usually have opposite incentives to manipulate the price of capital in its favor, thus inducing them to set the tax rates of opposite signs (recall (14)). It is also important to note that there is another conflict between the union members since the formation of a tax union forces all member countries to accept a common coordinated tax rate, although the most favorable tax rates for the respective members are usually different from this common tax rate due to the asymmetry of productivity; for example, when countries $H$ and $L$ form a tax union, capital-importing country $H$ prefers a positive tax rate, whereas capital-exporting country $L$ prefers a negative tax rate. Then if that tax union were to set a positive common tax rate (i.e., if $(A_H - A_M) + (A_S - A_M) > 0$, then $\tau^C(G^S) > 0$ in (14)), capital-exporting country $L$ is forced to make income transfers to country $H$, and thus incurs losses.

The utility levels of any member $i \in G$ and country $h$ are respectively given by

$$u^C_i(G^S) = (A_i - \overline{k})\overline{k} + \frac{(7A_i - 5A_j - 2A_h)(11A_i - A_j - 10A_h)}{576},$$

$$u^C_h(G^S) = (A_h - \overline{k})\overline{k} + \frac{(A_i + A_j - 2A_h)^2}{72}.$$ (17) (18)

By making use of (11) and (17), the participation constraint for country $i$ (i.e., $\forall i \in G$) is given by:

$$u^C_i(G^S) - u^N_i = \frac{243(A_i - A_j)(A_i - A_h) - (2A_i - A_j - A_h)(31A_i - 83A_j + 52A_h)}{5184} \geq 0.$$ (19)

### 3.2 Tax union acts as a leader

In this subsection, we consider a sequential-move stage game in which a tax union $G$ chooses its coordinated tax rate before the outside country $h$ has chosen its optimal tax rate. After observing the tax rate set by the tax union, country $h$ chooses its tax rate in accordance with (7). In this case, the governments of countries $i$ and $j$ belonging to the tax union solve the

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8In contrast, for the outside country $h$, we obtain that $u^C_h(G^S) - u^N_h = -7(A_i + A_j - 2A_h)^2/648 \leq 0$. This implies that the welfare of country $h$ unambiguously falls as a result of the formation of tax union, regardless of type of tax union.
sequence of the following one-period’s maximization problem period by period:

$$\max_{\tau_i, \tau_j} W(G) = f_i(k_i^*) + f_j(k_j^*) + r^*(k_h^* - \bar{k}) \text{, s.t. (7) for h.}$$

The first-order conditions with respect to $\tau_i$ and $\tau_j$ are given by

$$\frac{\partial W(G)}{\partial \tau_i} = f_i'(k_i^*) \left( \frac{\partial k_i^*}{\partial \tau_i} + \frac{\partial k_i^*}{\partial \tau_h} \frac{\partial \tau_h}{\partial \tau_i} \right) + f_j'(k_j^*) \left( \frac{\partial k_j^*}{\partial \tau_i} + \frac{\partial k_j^*}{\partial \tau_h} \frac{\partial \tau_h}{\partial \tau_i} \right)$$

$$+ r^* \left( \frac{\partial k_h^*}{\partial \tau_i} + \frac{\partial k_h^*}{\partial \tau_h} \frac{\partial \tau_h}{\partial \tau_i} \right) + (k_h^* - \bar{k}) \left( \frac{\partial r^*}{\partial \tau_i} + \frac{\partial r^*}{\partial \tau_h} \frac{\partial \tau_h}{\partial \tau_i} \right) = 0,$$

and, similarly, $\partial W(G)/\partial \tau_j = 0$ for $i, j \in G; h \notin G$. By substituting (3), (4), (5), (7) and (??) into the above expression and rearranging, we obtain the coordinated tax rate, $\tau_i = \tau_j = \tau^C(G^L)$, and the tax rate set by the outside country $h$, $\tau^C_h(G^L)$. Further, substituting these tax rates into (3) and (4) gives the equilibrium price of capital, $r^C(G^L)$, and the capital demands $k^C_i(G^L)$ for $\forall i \in G$, and $k^C_h(G^L)$ for the outside country:

$$\tau^C(G^L) = \frac{3(A_i + A_j - 2A_h)}{14}, \quad \tau^C_h(G^L) = \frac{-A_i + A_j - 2A_h}{14},$$

$$r^C(G^L) = \frac{3A_i + 3A_j + 8A_h}{14} - 2\bar{k},$$

$$k^C_i(G^L) = \frac{4A_i - 3A_j - A_h}{14}, \quad k^C_h(G^L) = \frac{A_i + A_j - 2A_h}{14},$$

where the superscript $L$ of $G$ stands for a sequential-move stage game in which the tax union $G$ acts as a leader. The corresponding one-period’s utility levels of the union members $i$ (i.e., $\forall i \in G$) and the outside country $h$ are respectively given by:

$$u^C_i(G^L) = (A_i - \bar{k})k + \frac{(A_i - A_h)(4A_i - 3A_j - A_h)}{28},$$

$$u^C_h(G^L) = (A_h - \bar{k})k + \frac{(A_i + A_j - 2A_h)^2}{98}.$$
\[ u_i^C(G^L) - u_i^N = \frac{162(A_i - A_j)(A_i - A_h) - (2A_i - A_j - A_h)(31A_i - 56A_j + 25A_h)}{2268} \geq 0. \quad (25) \]

### 3.3 Tax union acts as a follower

Finally, consider a sequential-move stage game, where the outside country \( h \) leads and a tax union \( G \) follows (which we may call \( GF \)). In this case, the tax union \( G \) first sets its tax rate according to (13), while the leader (i.e., the outside country \( h \)) solves the following maximization problem in every stage game:

\[
\max_{\tau_h} u_h(GF) = f_h(k^*_h) + r^*(\bar{k} - k^*_h), \quad \text{s.t. (13)},
\]

The first-order condition is

\[
\frac{\partial u_h}{\partial \tau_h} = [f'_h(k^*_h) - r^*] \left( \frac{\partial k^*_h}{\partial \tau_h} + \sum_{l=i,j \in G} \frac{\partial k^*_h}{\partial \tau_l} \frac{\partial \tau_l}{\partial \tau_h} \right) + (\bar{k} - k^*_h) \left( \frac{\partial r^*}{\partial \tau_h} + \sum_{l=i,j \in G} \frac{\partial r^*}{\partial \tau_l} \frac{\partial \tau_l}{\partial \tau_h} \right) = 0.
\]

Combining the above condition with (3), (4), (5), and (13) yields the coordinated tax rate, \( \tau^C(GF) \), the tax rate set by \( h \), \( \tau^C_h(GF) \), the equilibrium capital remuneration, \( r^C(GF) \), and the capital demands, \( k^C_i(GF) \) for \( \forall i \in G \), and \( k^C_h(GF) \) for \( h \not\in G \):

\[
\begin{align*}
\tau^C(GF) &= A_i + A_j - 2A_h, \quad \tau^C_h(GF) = -\frac{3}{16} (A_i + A_j - 2A_h), \quad (26) \\
r^C(GF) &= \frac{5A_i + 5A_j + 6A_h}{16} - 2\bar{k}, \quad (27) \\
k^C_i(GF) &= \frac{\bar{k} + \frac{9A_i - 7A_j - 2A_h}{32}}{32}, \quad k^C_h(GF) = \frac{\bar{k} - A_i + A_j - 2A_h}{16}. \quad (28)
\end{align*}
\]

The corresponding one-period’s utility levels for the union members (\( \forall i \in G \)) and the outside country \( h \) are as follows:

\[
\begin{align*}
u^C_i(GF) &= (A_i - \bar{k})\bar{k} + \frac{(9A_i - 7A_j - 2A_h)(13A_i - 3A_j - 10A_h)}{1024}, \quad (29) \\
u^C_h(GF) &= (A_h - \bar{k})\bar{k} + \frac{(A_i + A_j - 2A_h)^2}{64}. \quad (30)
\end{align*}
\]
The participation constraints for $\forall i \in G$ is expressed by:

$$u^C_i(G^F) - u^N_i = \frac{1}{82944} [81(7A_i + 6A_j - A_h)(11A_i - 2A_j - 9A_h) \\
-(2A_i - A_j - A_h)(2476A_i - 1319A_j - 1157A_h)] \geq 0. \quad (31)$$

### 3.4 Comparison of tax rates

Straightforward comparison of the tax rates obtained so far (i.e., (8), (14), (20) and (26)) yields the following lemma:

**Lemma 1** The ranking of the tax rates set by the tax union $\{H, L\}$ is given by

$$\tau^N_L < \tau^N_M < 0 < \tau^C(G^F) < \tau^C(G^S) < \tau^C(G^L) < \tau^N_H, \text{ for } \varepsilon_H > \varepsilon_L, \quad (32)$$

$$\tau^N_L < \tau^C(G^L) < \tau^C(G^S) < \tau^C(G^F) < 0 < \tau^N_M < \tau^N_H, \text{ for } \varepsilon_H < \varepsilon_L, \quad (33)$$

where $\varepsilon_H \equiv A_H - A_M > 0$ and $\varepsilon_L \equiv A_M - A_L > 0$.

The ranking of the tax rates set by the tax union $\{H, M\}$ is given by

$$\tau^N_L < 0 < \tau^N_M < \tau^N_H < \tau^C(G^F) < \tau^C(G^S) < \tau^C(G^L) < \tau^N_H, \text{ for } \varepsilon_H < \varepsilon_L. \quad (34)$$

The ranking of the tax rates set by the tax union $\{M, L\}$ is given by

$$\tau^C(G^L) < \tau^C(G^S) < \tau^C(G^F) < \tau^N_L < \tau^N_M < 0, \text{ for } \varepsilon_H > \varepsilon_L. \quad (35)$$

As pointed out by Kempf and Rota-Graziosi (2010), under the strategic complementary property of taxes and the positive externalities created by asymmetric tax rates both of the Stackelberg leader and follower are able to set their favorable tax rates compared to those at the fully noncooperative Nash equilibrium. In particular, the Stackelberg leader has an incentive to exploit the gain associated with the "first-mover advantage". Consider the tax union $\{H, L\}$ which acts as a Stackelberg leader. When $\varepsilon_H > \varepsilon_L$ ($\varepsilon_H < \varepsilon_L$), it is a capital-importing (capital-exporting) tax union and thus prefers a higher positive (lower negative) tax.
rate. As indicated by (32) ((33)), therefore, it would like to set the second-highest (second-
lowest) tax rate. Since the tax union \{H, M\} is a capital importer for \(\varepsilon_H > \varepsilon_L\),\(^9\) it prefers
higher tax rates; consequently, the tax union \{H, M\} wants to become a Stackelberg leader
in order to set higher tax rates as indicated by (34). Similarly, when \(\varepsilon_H < \varepsilon_L\), the capital-
exporting tax union \{M, L\} also wants to become a Stackelberg leader in order to set lower
tax rates as indicated by (35).

3.5 Timing selection

The payoff matrix depicted in Table 1 represents the payoffs to each player for each combination
of strategies that are chosen at each stage game:

<table>
<thead>
<tr>
<th>outsider h \ tax union{i, j}</th>
<th>Lead</th>
<th>Follow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead</td>
<td>(u_h^C(G^S), u_i^C(G^S) + u_j^C(G^S))</td>
<td>(u_h^C(G^F), u_i^C(G^F) + u_j^C(G^F))</td>
</tr>
<tr>
<td>Follow</td>
<td>(u_h^C(G^L), u_i^C(G^L) + u_j^C(G^L))</td>
<td>(u_h^C(G^S), u_i^C(G^S) + u_j^C(G^S))</td>
</tr>
</tbody>
</table>

Table 1. A payoff matrix of each stage game.

To start with, we compare between the utility levels of outside country \(h\) in the stage games
with different timing of moves described so far, which yields the following result:

**Lemma 2** An outside country is always willing to move first.

**Proof.** Comparing between (18), (24) and (30) yields:

\[
\begin{align*}
    u_h^C(G^S) - u_h^C(G^L) &= \frac{13 (A_i + A_j - 2A_h)^2}{3528} \geq 0, \\
    u_h^C(G^F) - u_h^C(G^S) &= \frac{(A_i + A_j - 2A_h)^2}{576} \geq 0.
\end{align*}
\]

Hence, the outside country \(h\) has a dominant strategy unless \(A_i + A_j = 2A_h\); it always has an
incentive to be a leader regardless of the timing chosen by the tax union. \(\blacksquare\)

Hence, an outside country always chooses a strategy of being a Stackelberg leader in the
2\times2 game given by the payoffs matrix depicted in Table 1 except for the degenerate case

\(^9\)As shown later, the tax union \(\{H, M\}\) (\(\{M, L\}\)) will not be formed for the range of \(\varepsilon_H < \varepsilon_L\) (\(\varepsilon_H < \varepsilon_L\)).
\[ A_i + A_j = 2A_h. \]

From (17), (23), and (29), furthermore, we obtain the following results for all tax union-member countries \( i \in G \):

\[
\begin{align*}
    u^C_i(G^L) - u^C_i(G^S) &= \frac{(A_i + A_j - 2A_h)(37A_i - 35A_j - 2A_h)}{4032} \geq 0, \\
    u^C_i(G^F) - u^C_i(G^S) &= -\frac{(A_i + A_j - 2A_h)(179A_i - 109A_j - 70A_h)}{9216} \geq 0.
\end{align*}
\]

(36)

(37)

Although the signs of (36) and (37) appear to be ambiguous, their signs would be determined depending on the productivity parameters of all three countries. Before going further, since the outside country \( h \) always chooses to be a leader (recall Lemma 1), it turns out that the game \( G^L \) is never played; hence, we ignore (36). A further inspection of (37) yields the following lemmas:

**Lemma 3** The tax union \( \{ H, M \} \) is possible in the simultaneous-move game when \( \varepsilon_H/\varepsilon_L \leq (72\sqrt{3} - 106)/83 \simeq 0.225 \), while the tax union \( \{ M, L \} \) is possible in the simultaneous-move game when \( \varepsilon_H/\varepsilon_L \geq (53 + 36\sqrt{3})/26 \simeq 4.437 \).

**Proof.** Using these notations, we can rewrite (37) for the respective members of the tax union \( \{ H, M \} \) as:

\[
\begin{align*}
    u^C_H(G^S) - u^C_H(G^F) &= \frac{(\varepsilon_H + 2\varepsilon_L)(179\varepsilon_H + 70\varepsilon_L)}{9216} > 0, \\
    u^C_M(G^S) - u^C_M(G^F) &= \frac{(\varepsilon_H + 2\varepsilon_L)(-109\varepsilon_H + 70\varepsilon_L)}{9216} \leq 0, \text{ iff } \frac{\varepsilon_H}{\varepsilon_L} \geq 70/109 \simeq 0.642. \tag{38}
\end{align*}
\]

To make it possible to form the tax union \( \{ H, M \} \) in the simultaneous-move game \( G^S \), the participation constraints (19) for the union-members \( H \) and \( M \) must be satisfied; i.e., \( u^C_H(G^S) \geq u^N_H \) and \( u^C_M(G^S) \geq u^N_M \). Since the second inequality can be rewritten as

\[
u^C_M(G^S) - u^N_M = \frac{52\varepsilon_L^2 - 212\varepsilon_H\varepsilon_L - 83\varepsilon_H^2}{5184} \geq 0, \tag{39}\]

\[10\text{However, we do not further investigate the degenerate case where } A_i + A_j = 2A_h \text{ (i.e., } A_i = A_j = A_h) \text{ because in this case the tax rates set by all countries end up being equal to zero in equilibrium so that there is no need for tax harmonization. In what follows, we ignore this case.}\]
it is easy to see that (39) holds only when $\frac{\varepsilon_H}{\varepsilon_L} \leq \frac{(72\sqrt{3} - 106)}{83} \approx 0.225$. Since this upper bound is smaller than the upper bound given by (38), i.e., $\frac{\varepsilon_H}{\varepsilon_L} \leq \frac{70}{109} \approx 0.642$, the inequality $u_C^H(G^S) > u_C^H(G^F)$ is satisfied. In addition, the first participation constraint for country $H$, $u_C^H(G^S) \geq u_H^N$, is always satisfied, because

$$u_C^H(G^S) - u_H^N = \frac{181\varepsilon_H^2 + 316\varepsilon_H\varepsilon_L + 52\varepsilon_L^2}{5184} > 0.$$  

To sum up, the tax union $\{H, M\}$ in the simultaneous-move game $G^S$ is possible as long as $\frac{\varepsilon_H}{\varepsilon_L} \leq \frac{(72\sqrt{3} - 106)}{83} \approx 0.225$.

On the other hand, when $\frac{\varepsilon_H}{\varepsilon_L} > \frac{(72\sqrt{3} - 106)}{83} \approx 0.225$, (39) does not hold due to the above result. Moreover, the participation constraint (31) for country $L$ does not hold also, because

$$u_C^L(G^F) - u_L^N = \frac{-347\varepsilon_L^2 - 2060\varepsilon_L\varepsilon_H - 42\varepsilon_H}{82944} < 0.$$  

As a result, the tax union is not possible regardless of whether the tax union acts as a leader or a follower when $\frac{\varepsilon_H}{\varepsilon_L} > \frac{(72\sqrt{3} - 106)}{83} \approx 0.225$.

Next, consider the tax union $\{M, L\}$. We can show that

$$u_C^M(G^S) - u_M^C(G^F) = \frac{(2\varepsilon_H + \varepsilon_L)(109\varepsilon_L - 70\varepsilon_H)}{9216} \geq 0, \text{ iff } \frac{\varepsilon_H}{\varepsilon_L} \geq \frac{109}{70} \approx 1.557, \quad (40)$$  

$$u_C^M(G^S) - u_M^C(G^F) = \frac{(2\varepsilon_H + \varepsilon_L)(179\varepsilon_L + 70\varepsilon_H)}{9216} > 0.$$  

When $\varepsilon_H/\varepsilon_L > 109/70 \approx 1.557$, it holds that $u_C^M(G^S) > u_C^M(G^F)$, and thus both member countries are willing to choose simultaneous-moves. Moreover, the participation constraints (19) for the union members $M$ and $L$ also hold for this range of $\varepsilon_H/\varepsilon_L$, because

$$u_C^M(G^S) - u_M^N = \frac{52\varepsilon_H^2 - 212\varepsilon_H\varepsilon_L - 83\varepsilon_L^2}{5184} \geq 0, \text{ iff } \frac{\varepsilon_H}{\varepsilon_L} \geq \frac{53 + 36\sqrt{3}}{26} \approx 4.437, \quad (41)$$  

$$u_C^L(G^S) - u_L^N = \frac{52\varepsilon_H^2 + 316\varepsilon_H\varepsilon_L + 181\varepsilon_L^2}{5184} > 0.$$  

Put together, when $\varepsilon_H/\varepsilon_L \geq (53 + 36\sqrt{3})/26 \approx 4.437$, the tax union $\{M, L\}$ which opts for acting as a leader (i.e., the simultaneous-move game) is possible, because the lower bound of
4.437 is greater than the lower bound of (40), i.e., 1.557.

When \( \varepsilon_H/\varepsilon_L < (53 + 36\sqrt{3})/26 \simeq 4.437 \), however, it is also confirmed that

\[
\frac{u^C_M(G^F) - u^N_M}{82944} = \frac{-428\varepsilon_H^2 - 2060\varepsilon_L\varepsilon_H - 347\varepsilon_L^2}{82944} < 0,
\]

thus implying that country \( M \) does not want to participate in the tax union regardless of whether it acts as a leader or follower. Consequently, the tax union \( \{M, L\} \) is not possible when \( \varepsilon_H/\varepsilon_L < (53 + 36\sqrt{3})/26 \simeq 4.437 \).

**Lemma 4** The tax union \( G = \{H, L\} \) which chooses simultaneous moves is possible when 
\[
(72\sqrt{3} - 23)/181 \leq \varepsilon_H/\varepsilon_L \leq (23 + 72\sqrt{3})/831,
\]
while the tax union \( G = \{H, L\} \) which chooses sequential moves is possible if 
\[
(288\sqrt{11} - 683)/1285 \leq \varepsilon_H/\varepsilon_L \leq (683 + 288\sqrt{11})/347.
\]

**Proof.** For the tax union \( \{H, L\} \), the expressions in (37) can be rewritten as follows:

\[
\begin{align*}
\frac{u^C_H(G^S) - u^C_H(G^F)}{9216} &= \frac{(\varepsilon_H - \varepsilon_L)(179\varepsilon_H + 109\varepsilon_L)}{9216}, \quad (42) \\
\frac{u^C_L(G^S) - u^C_L(G^F)}{9216} &= \frac{-\varepsilon_H - \varepsilon_L)(109\varepsilon_H + 179\varepsilon_L)}{9216}. \quad (43)
\end{align*}
\]

Since these two expressions display the opposite signs depending on the difference \( \varepsilon_H - \varepsilon_L \), the most preferable timings of the respective members are always opposed except for the case of \( \varepsilon_H = \varepsilon_L \).

First, suppose that the tax union \( \{H, L\} \) acts a leader, i.e., a simultaneous-move game arises. Then we have to examine whether the participation constraints (19) for the respective members of this tax union are satisfied or not. The participation constraint for country \( H \) is given by

\[
u^C_H(G^S) - u^N_H = \frac{181\varepsilon_H^2 + 46\varepsilon_H\varepsilon_L - 83\varepsilon_L^2}{5184} \geq 0, \text{ iff } \frac{\varepsilon_H}{\varepsilon_L} \geq \frac{72\sqrt{3} - 23}{181} \simeq 0.562,
\]

while that for country \( L \) is given by

\[
u^C_L(G^S) - u^N_L = \frac{-83\varepsilon_H^2 + 46\varepsilon_H\varepsilon_L + 181\varepsilon_L^2}{5184} \geq 0, \text{ iff } \frac{\varepsilon_H}{\varepsilon_L} \leq \frac{23 + 72\sqrt{3}}{83} \simeq 1.78.
\]
It is immediate that both participation constraints are simultaneously satisfied, so long as 
\[(\sqrt{3} - 23)/181 \leq \varepsilon_H/\varepsilon_L \leq (23 + 72\sqrt{3})/83\] (i.e., approximately, \(0.562 \leq \varepsilon_H/\varepsilon_L \leq 1.78\)). Hence, the tax union \(\{H, L\}\) is possible in the simultaneous-move game for this overlapping range of \(\varepsilon_H/\varepsilon_L\) (recall the outside country always prefers to act as a leader).

Next, we examine whether or not it is possible that the tax union \(\{H, L\}\) acts as a follower. In this case the participation constraints (31) for countries \(L\) and \(H\) are given by

\[
\begin{align*}
    u^C_H(G^F) - u^N_H &= \frac{1285\varepsilon_H^2 + 1366\varepsilon_H\varepsilon_L - 347\varepsilon_L^2}{82944} \geq 0, \quad \text{iff} \quad \frac{\varepsilon_H}{\varepsilon_L} \geq \frac{288\sqrt{11} - 683}{1285} \approx 0.212, \\
    u^C_L(G^F) - u^N_L &= -\frac{83\varepsilon_H^2 + 46\varepsilon_H\varepsilon_L + 181\varepsilon_L^2}{5184} \geq 0, \quad \text{iff} \quad \frac{\varepsilon_H}{\varepsilon_L} \leq \frac{683 + 288\sqrt{11}}{347} \approx 4.721.
\end{align*}
\]

A close inspection of the above two conditions reveals that there exists a common overlapping range in which both participation constraints are simultaneously satisfied; i.e., \((288\sqrt{11} - 683)/1285 \leq \varepsilon_H/\varepsilon_L \leq (683 + 288\sqrt{11})/347\) (approximately, \(0.212 \leq \varepsilon_H/\varepsilon_L \leq 4.721\)). Moreover, it turns out that the range of \(\varepsilon_H/\varepsilon_L\) in which the tax union \(\{H, L\}\) taking sequential-moves is possible contains the possible range for that tax union taking simultaneous-moves.

To sum up, we have the following important result:

**Proposition 1** The tax unions \(\{H, M\}\) and \(\{M, L\}\) always take a simultaneous-move, while the tax union \(\{H, L\}\) can take both a simultaneous-move or sequential-move in a common range of production asymmetries, i.e., \((72\sqrt{3} - 23)/181 \leq \varepsilon_H/\varepsilon_L \leq (23 + 72\sqrt{3})/831\).

Three remarks are in order. First, it follows from Lemma 2 that the capital-importing and capital-exporting tax unions, \(\{H, M\}\) and \(\{M, L\}\), both prefer simultaneous moves to sequential moves. This result is quite consistent with Ogawa (2013) which uses a two-country, two-stage tax competition game. He finds that for economies with non-absentee capital ownership, the two asymmetric countries have opposite incentives to manipulate the price of capital (i.e., the terms-of-trade effect), so that such dissimilar incentives allow for a simultaneous-move equilibrium to emerge. Since in our setting capital-exporting tax union \(\{M, L\}\) (capital-importing tax union \(\{H, M\}\)) is willing to raise (lower) the price of capital to augment the
income (diminish the payment) from capital trade, while the outside country wishes to manipulate it in the other direction, their opposed incentives toward the price of capital emerge like in Ogawa’s (2013) two-country model. The reason for this, raised by Ogawa, is that in such a setting Stackelberg leader’s payoffs exceed its simultaneous-move payoffs, while its simultaneous-move payoffs exceed its Stackelberg follower’s payoffs. These features continue to hold at every stage of the present repeated tax-competition game whose payoffs are depicted in Table 1; namely,

\[
[u_C^G(G^S) + u_{CM}^G(G^S)] - [u_C^G(G^F) + u_{CM}^G(G^F)] = > 0,
\]

\[
[u_{CM}^G(G^S) + u_C^L(G^S)] - [u_{CM}^G(G^F) + u_C^L(G^F)] = > 0,
\]

\[
[u_C^H(G^S) + u_C^L(G^S)] - [u_C^H(G^F) + u_C^L(G^F)] = \frac{35}{4608} (\varepsilon_H - \varepsilon_L)^2 > 0,
\]

hence, the only strategy profile (Lead, Lead) constitutes a unique Nash equilibrium of every stage game, and thus the infinite repetition of this one-shot Nash equilibrium constitutes a SPNE of the present repeated tax competition game.

Secondly, there is, however, a significant difference between Ogawa’s two-stage game and our repeated game. As shown later, there is a common range of the relative productivity ratio \( \varepsilon_H / \varepsilon_L \) in which the infinite repetitions of the strategy profiles (Lead, Lead) and (Lead, Follow) both constitute SPNE’s of the repeated tax-competition game.\(^{11}\) Although the strategy profile (Lead, Follow) is not a Nash equilibrium of the announcement stage depicted in Table 1 (as well as in the two-stage game of Ogawa (2013)), it may be possible that it is a Nash equilibrium (i.e., a SPNE) of the infinitely repeated game due to the argument based on the folk theorem. The folk theorem states that any payoff vector to an infinitely repeated game that satisfies individual rationality can be sustained as a SPNE so long as players are sufficiently patient. Although the requirement of individual rationality is met when the participation constrains for all union-members hold, Lemma 3 indicates that the strategy profile (Lead, Follow) does not

\(^{11}\)The simultaneous-move equilibrium (Lead, Lead) would be Pareto superior to the sequential-move equilibrium (Lead, Follow) in the sense that the welfare level of the tax union at the former equilibrium is higher than that at the latter one. However, this Pareto ranking does not imply that the tax union always agree to choose simultaneous-moves, because the payoffs accrued to the union members corresponding to the respective equilibria are completely opposed (recall (42) and (43)).
satisfy the participation constrains for union-members \( \{M, L\} \) or \( \{H, M\} \), whereas Lemma 4 reveals that there exists a certain range of \( \varepsilon_H/\varepsilon_L \) in which the strategy profile (Lead, Follow) does the participation constrains of union-members \( \{H, L\} \). This difference stems from the fact that the tax union \( \{H, L\} \) must allow for a wider range of productivity asymmetry in order to fulfill their participation constraints, thereby making it possible that the simultaneous and sequential-move equilibria both emerge at the same time. However, the infinite repetition of the strategy profile (Lead, Follow) should not be enough to constitute a SPNE of the repeated tax-competition game. To this end, we need to assume that players should not discount the future too much. In the next section, we identify a threshold value for the discount factor which sustains partial tax harmonization as a SPNE’s outcome.

Thirdly, when the tax union \( \{H, L\} \) acts as a follower, it is easier for the participation constraints for its members to be satisfied compared to those when it acts as a leader (see Lemma 4). As shown later, this implies that the sequential-move equilibrium which comprises a SPNE of the repeated game prevails in a wider range of the ratio \( \varepsilon_H/\varepsilon_L \) compared to the range in which the simultaneous-move equilibrium emerges as its SPNE (see Figure 3). The intuitive reason for this outcome is as follows. It turns out from (14) and (26) that in the simultaneous-move game the resulting positive harmonized tax rate is higher than that in the sequential-move game for \( \varepsilon_H/\varepsilon_L > 1 \), thus leading to a lower net return. The resulting lower net return raises the utility of capital-importing country \( H \), while it reduces that of capital-exporting country \( L \). This effect ends up making the utility difference \( u_C^H(G^S) - u^N_H \) larger but \( u_C^L(G^S) - u^N_L \) smaller relative to the corresponding utility differences under the sequential-move equilibrium. As a result, the participation constraint \( u_C^L(G^F) \geq u^N_L \) is less likely to be satisfied compared to \( u_C^L(G^F) \geq u^N_L \), and vice versa for \( \varepsilon_H/\varepsilon_L < 1 \).

4 Sustainability

In this section, we investigate under which timing of plays it is more likely to sustain the tax union \( \{H, L\} \) in the repeated tax-competition game (we relegate the other types of tax union such as \( \{M, L\} \) and \( \{H, M\} \) to the Appendix). Assume that in every period, the tax union
\(\{H, L\}\) jointly sets a common capital tax rate on condition that the other member follows it in the previous period. If at least one country deviates from it, then their cooperation collapses, thus triggering the punishment phase that results in the Nash equilibrium, which persists forever. *Provided that all countries possess a common discount factor* \(\delta \in [0, 1)\), the following conditions must be satisfied so as to sustain cooperation:

\[
\frac{1}{1-\delta} u_i^C(G^m) \geq u_i^D(G^m) + \frac{\delta}{1-\delta} u_i^N, \quad i = H, L, \ m = F, S. \tag{44}
\]

The LHS of \((44)\) is the discounted total utility for a resident in the union-member country \(i = H, L\), when the tax harmonization implemented by the tax union is sustained over an infinite period, while the RHS of \((44)\) represents the sum of the utility resulting from the deviation in the current period, \(u_i^D(G^m)\), and the discounted value of total utility resulting from the Nash phase in all following periods.

### 4.1 Sustainability under simultaneous-move

In a simultaneous-move stage game, by setting \(\tau_h^C = \tau_M^C(G^S)\) and \(\tau_j = \tau^C(G^S)\) (see \((14)\)), we can obtain the best-deviation tax rate for country \(i\), \(\tau_i^D(G^S)\) (using \((7)\)), the resulting capital remuneration, \(r_i^D(G^S)\) (using \((3)\)), the amount of capital demanded, \(k_i^D(G^S)\) (using \((4)\)), and the corresponding one-period’s utility level, \(u_i^D(G^S)\) for \(i \in \{H, L\}\), respectively, as follows:

\[
\begin{align*}
\tau_i^D(G^S) &= \frac{25A_i - 11A_j - 14A_M}{96}, \\
r_i^D(G^S) &= \frac{7A_i + 11A_j + 14A_M}{32} - \frac{2}{k}, \\
k_i^D(G^S) &= \frac{k + 25A_i - 11A_j - 14A_M}{96} = k + \tau_i^D(G^S), \\
u_i^D(G^S) &= (A_i - k)k + \frac{(25A_i - 11A_j - 14A_M)^2}{4608}. \tag{45}
\end{align*}
\]

Substituting \((11)\), \((17)\), and \((45)\) into the equality of \((44)\) yields the *minimum discount factors* of country \(i \in \{H, L\}\), above which they find it to be in their interest to cooperate:

\[
\delta_i(G^S) = \frac{u_i^D(G^S) - u_i^C(G^S)}{u_i^D(G^S) - u_i^N} = \frac{81(A_i - 3A_j + 2A_M)^2}{(11A_i - 10A_M)(139A_i - 65A_j - 74A_M)}, \tag{46}
\]

---

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Figure 1: Minimum discount factors for $G = \{H, L\}$ in a simultaneous-move game.

It is straightforward to show that $\delta_H(G^S) \gtrless \delta_L(G^S)$ if and only if $\varepsilon_H \lesssim \varepsilon_L$, while $\delta_H(G^S) = \delta_L(G^S) = 9/17 \simeq 0.53$ when $\varepsilon_H = \varepsilon_L$. The tax harmonization implemented by the tax union $\{H, L\}$ is sustainable as a SPNE of the repeated tax-competition game only if the actual (common) discount factor of both countries $\delta$ is larger than the threshold discount factor defined by $\delta^*(G^S) \equiv \max\{\delta_H(G^S), \delta_L(G^S)\}$. It is easy to confirm that $\delta^*(G^S) < 1$ holds only when $(72\sqrt{3} - 23)/181 < \varepsilon_H/\varepsilon_L < (72\sqrt{3} + 23)/83$ (i.e., approximately, $0.562 < \varepsilon_H/\varepsilon_L < 1.78$). Furthermore, differentiating (46) with respect to $\varepsilon_H/\varepsilon_L$ yields

$$\frac{d\delta_H(G^S)}{d(\varepsilon_H/\varepsilon_L)} < 0 \text{ and } \frac{d\delta_L(G^S)}{d(\varepsilon_H/\varepsilon_L)} > 0,$$

which implies that the locus of the minimum discount factor of country $H$ ($L$) is sloped downward (upward). Taken together, we can draw Fig. 1 in which $\delta_H(G^S) < \delta_L(G^S)$ holds for $\varepsilon_H/\varepsilon_L > 1$, while $\delta_H(G^S) > \delta_L(G^S)$ holds for $\varepsilon_H/\varepsilon_L < 1$. An intuitive explanation for (47) will be given in Subsection 4.3.

### 4.2 Sustainability under sequential-move

In a sequential-move stage game, country $i = H, L$ can deviate from their cooperation by setting its best-deviation tax rate $\tau^D_i(G^F)$ given the tax rates set by the other union-member $j$ and the outside country $h$ which behaves as a Stackelberg leader. As before, by setting $\tau^C_h = \tau^C_M(G^F)$ and $\tau_j = \tau^C(G^F)$ in (14), we can obtain the best-deviation tax rate for country $i$, $\tau^D_i(G^F)$ (using (7)), the resulting capital remuneration, $r^D_i(G^F)$ (using (3)), the amount
of capital demanded, $k_i^D(G^F)$ (using (4)), and the corresponding one-period’s utility level, $u_i^D(G^F)$ for $i \in \{H, L\}$, respectively, as follows:

\[
\begin{align*}
\tau_i^D(G^F) &= \frac{31A_i - 17A_j - 14A_M}{128}, \\
\tau^D_i(G^F) &= \frac{35A_i + 51A_j + 42A_M}{128} - 2\bar{k}, \\
k_i^D(G^F) &= \bar{k} + \frac{31A_i - 17A_j - 14A_M}{128} = \bar{k} + \tau_i^D(G^F), \\
u_i^D(G^F) &= (A_i - \bar{k})\bar{k} + \frac{(31A_i - 17A_j - 14A_M)^2}{8192}. 
\end{align*}
\] (48)

Substituting (11), (29), and (48) into the equality of (44) yields the minimum discount factors of country $i \in \{H, L\}$ for the repeated tax-competition game with sequential-moves as follows:

\[
\delta_i(G^F) = \frac{u_i^D(G^F) - u_i^C(G^F)}{u_i^N - u_i^D(G^F)} = \frac{81 (5A_i - 11A_j + 6A_M)^2}{(23A_i - 25A_j + 2A_M) (535A_i - 281A_j - 254A_M)}. 
\] (49)

It is straightforward to show that $\delta_H(G^F) \geq \delta_L(G^F)$ if and only if $\varepsilon_H \leq \varepsilon_L$, while $\delta_H(G^F) = \delta_L(G^F) = 9/17 \approx 0.53$ when $\varepsilon_H = \varepsilon_L$. If the actual discount factor $\delta$ is greater than the threshold discount factor defined by $\delta^*(G^F) = \max\{\delta_H(G^F), \delta_L(G^F)\}$, the tax union $\{H, L\}$ is sustainable. More precisely, $\delta^*(G^F) < 1$ holds only when $(288\sqrt{11} - 683)/1285 < \varepsilon_H/\varepsilon_L < (288\sqrt{11} + 683)/347$; consequently, their cooperation is sustainable as a SPNE of the repeated tax-competition game. Differentiation of (49) with respect to $\varepsilon_H/\varepsilon_L$ confirms that

\[^{12}\text{This range precisely coincides with the range in which the participation constraints of countries } L \text{ and } H \text{ are satisfied.}\]
Figure 3: Minimum discount factors of \( G = \{ H, L \} \) for their partial tax harmonization.

d\( \delta_H(G^F) / d(\varepsilon_H/\varepsilon_L) < 0 \) and d\( \delta_L(G^F) / d(\varepsilon_H/\varepsilon_L) > 0 \). Put together, we can draw Fig. 2 which shows that \( \delta_H(G^F) < \delta_L(G^F) \) holds for \( \varepsilon_H/\varepsilon_L < 1 \), and thus country \( L \) has a stronger incentive to deviate than country \( H \) does, while \( \delta_H(G^F) > \delta_L(G^F) \) holds for \( \varepsilon_H/\varepsilon_L > 1 \), and thus country \( H \) has a stronger incentive to deviate than country \( L \) for the reason stated before. Fig. 2 further shows that the larger is the difference between \( \varepsilon_H \) and \( \varepsilon_L \) (i.e., countries \( H \) and \( L \) become more heterogenous), the harder it is to sustain their cooperation.

4.3 Discussion

By comparing (46) with (49) it turns out that \( \delta^*_i(G^F) < \delta^*_i(G^S) \), \( i = H, L \), for either range of \( \varepsilon_H/\varepsilon_L \) except for the case of \( \delta^*_i(G^F) = \delta^*_i(G^S) = 9/17 \approx 0.53 \) at \( \varepsilon_H/\varepsilon_L = 1 \). This is illustrated in Fig. 3. An inspection of Fig. 3 immediately reveals the following results for the behavior of the tax union \( \{ H, L \} \):

**Proposition 2** In the repeated tax-competition game with the tax union \( \{ H, L \} \),

(i) there exists a SPNE in which the coordinated tax rate is sustained if countries \( H \) and \( L \) are sufficiently patient;

(ii) when the tax union acts as a Stackelberg follower, it can sustain their partial tax harmonization in a wider range of the asymmetry between \( \varepsilon_H \) and \( \varepsilon_L \) compared to the tax union when
it acts a Stackelberg leader except for the case of $\varepsilon_H = \varepsilon_L$; and (iii) as asymmetry between $\varepsilon_H$ and $\varepsilon_L$ becomes smaller (i.e., $\varepsilon_H/\varepsilon_L \to 1$), it is easier to sustain their partial tax harmonization in both simultaneous and sequential-move games, whereas as asymmetry between $\varepsilon_H$ and $\varepsilon_L$ becomes larger, the opposite result holds.

To understand the economic logic behind Proposition 2, we suppose that the ratio $\varepsilon_H/\varepsilon_L$ is increased (maintaining $\varepsilon_H > \varepsilon_L$). In this range, the tax union $\{H, L\}$ imports capital from country M regardless of the timing of moves. As seen from (14) and (26); i.e., $\tau^C(G^S) = (\varepsilon_H - \varepsilon_L)/6 > 0$ and $\tau^C(G^F) = (\varepsilon_H - \varepsilon_L)/8 > 0$, the capital-importing tax union $\{H, L\}$ is willing to choose a positive harmonized tax rate in order to reduce the capital payments regardless of the timing of moves. As a result, the larger is the ratio $\varepsilon_H/\varepsilon_L$, the more productive is the production function of country $H$ and the more amount of capital country $H$ (i.e., the tax union) is to demand (i.e., import), thus inducing the tax union to set a higher (positive) coordinated tax rate. The increased $\tau^C(G^p)$, $p = S, F$, lowers the net return, which creates income transfers from capital-exporting country $L$ to capital-importing country $H$. As a result, the utility of country $H$, $u_H^C(G^p)$ is increased, while $u_L^C(G^p)$ is decreased. Hence, country $L$ will be a pivotal player in the sense that it determines whether or not to sustain tax coordination.

To identify how the higher $\tau^C(G^p)$ caused by the increased $\varepsilon_H/\varepsilon_L$ affects the sustainability of cooperation, we rewrite the sustainability condition (44) as follows:

$$\frac{\delta}{1 - \delta} \left( u_L^C(G^p) - u_L^p \right) \geq u_L^D(G^p) - u_L^C(G^p), \quad p = S, F, \quad (50)$$

which says that the tax union is sustainable as long as the discounted future losses inflicted by the punishment (i.e., the opportunity cost from deviation) appearing on the left-hand side should be greater than the immediate gain from deviation appearing on the right-hand side. Since $u_L^C(G^p)$ falls with $\tau^C(G^p)$, so does the opportunity cost from deviation (i.e., $u_L^C(G^p) - u_L^N$).

Although the immediate gain from deviation (i.e., $u_L^D(G^p) - u_L^C$) also de-

\[13\] More precisely, there are two channels through which changes in the ratio $\varepsilon_H/\varepsilon_L$ affect the utility level of country $L$. The first channel is to operate through changes in $\tau^C(G^p)$, while the second one is to operate through shifts of the production function caused by direct productivity changes. The first effect of an increase
creases with $\tau^C$; it can be verified from (47) that the minimum discount factor of country $L$
risers with the ratio $\varepsilon_H / \varepsilon_L$ (maintaining $\varepsilon_H / \varepsilon_L > 1$), which implies that the positive impact
on the opportunity cost $u_L^C(G^P) - u_L^N$ dominates; consequently, its incentive to cooperate will
be discouraged by the increased ratio $\varepsilon_H / \varepsilon_L$. In short, the more heterogenous are the productiv-
ties of union-member countries, the more vulnerable is the sustainability of the tax union.
Conversely, the more homogenous (i.e., the ratio $\varepsilon_H / \varepsilon_L$ approaches 1) are the productivities
of union-member countries, the more robust is the sustainability of the tax union. It is, therefore,
concluded that the likelihood of sustainability for their tax harmonization depends negatively
on the degree of asymmetry, as in Itaya et al. (2008).

Why does the tax union which acts as a Stackelberg follower can sustain tax harmonization
in a wider range of $\varepsilon_H / \varepsilon_L$ compared to the tax union which acts as a Stackelberg leader?
The intuitive reason is as follows. A Stackelberg follower cannot exploit “the first-mover
advantage”, since the tax union acting as a Stackelberg follower is reluctant to choose the most
favorable tax rate. Although this choice places the follower tax union at a disadvantage relative
in $\tau^C(G^P)$ on the utility level of country $L$ is given by

$$
\frac{du_L^C(G^P)}{d\tau^C(G^P)} = \left[ f'_L(k_L^C(G^P)) - \tau^C(G^P) \right] \frac{dk_L^C(G^P)}{d\tau^C(G^P)} + \frac{dr_L^C(G^P)}{d\tau^C(G^P)} \left[ k_L - k_L^C(G^S) \right] > 0, \quad p = S, F,
$$

whose positive sign stems from the fact that the terms-of-trade and capital-moving effects are both positive.
On the other hand, at the fully non-cooperative Nash equilibrium the effect of an increase in $\tau_L^N$ is given by

$$
\frac{du_L^N}{d\tau_L^N} = \left[ f'_L(k_L^N) - \tau_L^N \right] \frac{dk_L^N}{d\tau_L^N} > 0,
$$

where noting that the tax rate $\tau_L^N$ does not affect the equilibrium return on capital, the terms-of-trade effect
vanishes, while the only capital movement effect remains. Since, however, the direct effect affects $u_L^C(G^P)$ and
$u_L^N$ in the same direction, the resulting effect on the utility difference $u_L^C(G^P) - u_L^N$ would be almost negligible.
Since the induced changes in the tax rates have a dominant effect on the utility difference $u_L^C(G^P) - u_L^N$, the
effect on the utility difference $u_L^C(G^P) - u_L^N$ turns out to be positive.

14 The effect of an increase in $\tau_L^P(G^S)$ on the utility level of country $L$ when country $L$ deviates is given by

$$
\frac{du_L^P(G^S)}{d\tau_L^P(G^S)} = \left[ f_L[k_L^P(G^S)] - r_L^P(G^S) \right] \frac{dk_L^P(G^S)}{d\tau_L^P(G^S)} + \frac{dr_L^P(G^S)}{d\tau_L^P(G^S)} \left[ k_L - k_L^P(G^S) \right] > 0,
$$

whose positive sign stems from the fact that the terms-of-trade and capital-moving effects are both positive.
As stated in footnote 12, since the direct productivity effect through the production function affects the utility
levels $u_L^P(G^S)$ and $u_L^C$ in the same direction, the effect on the utility difference $u_L^P(G^S) - u_L^C$ varies according
to the above sign of the tax effect.
to the tax union acting a Stackelberg leader, it would improve the well-being of an *unfavorable* partner, which will be a potential *first* deviator from tax harmonization, by reducing income transfers from an *unfavorable* country to a *favorable* one. More specifically, when \( \varepsilon_H > \varepsilon_L \), straightforward comparison of \((15)\) with \((27)\) reveals that \( r^C(G^F) > r^C(G^S) \); consequently, the capital-importing tax union as a whole always prefers a lower capital price \( r^C(G^S) \) associated with a higher capital tax rate and thus the simultaneous-moves. Nevertheless, union-member country \( L \) prefers moving late, not only because capital-exporting country \( L \) prefers a lower capital price, but also because a lower capital price can be realized in the sequential-move game in which the tax union is willing to set *moderate* tax rates. Since country \( L \) is clearly an *unfavorable* country, it is a *pivotal* player in determining the sustainability of tax coordination. This is manifest in the observation of \( \delta_L(G^F) < \delta_L(G^S) \) for \( \varepsilon_H / \varepsilon_L > 1 \) in Fig. 3. Similarly, when \( \varepsilon_H / \varepsilon_L < 1 \), the tax union is a capital-exporting one; hence, capital-importing country \( H \) plays a pivotal role in sustaining tax harmonization. Since it always holds that \( r^C(G^F) < r^C(G^S) \), capital-importing country \( H \) is more beneficial under moving-late than under moving-first. The same reasoning, therefore, leads to the conclusion that \( \delta_H(G^F) < \delta_H(G^S) \) for \( \varepsilon_H / \varepsilon_L < 1 \) as shown in Fig. 3. The deriving force is that the most unfavorable union-member would prefer late-moves rather than early-moves with the consequence that the sequential-move equilibrium can prevail in a wider range of \( \varepsilon_H / \varepsilon_L \).

As seen from Fig. 4, which illustrates the minimum discount factors of the member countries consisting of all possible partial tax unions, it is found that there is no range of \( \varepsilon_H / \varepsilon_L \) that is consistent with any partial tax harmonization (see also the Appendix). In other words, *if the timing of moves is exogenously fixed*, this may mislead to conclude not only that no tax coordination is impossible for some range of the degree of asymmetry, but also that the presence of asymmetry may prevent from forming any tax coordination. In contrast, *if the timing of moves is endogenously determined*, it is always possible to find some type of partial tax union for any value of \( \varepsilon_H / \varepsilon_L \); in this sense, the endogenous timing of moves matters.

The sustainability of partial tax harmonization crucially depends on the asymmetry of productivity between countries \( H \) and \( M \) relative to that between countries \( L \) and \( M \), i.e., the ratio \( \varepsilon_H / \varepsilon_L \). More precisely, the similar the ratio between these two asymmetries (i.e.,
Figure 4: Minimum discount factors of the respective countries under simultaneous-move games.

$\varepsilon_H / \varepsilon_L \to 1$), the more likely is the partial tax harmonization excluding the median country $M$ to be sustained. This is because the closer its productivity to the average one between countries $H$ and $L$, the less the amount of trading and, consequently, the less the amount of income transfers between the union-member countries $H$ and $L$, which ends up weakening the incentive of deviation, and vice versa. Even if country $M$ were to join the tax union, not only does the same result hold, but also it always has a stronger incentive to deviate compared to the other member country, i.e., country $H$ or $L$, because country $M$ is always forced to make income transfers to its partner as a result of a common harmonized tax rate.

5 Concluding remarks

This paper reveals that the sustainability of partial tax coordination in an infinitely repeated tax-competition model would affect the endogenous timing of moves. It shows that in the infinitely repeated tax-competition game a sequential-move equilibrium emerges as its SPNE even if a stage game of this repeated game has the same structure as the standard static tax-competition model such as Ogawa (2003) or others in which Stackelberg leader’s payoffs exceed Stackelberg follower’s payoffs. The key to understanding this result is that infinitely
repetition creates the opportunity to sustain a wider range of behavior as a Nash equilibrium (or a SPNE) of repeated games than is possible in one-shot games. To do this, two crucial assumptions are required; sufficiently patient players and the fulfilment of the participation constraints for union-members. In the present setting, the requirement of individual rationality is met if the participation constraints for countries to form a tax union implementing tax harmonization hold. Recently, Ida (2015) has shown that a tax credit system not only makes countries being better in the sequential-move (i.e., Stackelberg) tax-competition game than in the simultaneous-move tax game, but also causes Stackelberg tax competition, while Eichner (2014) has found that in the tax competition model at which governments provide public goods if both jurisdictions cause positive externalities in taxes in Nash as well as in Stackelberg games, both jurisdictions have second-mover incentive. In comparison of these contributions, we would like to say that our repeated game setting would also provide another important and inherent channel through which essentially affects the timing of moves without further institutional ingredients when considering partial tax harmonization.

These results have quite important policy implications. The first implication is that the insights obtained from the two-stage timing game of tax competition such as Kempf and Rota-Graziosi (2010) and Ogawa (2013) may not carry over to the repeated tax-competition model between a tax-coalition group and outside countries. In particular, unlike the results of those authors, our result indicates a possibility that a tax union may resist against acting as a first mover in tax competition games to sustain tax harmonization. As the most likely scenario, the ECAs are expected to move the first on the ground that one would expect the ECAs to take a leadership for establishing full tax harmonization among EU’s member countries. Unfortunately, our paper indicates that such an optimistic expectation would not be voluntarily materialized; accordingly, other motivations, such as political motivations, are called upon for the ECA to play a role of Stackelberg leadership in establishing comprehensive reforms for the cooperate tax systems of EU Member States, such as a so-called Common Consolidated Corporate Tax Base for European Multinational Enterprises.

The results obtained in this paper critically rely on the restrictive structure of the present model; e.g., a linear utility function and a quadratic production function in a three-country
setting. To ascertain the robustness of our results, we have to conduct the same analysis under more general functions and/or more than three countries. Due to its complexity, we need to resort to a numerical analysis. It also remains an important task to investigate whether our conclusion is still robust or not in a heterogeneous model with respect to population size, initial capital endowments or valuation of local public goods. The equally important extension is to construct a bargaining model which explains an entire coalition process to reach a self-enforcing agreement regarding tax harmonization among three countries or more. As a first step towards this direction, we have to introduce the notion of coalition formation and coalition proofness in which all options of all possible coalitions must be taken into consideration. Although this requirement increases the complexity enormously and implies ambiguous results, it also deserve future study.

Appendix

The minimum discount factors of country \( i, j \in G = \{H, M\} \) or \( \{M, L\} \) are as follows:

\[
\delta_i(G^S) = \frac{u_i^D(G^S) - u_i^C(G^S)}{u_i^D(G^S) - u_i^N} = \frac{81(A_i - 3A_j + 2A_h)^2}{(11A_i - A_j - 10A_h)(139A_i - 65A_j - 74A_h)}.
\]

Using the notations \( \varepsilon_H \equiv A_H - A_M \) and \( \varepsilon_L \equiv A_M - A_L \) as before and differentiating \( \delta_i(G^S) \) with respect to the ratio \( \varepsilon_H/\varepsilon_L \) yields:

\[
\frac{\partial \delta_H(G^S)}{\partial (\varepsilon_H/\varepsilon_L)} \gtrless 0 \text{ if } \frac{\varepsilon_H}{\varepsilon_L} \gtrsim \frac{46}{19}, \text{ and } \frac{\partial \delta_M(G^S)}{\partial (\varepsilon_H/\varepsilon_L)} \gtrless 0 \text{ if } \frac{\varepsilon_H}{\varepsilon_L} \gtrsim \frac{1}{2} \text{ for } G^S = \{H, M\},
\]

\[
\frac{\partial \delta_M(G^S)}{\partial (\varepsilon_H/\varepsilon_L)} \gtrless 0 \text{ if } \frac{\varepsilon_H}{\varepsilon_L} \gtrsim \frac{19}{46}, \text{ and } \frac{\partial \delta_L(G^S)}{\partial (\varepsilon_H/\varepsilon_L)} \gtrless 0 \text{ if } \frac{\varepsilon_H}{\varepsilon_L} \gtrsim \frac{1}{2} \text{ for } G^S = \{M, L\}.
\]

Since it can be verified not only that \( \delta_H(G^S) < \delta_M(G^S) \leq 1 \) for \( \varepsilon_H/\varepsilon_L \in (0, (36\sqrt{3} - 53)/83] \simeq 0.225 \), \( \delta_H(G^S) = \delta_M(G^S) = 81/185 \simeq 0.438 \) at \( \varepsilon_H/\varepsilon_L = 0 \) for \( G^S = \{H, M\} \), but also that \( 1 \geq \delta_M(G^S) > \delta_L(G^S) \) for \( \varepsilon_H/\varepsilon_L \in [(36\sqrt{3} + 53)/26, \infty) \simeq 4.437 \), and \( \delta_M(G^S) = \delta_L(G^S) = 81/185 \) as \( \varepsilon_H/\varepsilon_L \to 0 \) for \( G^S = \{M, L\} \), we obtain Fig. 4.
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