Discussion Paper, Series A, No.2015-286

Does Endogenous Timing Matter in Implementing Partial Tax Harmonization?

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June.2015

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Does Endogenous Timing Matter in Implementing Partial Tax Harmonization? *

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June 28, 2015

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 sequential-move (Stackelberg) outcomes can be sustained as SPNEs when a tax-union consists of *dissimilar* countries. This is in sharp contrast with the finding of Ogawa (2013). In his two-stage game, 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. 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.

JEL classification: H30; H87

Keywords: Tax competition; Tax harmonization, Endogenous timing; Repeated game;

*An earlier version of this paper was presented at the CESifo Area Conference 2015 on Public Sector Economics. We thank John Wilson for his useful comments. The first and second authors gratefully acknowledge the financial support provided by the Grant-in-Aid for Scientific Research from the Japan Society for the Promotion of Science (#21530290) and (#24530379), respectively.

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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 a remedy against inefficiently low taxes on mobile tax bases or against production inefficiency induced by asymmetric tax rates in the literature on tax competition. Although tax coordination among all countries in the economy is desirable, it is generally difficult to achieve full tax coordination among all existing countries. This is 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 (e.g., 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; 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 studies that examine how the formation of a partial tax union that 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 structures. Vrijburg (2009) sets up a three-country model with heterogenous population size and shows that partial harmonization unambiguously increases welfare for outside countries; here, however, the welfare of inside countries might either increase or decrease despite that their coordinated taxes unambiguously increase. More recently, Vrijburg and de Mooij (2010) compare between the simultaneous-move

Nash equilibrium and the sequential-move equilibrium in which a subset of countries acting as a Stackelberg leader that implement partial tax harmonization in the above three-country model. They show 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 that of the tax union in the Nash equilibrium (and vice versa the sequential-move equilibrium). This research agenda provides one possible answer to the practical question of whether countries such as those under an enhanced cooperation agreement (ECA) in the EU or the EU in the world economy are motivated to form a coalition group of countries that implements tax harmonization.

The analysis of Vrijburg and de Mooij (2010) is not only quite interesting theoretically but also the first attempt to introduce Stackelberg competition in the literature on tax coordination among a subset of countries. Most other studies have exclusively employed *simultaneous-move* tax competition games between a tax union and the remainder of the individual countries. The sequential-move game has been used frequently in the field of international policy coordination, such as international environmental agreements (IEAs; e.g., the Kyoto protocol). The literature on self-enforcing IEAs examines both cases where all countries (signatories and non-signatories) make their decisions simultaneously (Carraro and Siniscalco 1993) and those where countries that have ratified the IEAs (signatories) act as leaders whose decisions precede those of the countries that remain outside the IEA (Barrett 1994, Rubio and Ulph 2006, Diamantoudi and Sartzetakis 2006). These two different timing models are not only a type of workhouse tool used to study IEAs, but they also offer significant and critical 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 the usual criticism of the Stackelberg equilibrium in that the order of moves of the players is *exogenously given ex-ante.* The present paper incorporates an *endogenous determination of the timing of moves* between a tax union and an outside country 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 governments compete for mobile capital in a *simultaneous-move* Nash equilibrium of a one-shot tax competition game in which competing governments simultaneously and independently select their tax rates. They also show that Stackelberg equilibria are subgame-perfect Nash equilibria (SPNEs) 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. In contrast, 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 this two-stage game. Although these authors do **not** consider the interaction between tax coalition groups and outside countries, the extension we consider may be justified by the presented literature on IEAs; furthermore, the timing of decision-making is shown to be an essential strategic variable of competing governments that affects the consequences of fiscal competition involving a coalition group of countries that harmonize their fiscal policies.

This study investigates an infinitely repeated tax competition game between a tax union (e.g., the ECA in the EU or the EU in the world economy) which implements tax harmonization and the rest of the *individual* countries. For analytical tractability, this analysis employs a *heterogenous three-country* version of the *repeated tax-competition model* developed by Itaya et al. (2015). The repeated game model would provide a more relevant and satisfactory workhouse that explains 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) for more details). In particular, it is well-documented that national tax authorities always have an incentive to unilaterally deviate from even a Pareto-improving coordinated tax rate in the hope of reaping gains such as increased tax revenues or higher welfare levels; hence, the countries generally fail to implement such implicit collusion or an explicit agreement for tax coordination without *supranational agency* or *institution* that could enforce it. Instead, maintenance of collusive agreements, explicitly or implicitly, requires repeated interaction that allows union members to punish deviators from an implicit agreement or a tax union in the future. Following Kempf and Rota-Graziosi (2010) and Ogawa (2013), we also introduce the pre-play (or announcement) 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 importantly, *the timing of moves endogenously chosen in the pre-play stage must be creditably committed in the sense that it is a Nash equilibrium (SPNE) of an infinitely repeated game rather than a Nash equilibrium of a one-shot or two-stage game.*

This paper demonstrates the following results. 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. They have opposed incentives to manipulate the price of capital, which is the favorable result in the simultaneous-move equilibrium of every stage of the repeated tax-competition game. In other words, the simultaneous-move outcome prevails in every stage of the repeated tax-competition game as the SPNE if a tax union consists of *similar* countries. Second, both the Stackelberg sequential-move and simultaneous-move outcomes can be sustained as a SPNE for every stage when a tax union consists of *dissimilar* countries. The reason for this difference is as follows. Within a tax union comprising of *dissimilar* countries a disadvantaged country suffers from a greater loss due to a common coordinated tax rate. The tax union has to choose a *moderate* common tax rate relative to that in the simultaneous-move equilibrium in order to ameliorate such a loss; otherwise, the disadvantaged country deviates from the tax union. It will be shown that the tax union acting as a Stackelberg follower is able to make this loss less compared to that when it acts as a Stackelberg leader, despite the fact that the Stackelberg follower's strategy does not comprise a Nash equilibrium of the one-shot tax competition game. Third, the Stackelberg sequential-move equilibrium can be sustained as a SPNE of the repeated tax-competition game in a wider range of productivity differences between member countries compared to the simultaneous-move equilibrium for the reason stated above. In other words, the Stackelberg sequential-move equilibrium allows for a larger degree of productivity asymmetry between member countries which is consistent with the sustainability of partial tax coordination.

The remainder of the paper is organized as follows. Section 2 presents our 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, 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* such that our dynamic game (or supergame) is reduced to an infinite 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 is a continuum of *homogenous* households normalized to 1. They are immobile across countries, while their capital endowments, denoted by $\overline{k}$, are identical, fixed through time, and perfectly mobile across countries. These production 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 loss of generality, we further assume that countries H, M, and L, respectively, use different technologies, whose productivities are ordered 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 τ_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

[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 adjustment costs when undertaking investment activity, and thus, *their intertemporal profit maximization problems simplify to an infinite repetition of a static profit maximization problem.*

[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).

maximization in country i are

$$r = f_i'(k_i) - \tau_i, \qquad i = H, M, L. \tag{1}$$

Since the entire amount of capital in the economy is fixed at $3\overline{k}$ through time, the market for capital is perfectly competitive; hence, capital flows across 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

$$3\overline{k} = k_H(r + \tau_H) + k_M(r + \tau_M) + k_L(r + \tau_L), \tag{2}$$

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 previously for $i = H, M, L$, yields the equilibrium net return r^* and the equilibrium amount of capital employed by country i, k_i^*:

$$r^* = \overline{A} - 2\overline{k} - \overline{\tau}, \tag{3}$$

$$k_i^* = \overline{k} - \frac{\left(\overline{A} - A_i\right) - \left(\overline{\tau} - \tau_i\right)}{2}, \tag{4}$$

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

$$\frac{\partial r^*}{\partial \tau_i} = \frac{\partial k_i^*}{\partial \tau_i} = -\frac{1}{3} < 0 \text{ and } \frac{\partial k_j^*}{\partial \tau_i} = \frac{1}{6} > 0,\ i \neq j. \tag{5}$$

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 savings opportunities, they spend their entire income on consumption of the numéraire good c_i every period. Accordingly, the period's budget constraint of the household residing in country i is expressed by $c_i = w_i + r^*\overline{k}$. To obtain the 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, that is, $u_i(c_i, g_i) \equiv c_i + g_i = f_i(k_i^*) + r^*\left(\overline{k} - k_i^*\right)$.[3] Here, g_i is either a publicly provided good or a lump-sum transfer from the production sector to the households, and the government's budget constraint of country i is balanced each period, that is, $g_i = \tau_i k_i^*$.

The government chooses an optimal tax rate to maximize the discounted present value of the sum of the 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 infinite 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 τ_i to maximize the one-period utility of country i's residents. The first-order condition of country i is as follows:[4]

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

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

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

which reveals that the tax rates of different countries are *strategic complements* (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 τ_i^N, the price of capital r^N, and the amount of capital demanded k_i^N, respectively:

[3] Assumptions of linear utility functions have been commonly used in the literature on tax competition. See Bucovetsky (1991, 2009) and Peralta and van Ypersele (2005).

[4] In what follows, we restrict the equilibrium to an interior solution.

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

$$r^N = \overline{A} - 2\overline{k}, \tag{9}$$

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

It follows from (8) and (10) that a country with the most productive technology (i.e., country H) 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; that is, 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, leading to a *zero average tax rate* in the Nash equilibrium, i.e., $\overline{\tau}^N = 0$ (which is confirmed by summing (8) over all i). Using (8), (9), and (10), we show that country i ($i = H, M, L$) can achieve the following one-period utility level in every period:

$$u_i^N = (A_i - \overline{k})\overline{k} + \frac{2\,(2A_i - A_j - A_h)^2}{81}. \tag{11}$$

3 Partial coordination in a stage game

Let $G \subsetneq \{H, M, L\}$ represent a subset of the existing countries. We consider three possible subsets forming a tax union that implements partial tax harmonization lasting over an infinite horizon period, such as $G \in \{\{H, M\}, \{M, L\}, \{H, L\}\}$.

Because the repeated game we consider can be viewed simply as an infinite repetition of an *identical* stage game, in order to endogenize the order of moves chosen by competing governments, we simply add an initial stage (which we may call a "pre-play stage game" or a "timing game") to the repeated tax-competition game in which every government simultaneously decides whether to *move early or late* in every stage game of the subsequent repeated game. 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 $\{$*lead*, *follow*$\}$. If their announced timings coincide with each other; that is, either the strategy profile (*lead*, *lead*), or (*follow*, *follow*) is announced, a simultaneous-move game between the tax union G and the outside country h is played in every stage game. Alternatively, a sequential-move stage game is played in every stage game if their announced timings are different; that is, either strategy profile (*lead*, *follow*) 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 late 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 the *same* tax rate in every stage game of the infinitely repeated game according to the moves committed 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 infinitely 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 and the outside country h. All member countries of the tax union have agreed to jointly choose their tax rates in order to maximize the sum of their one-period utilities, represented by $W(G) \equiv u_i + u_j = f_i(k_i^*) + f_j(k_j^*) + r^* \left(k_h^* - \overline{k}\right)$, while the outside country h independently and simultaneously chooses its tax rate to maximize u_h

in each period.[5,6] The first-order conditions of the tax union G with respect to τ_i and τ_j for $i,\, j \in G$; $h \notin G$ are given by

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

and $\partial W\left(G\right)/\partial \tau_j = 0$, respectively. By substituting (3), (4), and (5) into these conditions, the best-response functions of the tax union members and the outside country h are derived as follows:

$$\tau_i = \frac{2\tau_j + 2\tau_h + (A_i + A_j - 2A_h)}{7}, \;\; i, j \in G;\;\; h \notin G, \tag{12}$$

whereas τ_j is obtained by switching i and j in the (12). These symmetry forms lead to $\tau_i = \tau_j \equiv \tau^C$; namely, that 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

$$\tau^C = \frac{2\tau_h + (A_i + A_j - 2A_h)}{5}. \tag{13}$$

On the other hand, the outside country h individually and independently chooses its best-replied tax rate according to (7) with i being exchanged for h and setting $\tau_i = \tau_j \equiv \tau^C$. By simultaneously solving these best-response functions, we obtain the harmonized tax rate for the tax union, $\tau^C(G^S)$, and $\tau_h^C(G^S)$ for the outside country (the superscript S of G stands for the case where the tax union G and the outside country both move simultaneously), the equilibrium net return, $r^C(G^S)$ (using (3)), the amount of capital demanded for each union

[5] 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.*

[6] Since this equilibrium is also a Nash equilibrium of an one-shot tax competition game, it is often referred to as a subgroup Nash equilibrium to distinguish from the *fully noncooperative Nash equilibrium* that we have characterized thus far (see Konrad and Schjelderup, 1999, for a subgroup Nash equilibrium).

member, $k_i^C(G^S)$ for $\forall i \in G$, and $k_h^C(G^S)$ for the outside country h (using (4)), respectively:

$$\tau^C(G^S) = \frac{A_i + A_j - 2A_h}{6}, \quad \tau_h^C(G^S) = -\frac{A_i + A_j - 2A_h}{12}, \tag{14}$$

$$r^C(G^S) = \frac{A_i + A_j + 2A_h}{4} - 2\overline{k}, \tag{15}$$

$$k_i^C(G^S) = \overline{k} + \frac{7A_i - 5A_j - 2A_h}{24}, \quad k_h^C(G^S) = \overline{k} - \frac{A_i + A_j - 2A_h}{12}, \tag{16}$$

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), whereas the outside country exports (imports) with subsidies (taxes) $\tau_h^C(G^S) < 0$ (> 0). In particular, if there are no productivity asymmetries, that is, $A_i = A_j = A_h$, all countries have no incentive to trade capital and thus $\tau^C(G^S) = \tau_h^C(G^S) = 0$ 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 their favor, inducing them to set tax rates with opposite signs (recall (14)). There is *additional conflict between the union members*, because the formation of a tax union forces all member countries to accept a *common* coordinated tax rate despite that the most favorable tax rates for the respective member countries usually differ from this common tax rate owing 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 one. Then, if that tax union were to set a *positive* common tax rate (i.e., if $(A_H - A_M) + (A_L - A_M) > 0$), $\tau^C(G^S) > 0$ 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

$$u_i^C(G^S) = (A_i - \overline{k})\overline{k} + \frac{(7A_i - 5A_j - 2A_h)(11A_i - A_j - 10A_h)}{576}, \tag{17}$$

$$u_h^C(G^S) = (A_h - \overline{k})\overline{k} + \frac{(A_i + A_j - 2A_h)^2}{72}. \tag{18}$$

Using (11) and (17), the participation constraint for country i (i.e., $\forall i \in G$) is given by[7]

$$u_i^C(G^S) - u_i^N = \frac{243(A_i - A_j)(A_i - A_h) - (2A_i - A_j - A_h)(31A_i - 83A_j + 52A_h)}{5184} \geq 0. \quad (19)$$

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 tax union including the governments of countries i and j solves the sequence of the following one-period maximization problem *for each period*:

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

The first-order conditions with respect to τ_i and τ_j are given by

$$\begin{aligned} \frac{\partial W(G)}{\partial \tau_i} &= f_i'\left(k_i^*\right)\left(\frac{\partial k_i^*}{\partial \tau_i} + \frac{\partial k_i^*}{\partial \tau_h}\frac{\partial \tau_h}{\partial \tau_i}\right) + f_j'(k_j^*)\left(\frac{\partial k_j^*}{\partial \tau_i} + \frac{\partial k_j^*}{\partial \tau_h}\frac{\partial \tau_h}{\partial \tau_i}\right) \\ &+ r^*\left(\frac{\partial k_h^*}{\partial \tau_i} + \frac{\partial k_h^*}{\partial \tau_h}\frac{\partial \tau_h}{\partial \tau_i}\right) + \left(k_h^* - \overline{k}\right)\left(\frac{\partial r^*}{\partial \tau_i} + \frac{\partial r^*}{\partial \tau_h}\frac{\partial \tau_h}{\partial \tau_i}\right) = 0, \end{aligned} \quad (20)$$

and, similarly, $\partial W(G)/\partial \tau_j = 0$ for $i, j \in G$; $h \notin G$. By substituting (3), (4), (5), and (7) for h into (20) 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, $\tau_h^C(G^L)$. Furthermore, substituting these tax rates into (3) and (4) gives the equilibrium price of capital, $r^C(G^L)$, and the capital demands $k_i^C(G^L)$ for $\forall i \in G$, and $k_h^C(G^L)$ for the outside country:

$$\tau^C(G^L) = \frac{3\left(A_i + A_j - 2A_h\right)}{14}, \; \tau_h^C(G^L) = -\frac{A_i + A_j - 2A_h}{14}, \quad (21)$$

$$r^C(G^L) = \frac{3A_i + 3A_j + 8A_h}{14} - 2\overline{k}, \quad (22)$$

$$k_i^C(G^L) = \overline{k} + \frac{4A_i - 3A_j - A_h}{14}, \; k_h^C(G^L) = \overline{k} - \frac{A_i + A_j - 2A_h}{14}, \quad (23)$$

[7] In contrast, for the outside country h, we obtain that $u_h^C(G^S) - u_h^N = -7(A_i + A_j - 2A_h)^2/648 \leq 0$. This implies that the welfare of country h unambiguously falls as a result of the formation of a tax union regardless of the type of tax union.

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 utility levels of the union members i (i.e., $\forall i \in G$) and the outside country h are respectively given by:

$$u_i^C(G^L) = (A_i - \overline{k})\overline{k} + \frac{(A_i - A_h)(4A_i - 3A_j - A_h)}{28}, \tag{24}$$

$$u_h^C(G^L) = (A_h - \overline{k})\overline{k} + \frac{(A_i + A_j - 2A_h)^2}{98}. \tag{25}$$

Using (11) and (24), the participation constraints for $\forall i \in G$ are given by

$$u_i^C(G^L) - u_i^N = \frac{162(A_i - A_j)(A_i - A_h) - (2A_i - A_j - A_h)(31A_i - 56A_j + 25A_h)}{2268} \geq 0. \tag{26}$$

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 call G^F). 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:

$$\max_{\tau_h} u_h = f_h\left(k_h^*\right) + r^*\left(\overline{k} - k_h^*\right), \text{ s.t. } (13).$$

The first-order condition is

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

Combining this condition with (3), (4), (5), and (13) yields the coordinated tax rate set, $\tau^C(G^F)$, the tax rate set by h, $\tau_h^C(G^F)$, the equilibrium capital remuneration, $r^C(G^F)$, and the capital demands, $k_i^C(G^F)$ for $\forall i \in G$, and $k_h^C(G^F)$ for $h \notin G$:

$$\tau^C(G^F) = \frac{A_i + A_j - 2A_h}{8}, \; \tau_h^C(G^F) = -\frac{3\,(A_i + A_j - 2A_h)}{16}, \tag{27}$$

$$r^C(G^F) = \frac{5A_i + 5A_j + 6A_h}{16} - 2\overline{k}, \tag{28}$$

$$k_i^C(G^F) = \overline{k} + \frac{9A_i - 7A_j - 2A_h}{32}, \; k_h^C(G^F) = \overline{k} - \frac{A_i + A_j - 2A_h}{16}. \tag{29}$$

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

$$u_i^C(G^F) = (A_i - \overline{k})\overline{k} + \frac{(9A_i - 7A_j - 2A_h)\,(13A_i - 3A_j - 10A_h)}{1024}, \tag{30}$$

$$u_h^C(G^F) = (A_h - \overline{k})\overline{k} + \frac{(A_i + A_j - 2A_h)^2}{64}. \tag{31}$$

The participation constraints for $\forall i \in G$ are expressed as

$$\begin{aligned} u_i^C(G^F) - u_i^N = \frac{1}{82944} & [81(7A_i + 6A_j - A_h)(11A_i - 2A_j - 9A_h) \\ & -(2A_i - A_j - A_h)(2476A_i - 1319A_j - 1157A_h)] \geq 0. \end{aligned} \tag{32}$$

3.4 Comparison of tax rates

A straightforward comparison of the tax rates obtained thus far (i.e., (8), (14), (21) and (27)) yields the following lemma:

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

$$\tau_L^N < \tau_M^N < 0 < \tau^C(G^F) < \tau^C(G^S) < \tau^C(G^L) < \tau_H^N, \quad \text{for} \;\; \varepsilon_H > \varepsilon_L, \tag{33}$$

$$\tau_L^N < \tau^C(G^L) < \tau^C(G^S) < \tau^C(G^F) < 0 < \tau_M^N < \tau_H^N, \quad \text{for} \;\; \varepsilon_H < \varepsilon_L, \tag{34}$$

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

$$\tau_L^N < 0 < \tau_M^N < \tau_H^N < \tau^C(G^F) < \tau^C(G^S) < \tau^C(G^L), \quad \text{for} \;\; \varepsilon_H < \varepsilon_L. \tag{35}$$

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

$$\tau^C(G^L) < \tau^C(G^S) < \tau^C(G^F) < \tau_L^N < \tau_M^N < 0 < \tau_H^N, \quad for \ \ \varepsilon_H > \varepsilon_L. \tag{36}$$

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 the Stackelberg leader is able to set their most *favorable* (or the second most) tax rates compared to those set by the Stackelberg follower as well as at the fully noncooperative Nash equilibrium. In other words, the Stackelberg leader has an incentive to exploit the gain associated with the "first-mover advantage". Since the tax union $\{H, M\}$ is a capital importer for $\varepsilon_H > \varepsilon_L$,[8] 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 (35). 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 (36). On the other hand, the tax union $\{H, L\}$ becomes a capital-importing (capital-exporting) one when $\varepsilon_H > \varepsilon_L$ ($\varepsilon_H < \varepsilon_L$) and thus wants to become a Stackelberg leader (follower) in order to realize higher positive (lower negative) tax rates, which is the second-highest (second-lowest) tax rate as indicated by (33) ((34)).

3.5 Timing selection

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

outsider h \ tax union G	Lead	Follow
Lead	$u_h^C(G^S),\ u_i^C(G^S) + u_j^C(G^S)$	$u_h^C(G^F),\ u_i^C(G^F) + u_j^C(G^F)$
Follow	$u_h^C(G^L),\ u_i^C(G^L) + u_j^C(G^L)$	$u_h^C(G^S),\ u_i^C(G^S) + u_j^C(G^S)$

Table 1. A payoff matrix of each stage game.

[8] As shown later, the tax union $\{H, M\}$ ($\{M, L\}$) is not formed for the range of $\varepsilon_H > \varepsilon_L$ ($\varepsilon_H < \varepsilon_L$).

First, we compare between the utility levels of the outside country h in the stage games with different timings of moves described thus far, which yields the following result:

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

Proof. Comparing between (18), (25), and (31) yields

$$u_h^C(G^S) - u_h^C(G^L) = \frac{13\,(A_i + A_j - 2A_h)^2}{3528} \geq 0,$$
$$u_h^C(G^F) - u_h^C(G^S) = \frac{(A_i + A_j - 2A_h)^2}{576} \geq 0.$$

Hence, the outside country h has a *dominant strategy* unless $A_i + A_j = 2A_h$ (see Table 1 also); that is, it always has an incentive to be a Stackelberg leader *regardless of the timing chosen by the tax union.* ■

An outside country then always chooses a strategy of being a Stackelberg leader in the 2×2 game (the initial stage game) given by the payoffs matrix depicted in Table 1 except for the degenerate case $A_i + A_j = 2A_h$.[9]

From (17), (24), and (30), furthermore, we obtain the following results for all tax union-member countries $i \in G$:

$$u_i^C(G^L) - u_i^C(G^S) = \frac{(A_i + A_j - 2A_h)(37A_i - 35A_j - 2A_h)}{4032} \gtreqless 0, \tag{37}$$
$$u_i^C(G^F) - u_i^C(G^S) = -\frac{(A_i + A_j - 2A_h)(179A_i - 109A_j - 70A_h)}{9216} \gtreqless 0. \tag{38}$$

Although the signs of (37) and (38) appear to be ambiguous, their signs would be determined depending on the productivity parameters of all three countries. Before proceeding, because the outside country h always chooses to be a leader (recall Lemma 1), the game G^L is never played; hence, we ignore (37). A further inspection of (38) yields the following lemmas:

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

[9] However, we do not further investigate the degenerate case where $A_i + A_j = 2A_h$ (i.e., $A_i = A_j = A_h$), 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.

Proof. Using these notations, we can rewrite (38) for the respective members of the tax union $\{H, M\}$ as follows:

$$u_H^C(G^S) - u_H^C(G^F) = \frac{(\varepsilon_H + 2\varepsilon_L)(179\varepsilon_H + 70\varepsilon_L)}{9216} > 0,$$
$$u_M^C(G^S) - u_M^C(G^F) = \frac{(\varepsilon_H + 2\varepsilon_L)(-109\varepsilon_H + 70\varepsilon_L)}{9216} \gtreqless 0, \text{ iff } \frac{\varepsilon_H}{\varepsilon_L} \lesseqgtr \frac{70}{109} \simeq 0.642. \quad (39)$$

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., $u_H^C(G^S) \geq u_H^N$ and $u_M^C(G^S) \geq u_M^N$. Since the second inequality can be expressed by

$$u_M^C(G^S) - u_M^N = \frac{52\varepsilon_L^2 - 212\varepsilon_H\varepsilon_L - 83\varepsilon_H^2}{5184} \geq 0, \quad (40)$$

it is easy to see that (40) holds only when $\varepsilon_H/\varepsilon_L \leq (72\sqrt{3} - 106)/83 \simeq 0.225$. Since this upper bound is smaller than the upper bound given by (39), i.e., $\varepsilon_H/\varepsilon_L \leq 70/109 \simeq 0.642$,the inequality $u_M^C(G^S) > u_M^C(G^F)$ is satisfied when country M prefers simultaneous moves. In addition, the first participation constraint for country H, $u_H^C(G^S) \geq u_H^N$, is always satisfied, because

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

In summary, the tax union $\{H, M\}$ in the simultaneous-move game G^S is possible as long as $\varepsilon_H/\varepsilon_L \leq (72\sqrt{3} - 106)/83 \simeq 0.225$.

Conversely, when $\varepsilon_H/\varepsilon_L > (72\sqrt{3} - 106)/83 \simeq 0.225$, (40) does not hold owing to the stated result. The participation constraint (32) for country M does not hold either, because

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

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

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

$$u_M^C(G^S) - u_M^C(G^F) = -\frac{(2\varepsilon_H + \varepsilon_L)(109\varepsilon_L - 70\varepsilon_H)}{9216} \gtreqless 0, \text{ iff } \frac{\varepsilon_H}{\varepsilon_L} \gtreqless \frac{109}{70} \simeq 1.557, \tag{41}$$
$$u_L^C(G^S) - u_L^C(G^F) = \frac{(2\varepsilon_H + \varepsilon_L)(179\varepsilon_L + 70\varepsilon_H)}{9216} > 0.$$

When $\varepsilon_H/\varepsilon_L > 109/70 \simeq 1.557$, it holds that $u_M^C(G^S) > u_M^C(G^F)$, 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

$$u_M^C(G^S) - u_M^N = \frac{52\varepsilon_H^2 - 212\varepsilon_H\varepsilon_L - 83\varepsilon_L^2}{5184} \geq 0, \text{ iff } \frac{\varepsilon_H}{\varepsilon_L} \geq \frac{53 + 36\sqrt{3}}{26} \simeq 4.437, \tag{42}$$
$$u_L^C(G^S) - u_L^N = \frac{52\varepsilon_H^2 + 316\varepsilon_H\varepsilon_L + 181\varepsilon_L^2}{5184} > 0.$$

Put together, when $\varepsilon_H/\varepsilon_L \geq (53 + 36\sqrt{3})/26 \simeq 4.437$, it is possible to form the tax union $\{M, L\}$ that opts to act as a leader thus leading to the simultaneous-move game, because the lower bound of 4.437 is greater than the lower bound of (41), i.e., 1.557.

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

$$u_M^C(G^F) - u_M^N = \frac{-428\varepsilon_H^2 - 2060\varepsilon_L\varepsilon_H - 347\varepsilon_L^2}{82944} < 0,$$

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 $\{H, L\}$ that chooses simultaneous moves is possible when $(72\sqrt{3} - 23)/181 \leq \varepsilon_H/\varepsilon_L \leq (23 + 72\sqrt{3})/83$, whereas the tax union $\{H, L\}$ that 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 (38) can be expressed by:

$$u_H^C(G^S) - u_H^C(G^F) = \frac{(\varepsilon_H - \varepsilon_L)(179\varepsilon_H + 109\varepsilon_L)}{9216}, \tag{43}$$
$$u_L^C(G^S) - u_L^C(G^F) = -\frac{(\varepsilon_H - \varepsilon_L)(109\varepsilon_H + 179\varepsilon_L)}{9216}. \tag{44}$$

Because 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*, that is, 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. The participation constraint for country H is given by

$$u_H^C(G^S) - u_H^N = \frac{181\varepsilon_H^2 + 46\varepsilon_H\varepsilon_L - 83\varepsilon_L^2}{5184} \geq 0, \text{ iff } \frac{\varepsilon_H}{\varepsilon_L} \geq \frac{72\sqrt{3} - 23}{181} \simeq 0.562,$$

while that for country L is given by

$$u_L^C(G^S) - u_L^N = \frac{-83\varepsilon_H^2 + 46\varepsilon_H\varepsilon_L + 181\varepsilon_L^2}{5184} \geq 0, \text{ iff } \frac{\varepsilon_H}{\varepsilon_L} \leq \frac{23 + 72\sqrt{3}}{83} \simeq 1.78.$$

It is immediate that both participation constraints are *simultaneously* satisfied as long as $(72\sqrt{3} - 23)/181 \leq \varepsilon_H/\varepsilon_L \leq (23 + 72\sqrt{3})/83$ (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 that the outside country always prefers to act as a leader).

Finally we examine whether it is possible for the tax union $\{H, L\}$ to act as a *follower*. In this case, the participation constraints (32) for countries H and L are given by

$$u_H^C(G^F) - u_H^N = \frac{1285\varepsilon_H^2 + 1366\varepsilon_H\varepsilon_L - 347\varepsilon_L^2}{82944} \geq 0, \text{ iff } \frac{\varepsilon_H}{\varepsilon_L} \geq \frac{288\sqrt{11} - 683}{1285} \simeq 0.212,$$
$$u_L^C(G^F) - u_L^N = \frac{-83\varepsilon_H^2 + 46\varepsilon_H\varepsilon_L + 181\varepsilon_L^2}{5184} \geq 0, \text{ iff } \frac{\varepsilon_H}{\varepsilon_L} \leq \frac{683 + 288\sqrt{11}}{347} \simeq 4.721.$$

A close inspection of these two conditions reveals that there certainly exists a *common* overlapping range in which both participation constraints are simultaneously satisfied, that is, $(288\sqrt{11} - 683)/1285 \leq \varepsilon_H/\varepsilon_L \leq (683 + 288\sqrt{11})/347$ (i.e., approximately, $0.212 \leq \varepsilon_H/\varepsilon_L \leq 4.721$). By straightforward comparison, moreover, it turns out not only that the range of $\varepsilon_H/\varepsilon_L$ in which the tax union $\{H, L\}$ takes sequential moves is larger than the possible range for that tax union taking simultaneous moves, but also that the latter range is contained in the former one. ■

In summary, we have the following important result:

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

Three remarks are in order. First, it follows from Lemma 2 that both the capital-importing and capital-exporting tax unions $\{H, M\}$ and $\{M, L\}$ 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, **two** asymmetric countries have opposite incentives to manipulate the price of capital (i.e., the terms-of-trade effect) such that dissimilar incentives allow for a simultaneous-move equilibrium to emerge. Because the capital-exporting tax union $\{M, L\}$ (capital-importing tax union $\{H, M\}$) in our setting is also 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 those in Ogawa's (2013) two-country model. According to Ogawa, the reason for this is that in such a setting, the 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; indeed,

$$\begin{aligned}
\left[u_H^C(G^S) + u_M^C(G^S)\right] - \left[u_H^C(G^F) + u_M^C(G^F)\right] &= \frac{35}{4608}\left(\varepsilon_H + 2\varepsilon_L\right)^2 > 0, \\
\left[u_M^C(G^S) + u_L^C(G^S)\right] - \left[u_M^C(G^F) + u_L^C(G^F)\right] &= \frac{35}{4608}\left(2\varepsilon_H + \varepsilon_L\right)^2 > 0, \\
\left[u_H^C(G^S) + u_L^C(G^S)\right] - \left[u_H^C(G^F) + u_L^C(G^F)\right] &= \frac{35}{4608}\left(\varepsilon_H - \varepsilon_L\right)^2 \geq 0.
\end{aligned}$$

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

Second, there is 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 infinite repetitions of both the strategy profiles (Lead, Lead) and (Lead, Follow) constitute SPNEs of the repeated tax-competition game.[10] Notably, 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 a Nash equilibrium (i.e., a SPNE) of the infinitely repeated game owing to the argument based on the *folk theorem*, which states that any payoff vector to an infinitely repeated game that satisfies *individual rationality* can be sustained as a SPNE as long as players are sufficiently patient. Recalling that the requirement of *individual rationality* is met when the participation constrains for all union members are satisfied, Lemma 3 indicates that the strategy profile (Lead, Follow) does not satisfy the participation constrains for union members $\{H, M\}$ or $\{M, L\}$, whereas Lemma 4 reveals that there exists a certain range of $\varepsilon_H/\varepsilon_L$ in which the strategy profile (Lead, Follow) enacts 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, making it possible that both simultaneous-move and sequential-move equilibria emerge at the same time. However, the infinite repetition of the strategy profile (Lead, Follow) should not be sufficient 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 that sustains partial tax harmonization as a SPNE's outcome.

Third, when the tax union $\{H, L\}$ acts as a follower, it is easier to satisfy the participation constraints for its members (in particular, a disadvantage member) compared to those when it acts as a leader (see Lemma 4). As shown later, this implies that the sequential-move equilibrium that 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

[10] 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 associated with the respective equilibria are completely different (recall (43) and (44)).

its SPNE (see Figure 3). The intuitive reason for this outcome is as follows. It turns out from (14) and (27) that in the simultaneous-move game, the resulting positive harmonized tax rate is higher than that in the sequential-move game for $\varepsilon_H / \varepsilon_L > 1$, leading to a lower net return. This resulting lower net return raises the utility of capital-importing country H and reduces that of capital-exporting country L. These opposed effects end up making the utility difference $u_H^C(G^S) - u_H^N$ larger but $u_L^C(G^S) - u_L^N$ smaller relative to the corresponding utility differences under the sequential-move equilibrium, respectively. As a result, the participation constraint $u_L^C(G^S) \geq u_L^N$ is less likely to be satisfied compared to $u_L^C(G^F) \geq u_L^N$. In a parallel manner, we can show that when $\varepsilon_H / \varepsilon_L < 1$, the participation constraint $u_H^C(G^S) \geq u_H^N$ is less likely to be satisfied compared to $u_H^C(G^F) \geq u_H^N$.

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 other types of tax unions such as $\{H, M\}$ and $\{M, L\}$ to the Appendix). Assume that in every period, the tax union $\{H, L\}$ sets a common capital tax rate on the condition that the other member follows it in the previous period. If at least one country unilaterally deviates from it, 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 to sustain cooperation:

$$\frac{1}{1-\delta} u_i^C(G^m) \geq u_i^D(G^m) + \frac{\delta}{1-\delta} u_i^N, \ i = H, L, \ m = S, F. \tag{45}$$

The LHS of (45) 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 (45) represents the sum of the utility of country i resulting from its unilateral 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 utility level, $u_i^D(G^S)$ for $i \in \{H, L\}$, respectively, as follows:

$$\begin{aligned}
\tau_i^D(G^S) &= \frac{25A_i - 11A_j - 14A_M}{96}, \\
r_i^D(G^S) &= \frac{7A_i + 11A_j + 14A_M}{32} - 2\overline{k}, \\
k_i^D(G^S) &= \overline{k} + \frac{25A_i - 11A_j - 14A_M}{96} = \overline{k} + \tau_i^D(G^S), \\
u_i^D(G^S) &= (A_i - \overline{k})\overline{k} + \frac{(25A_i - 11A_j - 14A_M)^2}{4608}.
\end{aligned} \tag{46}$$

Substituting (11), (17), and (46) into the equality of (45) yields the *minimum discount factor* of country $i \in \{H, L\}$, above which it is in their interest to cooperate:

$$\delta_i(G^S) \equiv \frac{u_i^D(G^S) - u_i^C(G^S)}{u_i^D(G^S) - u_i^N} = \frac{81\,(A_i - 3A_j + 2A_M)^2}{(11A_i - A_j - 10A_M)\,(139A_i - 65A_j - 74A_M)}, \tag{47}$$

It is straightforward to show that $\delta_H(G^S) \gtreqless \delta_L(G^S)$ if and only if $\varepsilon_H \lesseqgtr \varepsilon_L$, 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 δ 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 (47) with respect to $\varepsilon_H/\varepsilon_L$ yields

$$\frac{d\delta_H(G^S)}{d\,(\varepsilon_H/\varepsilon_L)} < 0 \text{ and } \frac{d\delta_L(G^S)}{d\,(\varepsilon_H/\varepsilon_L)} > 0, \tag{48}$$

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 $\varepsilon_H/\varepsilon_L > 1$, whereas $\delta_H(G^S) > \delta_L(G^S)$ holds for $\varepsilon_H/\varepsilon_L < 1$. An intuitive explanation for (48)

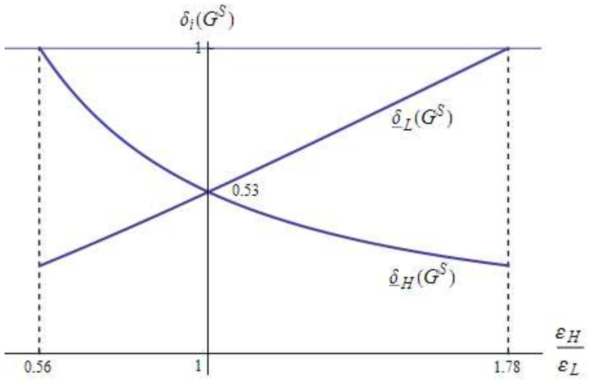

Figure 1: Minimum discount factors for $G = \{H, L\}$ in a simultaneous-move game.

is provided in Subsection 4.3.

4.2 Sustainability under sequential move

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

$$\begin{aligned}
\tau_i^D(G^F) &= \frac{31A_i - 17A_j - 14A_M}{128}, \\
r_i^D(G^F) &= \frac{35A_i + 51A_j + 42A_M}{128} - 2\overline{k}, \\
k_i^D(G^F) &= \overline{k} + \frac{31A_i - 17A_j - 14A_M}{128} = \overline{k} + \tau_i^D(G^F), \\
u_i^D(G^F) &= (A_i - \overline{k})\overline{k} + \frac{(31A_i - 17A_j - 14A_M)^2}{8192}.
\end{aligned} \tag{49}$$

Substituting (11), (30), and (49) into the equality of (45) yields the *minimum* discount factor of country $i \in \{H, L\}$ for the repeated tax-competition game with sequential moves as follows:

$$\delta_i(G^F) \equiv \frac{u_i^D(G^F) - u_i^C(G^F)}{u_i^D(G^F) - u_i^N} = \frac{81\,(5A_i - 11A_j + 6A_M)^2}{(23A_i - 25A_j + 2A_M)\,(535A_i - 281A_j - 254A_M)}. \tag{50}$$

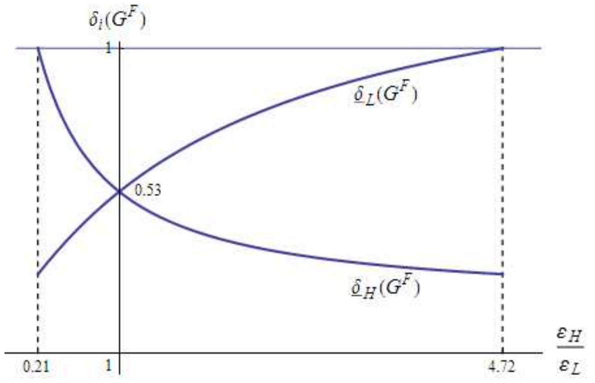

Figure 2: Minimum discount factors for $G = \{H, L\}$ in a sequential-move game.

It is straightforward to show that $\delta_H(G^F) \gtrless \delta_L(G^F)$ if and only if $\varepsilon_H \lessgtr \varepsilon_L$, while $\delta_H(G^F) = \delta_L(G^F) = 9/17 \simeq 0.53$ when $\varepsilon_H = \varepsilon_L$. If the *actual* discount factor δ is greater than the threshold discount factor defined by $\delta^*(G^F) \equiv \max\{\delta_H(G^F), \delta_L(G^F)\}$, the tax union $\{H, L\}$ is sustainable. More precisely, $\delta^*(G^F) < 1$ holds only when $(288\sqrt{11} - 683)/1285 < \varepsilon_H/\varepsilon_L < (288\sqrt{11} + 683)/347$;[11] consequently, their cooperation is sustainable as a SPNE of the repeated tax-competition game. Differentiation of (50) with respect to $\varepsilon_H/\varepsilon_L$ reveals that $d\delta_H(G^F)/d(\varepsilon_H/\varepsilon_L) < 0$ and $d\delta_L(G^F)/d(\varepsilon_H/\varepsilon_L) > 0$. Taken together, we can draw Fig.2, which shows that $\delta_H(G^F) < \delta_L(G^F)$ holds for $\varepsilon_H/\varepsilon_L < 1$; thus, country L has a stronger incentive to deviate than country H does. Furthermore, $\delta_H(G^F) > \delta_L(G^F)$ 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 ε_H and ε_L (i.e., countries H and L become more *heterogenous*), the harder it is to sustain their cooperation.

4.3 Discussion

By comparing (47) with (50) 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 $\delta_i^*(G^F) = \delta_i^*(G^S) = 9/17 \simeq 0.53$ 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 $\{H, L\}$,*

[11] This range precisely coincides with the range in which the participation constraints of countries H and L are satisfied.

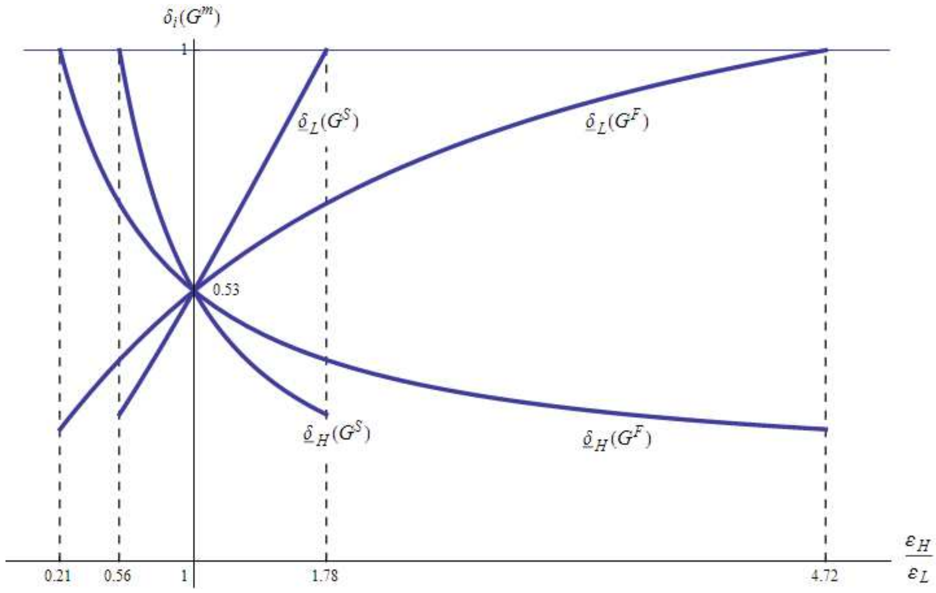

Figure 3: Minimum discount factors of $G = \{H, L\}$ for their partial tax harmonization.

(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 ε_H and ε_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 ε_H and ε_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 ε_H and ε_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 (27), 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 thus the more amount of capital country H (i.e., the tax union) is to demand (i.e., import), inducing the tax union to set a higher (positive) coordinated tax rate. The increased $\tau^C(G^m)$, $m = S, F$ 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, $u_H^C(G^m)$ is increased, while $u_L^C(G^m)$ is decreased. Hence, *country L is a pivotal player in the sense that it determines whether to sustain tax coordination*, since country L has a stronger incentive of deviation than country H.

To identify how the increased $\tau^C(G^m)$ caused by the increased $\varepsilon_H/\varepsilon_L$ affects the sustainability of cooperation, we rewrite the sustainability condition (45) for country L as follows:

$$\frac{\delta}{1-\delta}\left[u_L^C(G^m) - u_L^N\right] \geq u_L^D(G^m) - u_L^C(G^m), \;\; m = S, F, \tag{51}$$

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 LHS of (51) should be greater than the immediate gain from deviation appearing on the RHS. Since $u_L^C(G^m)$ falls with $\tau^C(G^m)$, so does the opportunity cost from deviation (i.e., $u_L^C(G^m) - u_L^N$).[12] Although the immediate gain from deviation (i.e., $u_L^D(G^m) - u_L^C$) also decreases with τ^C,[13] it can be

[12]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 indirectly operates through changes in $\tau^C(G^m)$, while the second one directly operates through shifts of the production function caused by productivity changes. The first effect of an increase in $\tau^C(G^m)$ on the utility level of country L is given by

$$\frac{du_L^C(G^m)}{d\tau^C(G^m)} = \underbrace{\left[f_L'(k_L^C(G^m)) - r^C(G^m)\right]\frac{dk_L^C(G^m)}{d\tau^C(G^m)}}_{\text{capital movement effect } (+)} + \underbrace{\frac{dr^C(G^m)}{d\tau^C(G^m)}\left[\bar{k} - k_L^C(G^m))\right]}_{\text{terms-of-trade effect } (+)} > 0, \, m = S, F,$$

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 τ_L^N is given by

$$\frac{du_L^N}{d\tau_L^N} = \underbrace{\left[f_L'(k_L^N) - r^N\right]\frac{dk_L^N}{d\tau_L^N}}_{\text{capital movement effect } (+)} > 0,$$

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

[13]The effect of an increase in $\tau_L^D(G^m)$ on the utility level of country L when country L deviates is given by

$$\frac{du_L^D(G^m)}{d\tau_L^D(G^m)} = \underbrace{\left[f_L'(k_L^D(G^m)) - r_L^D(G^m)\right]\frac{dk_L^D(G^m)}{d\tau_L^D(G^m)}}_{\text{capital movement effect } (+)} + \underbrace{\frac{dr_L^D(G^m)}{d\tau_L^D(G^m)}\left[\bar{k} - k_L^D(G^m)\right]}_{\text{terms-of-trade effect } (+)} > 0, \;\; m = S, F.$$

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 $u_L^D(G^m)$ and $u_L^C(G^m)$ in the same direction, the effect on the utility difference $u_L^D(G^m) - u_L^C(G^m)$ varies verified from (48) that the minimum discount factor of country L rises with the ratio $\varepsilon_H/\varepsilon_L$, which implies that the positive impact on the opportunity cost $u_L^C(G^m) - u_L^N$ dominates; consequently, its incentive to deviate is enhanced by the increased ratio $\varepsilon_H/\varepsilon_L$. In short, the *increased heterogeneity* of the productivities of the union-member countries tends to harm the sustainability of the tax union. Therefore, the likelihood of sustainability for their tax harmonization depends *negatively* on the degree of asymmetry, as in Catenaro and Vidal (2006).

Why can the tax union that acts as a Stackelberg follower sustains tax harmonization in a *wider* range of $\varepsilon_H/\varepsilon_L$ compared to the tax union that acts as a Stackelberg leader? The intuitive reason is as follows. A Stackelberg follower cannot exploit "the first-mover advantage," because the tax union $\{H, L\}$ acting as a Stackelberg follower is *not* able to choose the most favorable tax rate. Although this choice places the follower tax union at a disadvantage relative to the tax union acting a Stackelberg leader, the tax union $\{H, L\}$ can improve the well-being of a disadvantaged partner, which may potentially become a *first* deviator from tax harmonization, as a result of reducing income transfers from a disadvantaged member-country to an advantaged member-country. More specifically, when $\varepsilon_H > \varepsilon_L$, a straightforward comparison of (15) with (28) 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, the union-member country L **prefers moving late** partly because the capital-exporting country L prefers a higher capital price, and partly because a higher capital price can be realized in the sequential-move game in which the tax union is induced to set *moderate* tax rates. Since country L is adversely affected by the higher capital price, it becomes 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 $r^C(G^F) < r^C(G^S)$, the capital-importing country H is more beneficial under moving-late than under moving-early. The same reasoning, therefore,

according to the sign of the tax effect.

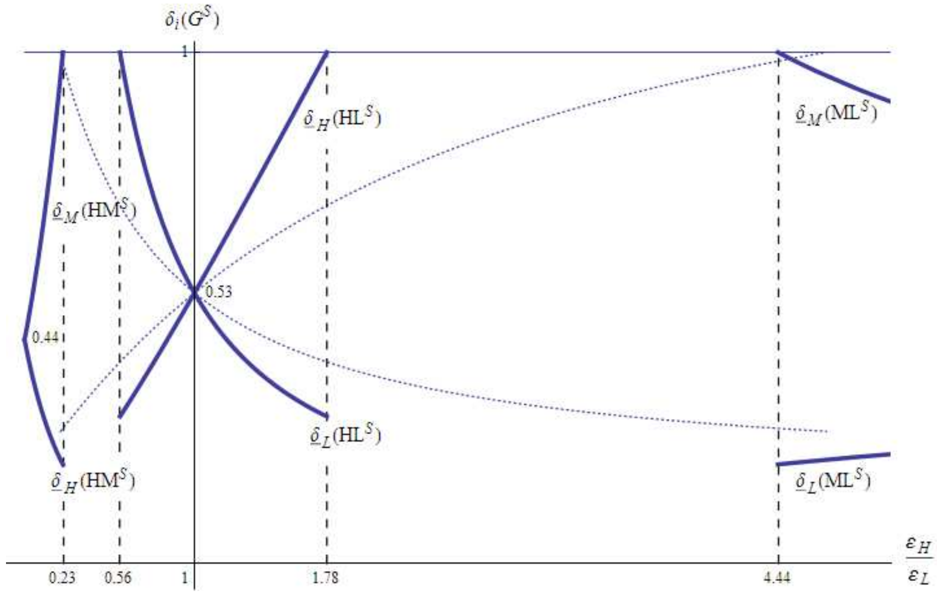

Figure 4: Minimum discount factors of the respective coutries under simultaneous-move games.

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 driving force is that the most disadvantaged union member would prefer late-moves to early-moves with the consequence that the sequential-move equilibrium can prevail in a wider range of $\varepsilon_H/\varepsilon_L$.

As shown in Fig.4, which illustrates the minimum discount factors of the member countries consisting of all possible partial tax unions, there is no range of $\varepsilon_H/\varepsilon_L$ that is consistent with any type of partial tax harmonization (see also the Appendix). In other words, *if the timing of moves is exogenously fixed*, a misleading conclusion may arise stating not only that no tax coordination is possible for some range of the degree of asymmetry but also that the presence of asymmetry may prevent the formation of tax coordination. In contrast, *if the timing of moves is endogenously determined*, it is always possible to find some type of partial tax union depending on values of $\varepsilon_H/\varepsilon_L$; in this sense, the endogenous timing of moves matters in implementing partial tax harmonization.

The sustainability of partial tax harmonization crucially depends on the asymmetry of productivity between countries H and M relative to that between countries M and L, that is, the ratio $\varepsilon_H/\varepsilon_L$. More precisely, the similar the ratio between these two asymmetries (i.e., $\varepsilon_H/\varepsilon_L \to 1$), 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. This ends up discouraging the incentive of deviation. Even if union-member country M were to join the tax union, not only does the same result hold but there is also always 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 the stage game of this repeated game has the same structure as a standard static tax-competition model such as those in Ogawa (2013) or others in which the Stackelberg leader's payoffs exceed the Stackelberg follower's payoffs. The key to understanding this result is that infinite repetition creates the opportunity to sustain a wider range of behavior as a Nash equilibrium (or a SPNE) of repeated games than would be possible in one-shot games. To do this, three crucial assumptions are required: *infinitely repeated interaction*, *sufficiently patient players and the fulfillment 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 (2014) showed that a tax credit system not only improves countries in the sequential-move (i.e., Stackelberg) tax-competition game than in the simultaneous-move tax game, but it also causes Stackelberg tax competition. Alternatively, Eichner (2014) found that in a tax competition model where governments provide public goods if both jurisdictions cause positive externalities in taxes in Nash as well as in Stackelberg games, both jurisdictions have a second-mover incentive. Compared to these contributions, our repeated-game setting would provide another important and inherent channel that makes a Stackelberg equilibrium possible without further institutional ingredients when considering partial tax harmonization.

These results have quite important policy implications. The first implication is that insights obtained from the two-stage timing games of tax competition (e.g., Kempf and Rota-Graziosi, 2010, and Ogawa, 2013) may not hold in the present repeated tax-competition model *between a tax-coalition group and outside countries.* In particular, unlike the results of those authors, our result indicates that a tax union may resist against acting as a first mover in implementing tax harmonization. As the most likely scenario, ECAs are expected to move first on the ground that the ECAs are expected to take leadership for establishing full tax harmonization among EU member countries. Unfortunately, our paper indicates that such an optimistic expectation may not be materialized. In light of the results of the present paper, there are two scenarios that could make the ECAs to be a first mover. The first is that the ECAs should be motivated by other reasons (e.g., political or ideological ones) that induce the ECA to play a role of Stackelberg leadership in establishing comprehensive reforms for the cooperate tax systems of EU member states. The second is that the ECAs should be comprised of *similar* countries.

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. Owing 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 in a *heterogenous* model with respect to population size, initial capital endowments, or valuation of local pubic goods. An equally important extension is to construct a bargaining model that 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 deserves 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 the following:

$$\begin{aligned}
&\frac{\partial \delta_H(G^S)}{\partial(\varepsilon_H/\varepsilon_L)} \gtreqless 0 \text{ if } \frac{\varepsilon_H}{\varepsilon_L} \gtreqless 2, \text{ and } \frac{\partial \delta_M(G^S)}{\partial(\varepsilon_H/\varepsilon_L)} \gtreqless 0 \text{ if } \frac{\varepsilon_H}{\varepsilon_L} \lesseqgtr \frac{46}{19} \text{ for } G^S = \{H, M\}, \\
&\frac{\partial \delta_M(G^S)}{\partial(\varepsilon_H/\varepsilon_L)} \gtreqless 0 \text{ if } \frac{\varepsilon_H}{\varepsilon_L} \lesseqgtr \frac{19}{46}, \text{ and } \frac{\partial \delta_L(G^S)}{\partial(\varepsilon_H/\varepsilon_L)} \gtreqless 0 \text{ if } \frac{\varepsilon_H}{\varepsilon_L} \gtreqless \frac{1}{2} \text{ for } G^S = \{M, L\}.
\end{aligned}$$

Because it can be verified not only that $\delta_H(G^S) < \delta_M(G^S) \leq 1$ for $\varepsilon_H/\varepsilon_L \in (0, 2(36\sqrt{3} - 53)/83] \simeq 0.225$ and $\delta_H(G^S) = \delta_M(G^S) = 81/185 \simeq 0.438$ 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 $\varepsilon_H/\varepsilon_L \to \infty$ for $G^S = \{M, L\}$, we obtain Fig.4.

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