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A Game Theoretic Analysis of Mechanisms to Induce Regional Technological Cooperation

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Abstract. A concept of regional technological cooperation is developed based on a cooperative game theoretic model, in which a plan of payoff distributions induces an agreement that is acceptable to each participant. Under certain conditions, the underlying game is shown to be convex, and hence to have a nonempty core with the Shapley value allocations belonging to the core. A compensation scheme is devised based on the Shapley value allocations, whereby participants who enjoy a greater payoff with respect to the technological cooperation compensate the participants who receive a relatively lesser payoff via cooperation. In this manner, regional technological cooperation can bring overall benefits to all the involved players in the game. Some insightful examples are provided to illustrate the methodological concept.

Key words: international technology transfer, regional technological cooperation, transfer mechanisms, game theory, coalitions, Shapley values, transferable utility.

1. Introduction

Technology is a type of production factor, and international technology transfer belongs to the realm of international trade. The objects of international trade are composed of products and production factors. While the theories of international trade that are related to products have been widely researched, the aspect of international trade pertaining to production factors has received relatively lesser attention. One of the main reasons is that there is no satisfying answer to the question on what would induce the countries holding technology to participate in technology transfer. Namely, how do the countries holding technology maintain and enhance competitive advantage while being involved in the technology transfer process? Unless some tangible benefits can be identified, such as future trade prospects, or geopolitical stability or advantage, the propensity would be toward an inherent monopoly of technology and a dearth of technology transfer.

The concept of international economic cooperation, which began to appear in 1945, was predicated on the premise that countries would coordinate with each other with respect to the realignment and redeployment of production factors in order to develop joint economies on a mutually beneficial basis (Feldstein, 1988; Li, 1997, 1995; Tinbergen, 1945). This concept is referred to as a regional technological cooperation if it involves a particular technology field in a certain region. The mechanisms whereby the participating companies, enterprises, organizations, and individuals transfer or license technology, which might represent knowledge, tools, equipment, and work techniques used by an organization in delivering its products or services, subject to legal and political restrictions, constitute the overall process of technology transfer. Accordingly, regional technological cooperation is a devise to promote the technology transfer among countries in a certain region.

Because regional economic cooperation is one of the basic characters of the modern global economy, and the $21st$ century is poised to be an era that is driven by technology, regional technological cooperation is an important significance in the process of global economic development. Generally, regional technological cooperation, as a special form of international technology transfer, has the following basic functions:

(1) creating conditions to produce more wealth;
(2) helping to envigor the economic development among the participants in a complementary fashion, and to upgrade potential markets to real markets;
(3) helping not only the participants receiving the new technology to enhance their economic strength, but also enabling the participants holding the technology to strengthen their economic power through delayed trade and geopolitical benefits, and through continued development;
(4) providing all participants opportunities via jobs and low cost labor to realize common economic development;
(5) reducing the distinction in the status of the economy and technology among the participants;
(6) helping to promote free trade and investments within the region as well as on a global basis; and
(7) helping to generally improve the competitive advantage of every participant.

Having said this, the reality of the progress in regional technological cooperation practice has been slow. Because the expectations of key players are different and abiding principles are unclear, it is not surprising concrete successful cases are lacking. Moreover, political, social, and cultural barriers further impede the process. At the same time, theoretical research addressing regional technological cooperation is lacking as well (APEC, 1997).

One of the principal aspects of a regional technological cooperation endeavor is the set of undertakings and agreements adopted by national governments that bind the rights and duties of the participants. This feature accords with the assumption which binds the actions of the players in a cooperative game (Roth, 1988; Shapley, 1971), as determined via solution concepts such as the core of the game or Shapley value allocations (Roth, 1988; Sherali and Rajan, 1986). By letting the countries that take part in such a cooperative framework be the players in a defined game, we can use the genre of game theory to bring to light inherent mechanisms that would induce regional technological cooperation.

This paper explores the use of cooperative game theory to develop a modeling framework for regional technological cooperation. In this model, we exclude considerations such as how countries actually coordinate payoffs and establish checks and balances to enforce binding agreements. Such issues go beyond the scope of the present paper and are governed by the dynamic circumstances that prevail once a general cooperative agreement as prompted by the game theoretic analysis has been adopted. Furthermore, we assume that each country participating in this cooperative game has complete information of the characteristic payoff functions of the game. This at least facilitates the development of undertakings and agreements that might have a self-binding propensity.

The remainder of this paper is organized as follows. We begin in Section 2 by discussing certain basic concepts pertaining to regional technological cooperation as well as general cooperative game theory. Based on these concepts, we propose in Section 3 the framework of a cooperative game to represent a regional technology transfer mechanism among participating countries, and establish that this game is convex, and hence that the Shapley value allocations belong to its core. A closed-form expression is derived for the allocation scheme, which affords interesting economic interpretations. Finally, Section 4 provides some insightful illustrative examples and Section 5 concludes the paper with comments related to the overall technology transfer process.

2. Basic Concepts

2.1. *The Definition of Regional Technological Cooperation*

By the discussion in Section 1 and that in Li (1995), we can define a regional technological cooperation framework as follows.

DEFINITION 1. *Regional technological cooperation* is a coordinated effort between the governments of two or more countries in a certain geographical region in order to promote their mutual economic and political development and technological advancements.

The goal of regional technological cooperation is to strengthen the economic, technological, and political bases of all the participants to their mutual benefit. These goals and subsequent actions are governed by a set of policies that are formulated by each participant. Such a concept can be represented by denoting the Regional Technological Cooperation (RTC) phenomenon as

$$\mathrm{RTC} = \{N, G, P\},$$

where, N, G, and P denote the three aforementioned components of this process, defined as follows. The set $N = \{1, \ldots, n\}$ denotes the n participating countries in the regional technological cooperation; G is the comprehensive goal of RTC constituted by the union of the goals G_i of participating country i in RTC; and likewise, P is the union of the respective policies and measures P_i adopted by participating country i in achieving its goals within the RTC.

For example, The Asia-Pacific Economic Cooperation (APEC) was established in 1989 in response to the growing interdependence among Asian-Pacific economies. Presently, it includes $n = 21$ members (Australia; Brunei Darussalam; Canada; Chile; People's Republic of China; Hong Kong, China; Indonesia; Japan; Republic of Korea; Malaysia; Mexico; New Zealand; Papua New Guinea; Peru; Republic of the Philippines; Russia; Singapore; Chinese Taipei; Thailand; United States; and Vietnam). Its goal (G) is to advance the Asian-Pacific economic dynamism and sense of community. Through dialogues, the members engage in economic and technical cooperation which include the following six areas and constitute the set P: developing human capital; fostering safe and efficient capital markets; strengthening the economic infrastructure; harnessing technologies of the future; promoting environmentally sustainable growth; and encouraging the growth of small and medium-sized enterprises.

Naturally, some common ground should exist among the individual goals and policies to foster a joint cooperative agreement. This common ground, in essence, defines the characteristic function of the cooperative game as discussed in the sequel.

2.2. *Basic Concepts of Game Theory*

Generally, a standard game is defined as:

$$\Gamma = \{N,\ (C_i)_{i \in N},\ (u_i)_{i \in N}\},$$

in which N is a non-empty set of players, C_i is the non-empty set of all possible strategies that are feasible for Player i, and u_i is the payoff function for Player i.

DEFINITION 2 (Shapley, 1971). For a set $N = \{1, \dots, n\}$ of players, each non-empty subset $S \subseteq N$ of cooperating players is called a *coalition*. The (power) set of all possible coalitions is denoted by $P(N)$.

For instance, using the illustrative example of the foregoing subsection, $S = \{$Canada, Mexico, United States$\}$ based on the North American Free Trade Agreement, and $S = \{$People's Republic of China, Japan, Republic of Korea$\}$ based on their Summit Meeting coordinated by the Association of South-East Asian Nations (ASEAN) are two such existing coalitions, while some other "coalitions" could be comprised of simply individual countries.

In a cooperative game, the incentive for players to take part in coalitions is governed by a so-called characteristic function which is defined as follows.

DEFINITION 3 (Shapley, 1971). The *characteristic function* of an n-player cooperative game is a real function $\nu(S)$ defined on $P(N)$, which indicates the payoff that Coalition S can receive by means of coordinating the strategies of the participants within S. Obviously, $\nu(\varnothing) \equiv 0$, where $\varnothing$ is the empty set.

DEFINITION 4 (Shapley, 1971). A characteristic function is called *supperadditive* if for any two disjoint coalitions S and T, we have that their payoff under a joint coalition is not less than the sum of their independent payoffs, that is

$$\nu(S \cup T) \geqslant \nu(S) + \nu(T), \quad \forall S, T \subseteq N, \quad S \cap T = \varnothing.$$

DEFINITION 5 (Shapley, 1971). A game with characteristic function v is *convex* if

$$\nu(S) + \nu(T) \leqslant \nu(S \cup T) + \nu(S \cap T)$$

for each $S, T \subseteq N$. Equivalently, a game is convex if

$$\nu(T \cup \{i\}) - \nu(T) \geqslant \nu(S \cup \{i\}) - \nu(S), \quad \forall S \subseteq T \subset N,\ i \in N - T.$$

Note that by definition, a convex game is supperadditive.

DEFINITION 6 (Myerson, 1991). A game Γ with *transferable utility* is one for which in addition to the strategy options listed in C_i, each player i has the option to give any number of units of payoff to any other player, including to itself (i.e., self-consumption), where each unit of payoff corresponds to a unit of utility.

When using the characteristic function to research an n-player cooperative game (N, v), we assume that all players weigh their payoffs by the same measure, and that the payoff $v(S)$ of every coalition can be distributed to participants using some appropriate method. Namely, the payoffs (utilities) of the players are transferable.

Similar to the concept of *trade creation* (Viner, 1950), we can define the concept of technology transfer creation as follows.

DEFINITION 7. *Technology transfer creation* is the process by which the formation of a cooperative coalition for the purpose of technology transfer increases the net benefit or general welfare of every player in the coalition.

DEFINITION 8 (Shapley, 1971). A *payment vector*

$$\boldsymbol{x} = (x_1, \ldots, x_n) \in R^n$$

defines for each player $i \in N$, a share x_i which this player gains from the payoff of the coalition.

DEFINITION 9 (Shapley, 1971). A payment vector $\boldsymbol{x}$ is called a *distribution* for a cooperative game based on a grand coalition N and having a characteristic function ν if

$$x_i \geqslant v(\{i\}) \quad \forall i = 1, \ldots, n, \tag{1}$$

and

$$\sum_{i \in N} x_i = \nu(N). \tag{2}$$

The set of all possible distributions is denoted by $E(v)$.

Relation (1) is called the individual rational condition, since it indicates that the payoff gained by any player i is not less than the payoff available to i by taking independent action. Relation (2) is called the collective rational condition, since it indicates that the payment function, assuming a grand coalition, should distribute the total payoff $\nu(N)$ that is available to the participants in this coalition N. Note that under the assumption of a convex game, the formation of a grand coalition N is the most rational outcome. Therefore, such a characteristic function induces all participants to take part in a cooperative effort in order to increase the payoff of every participant. Furthermore, as discussed by Sherali and Rajan (1986), while supperadditivity ensures that the total payoff is a maximum for the grand coalition and admits a distribution satisfying (1) and (2), it does not necessarily imply that a grand coalition would be the most rational emerging coalition. The reason for this is that unlike as in the case of convex games, it does not preclude the possibility of particular players within other subcoalitions from enjoying greater payoffs.

DEFINITION 10 (Shapley, 1971). Given distributions $\boldsymbol{x}$ and $\mathbf{y}$, and a coalition $S \subseteq N$, $\boldsymbol{x}$ is said to be *superior* to $\mathbf{y}$ on S, denoted $\boldsymbol{x} \underset{S}{\succ} \mathbf{y}$, if

$$x_i \geqslant y_i, \quad \forall i \in S \text{ (with at least one inequality strict)},$$

and

$$\sum_{i \in S} x_i \leqslant \nu(S). \tag{3}$$

A distribution $\boldsymbol{x}$ satisfying inequality (3) is called a *feasible distribution* for the coalition S.

DEFINITION 11 (Shapley, 1971). For an n-player cooperative game (N, ν), the nondominated distributions in $E(\nu)$, that is, the distributions for which there does not exist any other superior distribution with respect to any coalition $S \subseteq N$, is called the *core* of the game. Hence, the core, denoted $C(N, v)$, is composed of all payment vectors satisfying

$$\sum_{i \in S} x_i \geqslant \nu(S), \quad \forall S \subseteq N, \tag{4}$$

$$\sum_{i \in N} x_i = \nu(N). \tag{5}$$

Relation (4) is called the coalition rational condition, analogous to the special case of the individual rational condition (1).

3. A Mechanism to Induce Regional Technological Cooperation

Obviously, the core is a closed convex set. If the core of a game is non-empty, such as when the game is convex (Shapley, 1971), the total payoff $\nu(N)$ available to a grand coalition can be distributed to each player in a manner such that this type of distribution method satisfies not only the individual rational condition and the collective rational condition, but also the coalition rational condition. Namely, what any subset of players $S \subseteq N$ gains under this type of a distribution is not less than the payoff that this coalition S could have received had it acted independently. Conversely, if a feasible distribution $\boldsymbol{x}$ is not in the core, there exists a coalition $S \subseteq N$ for which the players in Coalition S can distribute the value $\nu(S)$ available though their independent cooperation, so that the resulting distribution is superior to distribution $\boldsymbol{x}$ on S. Therefore, a distribution that belongs to the core can be rationally accepted by all the players in the grand coalition N.

Note that there might exist several rational methods for distributing the payoff of a coalition. Needless to say, such a distribution is not necessarily based on an average allocation. One eminently appealing concept whereby the distribution is determined by means of a weighted average of the marginal contribution that each player brings to every possible coalition, leads to the so-called Shapley value distribution mechanism.

Lemma 1 (Shapley, 1971). *A type of feasible distribution plan for allocating the payoff $\nu(N)$ of the grand coalition N is*

$$x_i \equiv \varphi_i(N,\nu) = \sum_{\substack{S \subseteq N \\ i \in S}} \frac{(|S|-1)!(n-|S|)!}{n!}\,[\nu(S)-\nu(S-\{i\})],\ \forall i = 1,\ldots,n, \tag{6}$$

where $|S|$ denotes the cardinality of the coalition $S \subseteq N$. (The collection $\{\varphi_i(N,\nu)\}_{i\in N}$ is called a set of Shapley Values.)

Lemma 2 (Shapley, 1971). *If (N,ν) is a convex game, then $\{\varphi_i(N,\nu)\}_{i\in N} \in C(N,\nu)$.*

Lemma 2 indicates that if the regional technological cooperative game is convex, then the Shapley allocations given by (6) belong to the core, and hence satisfy the desirable rationality conditions (4) and (5).

We now describe a characteristic function for a regional technological cooperative game, wherein each participant is viewed as a player whose strategy is its national technology transfer ability and level, and establish that the underlying game is convex.

A two-country case for cooperative behavior in which the countries could derive both common as well as different benefits was discussed in Peter (1993). The benefit allocation relationship between the two countries was represented in a two-dimensional space by a set of discrete points, where each point in the space delineated a possible combination of utilities. Viewing this example from our perspective, the decisions faced by these two countries would concern not only the question of whether or not they should cooperate, but also the question as to how they should redistribute the benefits if they do cooperate, and what cooperative strategies should they adopt.

Generally, $\nu(S), \forall S \subseteq N$ is called the worth of Coalition S. For any coalition $S \subseteq N$ and each player $i \in S$, we can formulate $\nu(S)$ based on the following four conceptual components. First, before any utility is transferred, player i has the reservation utility R_0^i, that is due to its technical ability and level in isolation, before taking part in any form of cooperation or interactions in the global market. One method of quantifying this is to use the related evaluation targets in recent years (World Economic Forum, 1998). Second, under the concept of a grand coalition, we define K_j^i as the payoff or benefit that player i receives due to the presence of each player $j \in N$, $j \neq i$, taking part in the cooperation (Yin, 1993). In the case of the regional technological cooperation game, K_j^i represents the increase and enhancement of player i's technical ability and level, which come from the activities and effects of technology transfer due to the progress and dissemination effects of player j being part of its coalition. The next two components occur as a result of adjustments in the foregoing utility transfer for each $i \in S$ due to player j in $N - S$ not taking part in coalition S. The first of these represents the loss of player $i \in S$ based on each player $j \in N - S$ that does not take part in Coalition S, and the other component represents any gain that player i might derive from each of the players $j \in N - S$, despite their not being a formal part of coalition S. Accordingly, for each $i \in S$ and $j \in N - S$, let δ_j^i be the reduction in the benefit or payoff of player i which comes from the loss of the direct benefits due to player j not being a part of Coalition S, and let π_j^i be the increment in the direct payoff of player i due to any interactions it might have with player j outside the framework of a formal coalition. Note that this allows for somewhat more general compensations and interaction effects than simply letting $\delta_j^i \equiv K_j^i$ and $\pi_j^i \equiv 0$, $\forall i \neq j$. Naturally, we can also assume the following to hold true:

$$\beta_j^i \equiv \delta_j^i - \pi_j^i \geqslant 0, \quad \forall i \in S, \quad j \in N - S. \tag{7}$$

In the context of regional technological cooperation, if player i is one of the participants receiving the new technology in the technology transfer process, δ_j^i is generally determined by the following economic factors:

(i) competitiveness and profitability of businesses;
(ii) new products and services;
(iii) nation's base of technical knowledge;
(iv) research, development and procurement costs;
(v) return on engineering, research and development investments;
(vi) access to industry expertise;
(vii) overall system performance, and
(viii) creation of skilled and high paying jobs.

Correspondingly, for this case, the entity π_j^i is generally determined by the following economic factors:

(i) opportunity to acquire the new technology, and
(ii) general availability of some products, technical information, and services.

If player i is one of the participants holding the new technology in the technology transfer process, δ_j^i is generally determined by the following economic factors:

(i) competitiveness and profitability of businesses;
(ii) economic advantages through delayed trade and continued development;
(iii) geopolitical benefits;
(iv) expanded opportunities for development;
(v) opportunities for jobs and low cost labor, and
(vi) market access for selling the technology.

Similarly, for this case, the entity π^i_j is generally determined by the following economic factors:

(i) opportunity to unilaterally sell technology, and
(ii) transfer of related products, information, and services via open conduits and markets.

From the foregoing discussion (see Forgo *et al.*, 1999; Myerson, 1991; Von Neumann and Morgenstern, 1953, for further details) we can formulate the following characteristic function for a regional technological cooperative game.

$$\nu(S) = \sum_{i \in S} \{\alpha^i - \sum_{j \in N-S} \beta^i_j\}, \quad \forall S \subseteq N, \tag{8a}$$

where

$$\alpha^i \equiv R^i_0 + \sum_{\substack{j \in N \\ j \neq i}} K^i_j, \quad \forall i \in N, \quad \text{and} \quad \beta^i_j \equiv \delta^i_j - \pi^i_j, \quad \forall i \in S,\ j \in N - S. \tag{8b}$$

Note that for each participant i in the coalition S, the first term α^i in the summand in (8a) is the reservation utility of i before taking part in any form of cooperation or interactions with the other players, plus the sum of the payoffs gained due to the other players when forming the grand coalition N. The second term β^i_j in the summand in (8a) is the net loss (noting (7)) that adjusts the foregoing term based on the players in $N - S$ not taking part in coalition S. This is comprised of a direct loss component δ^i_j minus the payoff π^i_j based on any unilateral cooperation of player i with each of the other players j in $N - S$. Observe that $\nu(S)$ for any $S \subset N$ (and $\nu(\{i\})$in particular), depends on the other players $j \in N - S$ because of the interactions due to a global market. That is, $\nu(S)$ does not simply depend on the actions and influences of the players within S itself in isolation. This is similar in concept to the characteristic functions defined for oligopolistic markets by Sherali and Rajan (1986).

Theorem 1. *The regional technological cooperative game defined by* (8a) *is convex.*

Proof. For each player $i \in N$, and for all $S \subseteq T \subseteq N - \{i\}$, we get from (8a) that

$$\nu(S \cup \{i\}) = \Big[\nu(S) + \sum_{j \in S} \beta^j_i\Big] + \Big[\nu(i) + \sum_{j \neq i} \beta^i_j\Big] - \sum_{\substack{j \notin S \\ j \neq i}} \beta^i_j.$$

Combining terms,

$$\nu(S \cup \{i\}) = \nu(S) + \nu(i) + \sum_{j \in S} (\beta_i^j + \beta_j^i),$$

or that,

$$\nu(S \cup \{i\}) - \nu(S) = \nu(i) + \sum_{j \in S} (\beta_i^j + \beta_j^i). \tag{9}$$

Similarly, we have

$$\nu(T \cup \{i\}) - \nu(T) = \nu(i) + \sum_{j \in T} (\beta_i^j + \beta_j^i).$$

Because $S \subseteq T$, and from (7) we have $\beta_j^i \geqslant 0$ and $\beta_i^j \geqslant 0$, we get

$$\sum_{j \in S} (\beta_i^j + \beta_j^i) \leqslant \sum_{j \in T} (\beta_i^j + \beta_j^i).$$

Therefore,

$$\nu(S \cup \{i\}) - \nu(S) \leqslant \nu(T \cup \{i\}) - \nu(T).$$

This completes the proof.

Because the technical ability and level of each participant is different, the utility for each participant to take part in cooperation is different. Each participant must inherit a rational payoff compensation for the cooperation to be stable. If the final payoff of the cooperation is distributed by the Shapley Value, then since this distribution belongs to the core because the game is convex (see Lemma 2 and Theorem 1), we will have prescribed a rational transfer mechanism among the participants. A closed-form expression for this rational transfer quantity is derived by the following result.

Theorem 2. *For the defined regional technological cooperative game* (N, v)*, where* v *is given by* (8a)*, the Shapley Value allocation is given by*

$$\varphi_i(N, v) = \alpha^i + \frac{1}{2} \sum_{\substack{j=1 \\ j \neq i}}^{n} (\beta_i^j - \beta_j^i), \quad \textit{for} \quad i = 1, \ldots, n. \tag{10}$$

Proof. By Eq. (9) and Formula (6), the Shapley allocation for any $i \in N$ is given by

$$\varphi_i(N, \nu) = \sum_{\substack{S \subseteq N \\ i \in S}} \frac{(|S| - 1)!(n - |S|)!}{n!} \Big[\nu(i) + \sum_{\substack{j \in S \\ j \neq i}} (\beta_i^j + \beta_j^i)\Big]$$

$$= \nu(i) + \sum_{\substack{j=1 \\ j \neq i}}^{n} (\beta_i^j + \beta_j^i) \sum_{\substack{S \subseteq N \\ i,j \in S}} \frac{(|S|-1)!(n-|S|)!}{n!},$$

where

$$\sum_{\substack{S \subseteq N \\ i \in S}} \frac{(|S|-1)!(n-|S|)!}{n!} = \sum_{s=1}^{n} \sum_{\substack{S \subseteq N \\ i \in S \\ |S|=s}} \frac{(s-1)!(n-s)!}{n!}$$
$$= \sum_{s=1}^{n} \frac{(s-1)!(n-s)!}{n!} \times \frac{(n-1)!}{(s-1)!(n-s)!} = 1.$$

Similarly, note that

$$\sum_{\substack{S \subseteq N \\ i,j \in S}} \frac{(|S|-1)!(n-|S|)!}{n!} = \sum_{s=2}^{n} \sum_{\substack{S \subseteq N \\ i,j \in S \\ |S|=s}} \frac{(s-1)!(n-s)!}{n!}$$
$$= \sum_{s=2}^{n} \frac{(s-1)!(n-s)!}{n!} \times \frac{(n-2)!}{(n-s)!(s-2)!} = \frac{1}{2}.$$

Therefore, we have

$$\varphi_i(N, \nu) = \nu(i) + \frac{1}{2} \sum_{\substack{j \in N \\ j \neq i}} (\beta_i^j + \beta_j^i). \quad (11)$$

But from Eq. (8a), we have

$$\nu(i) = \alpha^i - \sum_{\substack{j \in N \\ j \neq i}} \beta_j^i. \quad (12)$$

Hence, using (12) and (11), we get

$$\varphi_i(N, \nu) = \Big(\alpha^i - \sum_{\substack{j \in N \\ j \neq i}} \beta_j^i\Big) + \frac{1}{2} \sum_{\substack{j \in N \\ j \neq i}} (\beta_i^j + \beta_j^i) = \alpha^i + \frac{1}{2} \sum_{\substack{j \in N \\ j \neq i}} (\beta_i^j - \beta_j^i).$$

This completes the proof.

Observe that if we ignore any transferable utility, then the payoff for player i in the grand coalition N is α^i. Indeed, from (8a), we have that the total payoff for the grand coalition N is

$$\nu(N) = \sum_{i \in N} \alpha^i. \quad (13)$$

However, since we have transferable utility, the payoff for player i in the grand coalition N is adjusted as per the Shapley value (10). Therefore, the difference between this value in Eq. (10) and α^i is the amount of transferable utility that is distributed by the Shapley value allocation for each $i \in N$, and is given by

$$T_i = \frac{1}{2} \sum_{\substack{j=1 \\ j \neq i}}^{n} (\beta_i^j - \beta_j^i), \quad \text{for} \quad i = 1, \ldots, n. \tag{14}$$

Moreover, the difference between (10) and the reservation utility R_0^i of player i that is realized if i is in isolation is the overall payoff or inducement for player i that accrues from the regional technological cooperative game in the global market with transferable utility. This "inducement" factor is given by

$$I_i \equiv \sum_{\substack{j=1 \\ j \neq i}}^{n} K_j^i + \frac{1}{2} \sum_{\substack{j=1 \\ j \neq i}}^{n} (\beta_i^j - \beta_j^i), \quad \text{for} \quad i = 1, \ldots, n. \tag{15}$$

In the practice of regional technological cooperation, the quantity in (15) must be nonnegative (preferably positive) for each player i, since this expression represents in effect the inducement or motivation for player i to take part in this cooperative effort. Since the game is convex, we have that the grand coalition emerges and that the Shapley value allocation belongs to the core, thereby lending rationality to the transfer quantities $T_i, \forall i$, given by (14). Note that β_i^j is the net reduction in payoff for j if i does not coalesce with it, and β_j^i is the net reduction in payoff for i under this same condition. The transferable utility T_i that is distributed by the Shapley value allocation is half the sum of the difference between these two entities over all the other players in $N - \{i\}$. As a consequence of this allocation scheme, the countries that gain more benefit give a compensation to the countries that gain less benefit. There are many reasons why Country j might gain more benefit than Country i via a regional technological cooperation, and hence induce such a compensation scheme. For example, Country j might have a greater need for the technology of Country i than conversely, or Country j might have a greater relative ability to generate some common technology due to its cooperation with Country i than vice versa. At the same time, after the former countries provide such a compensation to the latter countries, their welfare should be higher than that of their assumed reservation utility in isolation, i.e., (15) should be positive. In this manner, a cooperative agreement can be reached, or a mutually beneficial undertaking can be made.

In practice, because there are many factors that influence the benefit of every participant, the characteristic function in Formula (8a) should be carefully crafted based on tangible economic factors from among the ones outlined above, and the payoff compensation or allocation scheme in Formula (10) should probably be combined with other compensation mechanisms.

4. Illustrative Examples

For the sake of illustration, consider a scenario involving three countries (indexed $i = 1, 2, 3$, with $N = \{1, 2, 3\}$). For example, this might refer to home-used electrical manufacturing industries in Japan ($i = 1$), The Republic of Korea ($i = 2$), and People's Republic of China ($i = 3$). Suppose that the data is specified as in Table 1 for a base-case scenario, where the units are some scaled commensurate monetary quantities. The relevant computations leading to the Shapley value allocations given by (10) and the inducement factors given by (15) are displayed in Table 2. We can see that the reservation utility of i before taking part in any form of cooperation is 10, 4, and 1, for $i = 1$, 2, and 3, respectively. After forming the grand coalition, and without any utility transfer, the payoffs for the countries $i = 1$, 2, and 3, are respectively 12, 8, and 8. However, when there is utility transfer, these payoffs are adjusted by the Shapley value allocations to the respective values 12.5, 8.5, and 7 (0.5 from player 3 to player 1 and 0.5 from player 3 to player 2). The quantities 2.5, 4.5, and 6, respectively, represent in effect the inducement or motivation for the players to take part in this cooperative effort.

Next, let us consider the special case in which the net reduction in benefit δ^i_j for player i when j is not a part of its coalition is K^i_j itself, with no extraneous interaction impact accruing (i.e., $\pi^i_j \equiv 0$), $\forall i, j$. Then, with the reservation utilities $R^i_0, \forall i$, and the cooperation benefits $K^i_j, \forall i \neq j$, being as given in Table 1, we obtain the results presented in Table 3. In this case, after forming the grand coalition and effecting utility transfer via the Shapley value allocations, the payoffs for players $i = 1$, 2, and 3 become 14.5, 8, and 5.5, respectively. Noting the α^i values, there is a net utility transfer of 4.5 from player 3 to player 1. The quantities 4.5, 4, and 4.5 respectively represent the inducement or motivation for the players to take part in this cooperative effort. By comparing these results with those given in Table 2, we notice that because of the complete loss of related benefits

Table 1

Base-case scenario data

i	R^i_0	K^i_j for $j \neq i$			δ^i_j for $j \neq i$			π^i_j for $j \neq i$		
		$j=1$	$j=2$	$j=3$	$j=1$	$j=2$	$j=3$	$j=1$	$j=2$	$j=3$
1	10	–	1	1	–	1	1	–	0	0
2	4	3	–	1	2	–	1	1	–	0
3	1	4	3	–	3	3	–	1	1	–

Table 2

Results for the base-case

i	α^i (Eq. (8b))	β^i_j for $j \neq i$ (Eq. (8b))			Shapley values φ_i (Eq. (10))	Inducement factors I_i (Eq. (15))
		$j=1$	$j=2$	$j=3$		
1	12	–	1	1	12.5	2.5
2	8	1	–	1	8.5	4.5
3	8	2	2	–	7	6

whenever a player is not part of a coalition, given the relative contributions reflected by the K_j^i values in Table 1, the Shapley value allocation of player 1 is further boosted in the present case, and the inducement factors have become more balanced as well.

Finally, consider the situation in which the data is as specified in Table 1, except that the reservation utility $R_0^i \equiv 5,\ \forall i = 1, 2, 3$ (the average value of the reservation utilities given in Table 1). For example, in the case of the coalition for home-used electrical manufacturing industries formed by Japan ($i = 1$), The Republic of Korea ($i = 2$), and People's Republic of China ($i = 3$), the base-case data for the reservation utilities might be more indicative of the situation about a decade ago, while the values assumed presently are somewhat more contemporary. However, let us assume hypothetically that the relative benefits of cooperation are as disparate as specified in Table 1. The results obtained in this case are displayed in Table 4. We can see that after forming the grand coalition, and when there is no utility transfer, the payoffs for the three players are given by 5, 9, and 12, respectively. These payoffs are adjusted to the values 5.5, 9.5, and 11 when there is utility transfer (0.5 from player 3 to player 1 and 0.5 from player 3 to player 2), by virtue of the Shapley value allocations. The quantities 0.5, 4.5, and 6 respectively represent the inducement or motivation for the players to take part in this cooperative effort. By comparing these results with those given in Table 2, we notice that in the present case, players 2 and 3 continue to derive strong synergistic benefits in the presence of player 1, while their reservation utilities are similar. Hence, the Shapley value allocations for players 2 and 3 have increased (more so for player 3), while the Shapley allocation, and hence inducement, for player 1 to participate in this grand coalition has further diminished.

Table 3

Results for the base-case cariation in which $\delta_j^i = K_j^i$ and $\pi_j^i \equiv 0,\ \forall i \neq j$

i	α^i (Eq. (8b))	β_j^i for $j \neq i$ (Eq. (8b))			Shapley values φ_i (Eq. (10))	Inducement factors I_i (Eq. (15))
		$j = 1$	$j = 2$	$j = 3$		
1	12	–	1	1	14.5	4.5
2	8	3	–	1	8	4
3	8	4	3	–	5.5	4.5

Table 4

Results for the base-case variation in which $R_0^i \equiv 5,\ \forall i$.

i	α^i (Eq. (8b))	β_j^i for $j \neq i$ (Eq. (8b))			Shapley values φ_i (Eq. (10))	Inducement factors I_i (Eq. (15))
		$j = 1$	$j = 2$	$j = 3$		
1	5	–	1	1	5.5	0.5
2	9	1	–	1	9.5	4.5
3	12	2	2	–	11	6

5. Conclusions

A necessary condition for a regional technological cooperation to occur is that every participant must be motivated by some incentive to change the status of technological development among the participants to complement each other's needs and objectives. A sufficient condition for inducing regional technological cooperation is that the participants in the coalition that emerges are able to coordinate payoff distributions, by using effective consultations, in order to reach binding agreements and mechanisms for conducting the technology transfer and regulating the payoff distributions. Moreover, the net effect of this cooperation should be that each participant enjoys an overall benefit that exceeds the expected reservation utility in isolation, prior to taking part in the cooperative effort.

We have described in this paper a cooperative game among players participating in a technology transfer via the definition of a suitable characteristic function which reflects net benefits under various scenarios of cooperative coalitions. We have shown that the game thus defined is convex, and hence, payoff distributions that are determined via the Shapley value allocations are in the core, and therefore, prescribe a stable and rational compensation mechanism. Moreover, this Shapley value distribution scheme has been computed via a closed-form formula that affords useful economic interpretations.

In practice, while implementing a regional technological cooperation plan among countries that widely differ in levels of technology, the countries which have a relatively lower technological ability and level might generally impose high tariffs to interrelated products in order to protect their own industries, and might also have a lower ability and level of competitiveness when implementing the technology transfer. Therefore, the above-mentioned payoff compensation mechanism is necessary in order to guarantee that the final payoff of each participant is rational. The property that such a payoff compensation mechanism provides a net utility gain for each participant is the essence of inducing a regional technological cooperation.

References

APEC, (1997). *APEC Economic Leaders Declaration: Connecting the APEC Community.* Leaders' Declaration–Vancouver, the 5^{th} Summit of Asia-Pacific Economic Cooperation, Vancouver, Canada, November 25.

Feldstein, M. (1988). *International Economic Cooperation.* The University of Chicago Press.

Forgo, F., J. Szep, F. Szidarovszky (1999). *Introduction to the Theory of Games: Concepts, Methods, and Applicaations*. Kluwer Academic Publishers.

Li, Q. (1995). *A Theory on Trade Development of Growth Triangle and its Application in Tumen River Economic Zone.* Ph.D. dissertation, School of Management, Xi'an Jiaotong University.

Li, Q. (1997). *Competitive and Cooperative Regional Economic Cooperation Theory and its Application.* Post-doctoral Report, Harbin Institute of Technology.

Myerson, B.R. (1991). *Game Theory: Analysis of Conflict*. Harvard University Press.

Peter, D. (1993). *Pluralism of International Economy.* Original Press.

Roth, A.E. (1988). *The Shapley Value: Essays in Honor of Lloyd S. Shapley.* Cambridge University Press.

Shapley, L.S. (1971). Cores of convex games. *International Journal of Game Theory*, **1**, 11–26.

Sherali, H.D., and R. Rajan (1986). A game theoretic-mathematical programming analysis of cooperative phenomena in oligopolistic markets. *Operations Research* , **34**(5), 683–697.
Tinbergen, J. (1945). *International Economic Cooperation.* Amsterdam: Ersefer Press.
Viner, J. (1950). *The Customs Union Issue*. New York, Carnegie Endowment for International Peace.
Von Neumann, J., and O. Morgenstern (1953). *Theory of Games and Economic Behavior*. Princeton University Press, third ed.
World Economic Forum (1998). *Global Competitiveness Report.* Davos, Switzerland.
Yin, Z. (1993). *Price of International Technology Transfer.* Shanghai People's Press, P. R. China.

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Mechanizmų, skirtų regioninei technologinei kooperacijai skatinti, analizė, naudojant lošimų teorijos metodus

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Sudarytas regioninės technologinės kooperacijos modelis, pagrįstas kooperatinių lošimų teorija. Pasiūlyta kompensacijų schema, pagrįsta Shapley metodais, kur dalyviai gauna daugiau naudos, kompensuoja mažiau gaunančius partnerius. Pateikti iliustraciniai pavyzdžiai.