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The Evolution of FTA Network: Empirics and Theory*

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Abstract

This study examines the historic evolution of FTA network during the period from 1973 to the mid-2010s. We first observe important empirical features that have appeared in FTA network evolution over time and, then, show that these features match with micro-incentives of participating individual countries. Finally, by incorporating empirical observations and micro-incentives of countries into the macro-evolution model, we explain how the FTA network evolves over time. The macro-evolution model based on empirical observations and micro-incentives well explains the evolution of FTA network, especially until the early 2000s. This fact implies that even random formation process of network produces a good approximation to the observed network as long as important features are well incorporated into the network formation process. Additionally, we observe that although the proliferation of regionalism may not lead to complete global trade liberalization, it makes substantial contribution to the establishment of global village.

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Keywords : Free Trade Agreement, Networks, Power Law, Network Formation Game, Mean Field Approximation

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Ⅰ. Introduction

Just as networks of relationships play an important role in a wide set of social and economic interactions, certain economic interactions result in certain structures of network. (Jackson and Wolinsky (1996)) Hence, economists have long paid substantial attention to both the underlying and resulting networks in many social and economic situations. (Refer to Jackson (2008) for an excellent survey.) Since Free Trade agreements (FTAs) are bilateral relationships between corresponding countries or economic entities and a stack of such bilateral FTAs correctly defines a FTA network in a given population, examining the deriving forces and the resulting structure of FTA network can be one of interesting topics in this regard.

Another implication of FTA network can be discussed with a special connection to an age-long question in international trade literature: whether FTAs help or hinder global free trade. (Bhagwati (1993), Krugman (1991), Levy (1997), and Aghion et at. (2007), to name a few)). Unlike the traditional approaches of the literature, Goyal and Joshi (2006) and Furusawa and Konishi (2007) examine the incentives of individual countries to form FTA links with others and characterize the structures of equilibrium networks, in the context of network formation game. They explore the scope of bilateral FTAs as a foundation for global trade liberalization in an n-country model and show that under some (strict) assumptions, the complete FTA network[1] might be a stable outcome, implying that bilateralism is consistent with free trade at the global level. Unfortunately, their analyses are essentially static in FTA network formation. In recent years, the models have been extended to dynamic network formation

1) A complete network is a network in which there is a direct link between all pairs of nodes. In a complete network with n nodes, there are $n(n-1)/2$ direct links.

environments: See, for instance, Daisaka and Furusawa (2011), Dutta et al. (2011), Zhang et al. (2013), and Zhang et al. (2014).

As is generally accepted, we agree that the network formation game is a powerful tool to investigate the formation of complex FTA network in the world of many strategic countries. However, the approach is exposed to some weaknesses. One of the main goals of network formation game is to find pairwise stable networks in both static and dynamic settings, but they are silent about dynamic paths leading to the stable networks. Moreover, the equilibrium network structures derived under critical assumptions are far from the real FTA network observed in the real world. Therefore, they fail to explain the real formation of FTA network which is still under evolution, regardless of whether they are static or dynamic. The real formation of FTA network and its evolution seems to involve much complicated motivations and processes and these are hard to explain in the existing network formation literature, which suggests the need for models of how the FTA network forms and evolves as it does. This is the goal that we aim to achieve in this paper.

While it is clear that completely random networks[2)] are not always a good approximation for real social and economic networks, the study here shows that they can produce a good approximation as long as some important features are incorporated into the network formation process. For this, we observe the real change of FTA network over time and find out important features of the evolution of the network, and check whether these features are consistent with individual countries' micro-incentives. Then we propose a macro-evolution model, based on and incorporating these features and patterns. Therefore, this paper's specialty is in its pursuit of

2) A random graph is obtained by starting with a set of m isolated vertices and adding successive edges between them at random. With this random network perspective, one can view the random network as a sample from a probability distribution.

theoretical reasoning which explains how and why FTA network forms and evolves as it does.

For empirics, this paper has benefited from numerous existing studies for various social and economic networks. (Refer to Jackson and Rogers (2005), Goyal et al. (2006), and Jackson (2008)) With significant hurdles associated with defining and measuring social networks, one of the most extensively checked aspects of the economic literature is whether the large social networks exhibit features of "small worlds". The notion of small worlds captures the idea that large networks tend to have small diameters and small average path lengths. The small world in this FTA network context is directly related to the concept of "global free trade" and "global village". Jackson and Rogers (2005) employ the connections model in Jackson and Wolinsky (1996) to examine "economic-based" reasoning for the small world formation and analyze how small world features can be traced to how benefits and costs vary across players. Goyal et al. (2006) empirically analyze the evolution of social distance between economists from 1970 to 2000 and conclude that economics is an emerging small world. On top of this, much attention in the empirical literature has been paid to the examination of whether the degree distributions of observed social networks tend to exhibit fat tails and the distribution functions follow a power law, after the seminal work by Price (1965). Price (1965) is the first to investigate such distribution in a network setting and observe that citation networks among science articles seems to follow a power law. Now it is well known that many social networks exhibit fat tails in that there are more nodes with relatively high and low degrees than would tend to arise if links were formed independently. However, it is not clear these distributions really follow a power law. This empirical question also needs to be addressed in our study. In this paper, observing the evolution of FTA network during the period from 1973 to the mid-2010s, we check whether FTA network statistics satisfy the four criteria for a network to display small world properties, and empirically estimate whether the degree distribution function follows a power law. The results obtained in the empirics, in turn, will be employed as basic properties in theoretic modeling of the evolution of FTA network.

This paper complements the existing literature by examining the empirical evolution of FTA network and by theoretically proposing an underlying mechanism of the evolution of the network. For this we take three steps: (1) Empirical observation – (2) Checking micro-incentives of individual countries – (3) modeling a macro-evolution of FTA network. From empirical observation, we find that the FTA network is a growing network, that there exist star countries[3] and their status as star persist in the growing network, that there exists a property of preferential attachment in the link formation between a new born country and existing countries, and that the FTA networks evolves to exhibit small world and the degree distribution follows a power law. For checking micro-incentives of countries, we use Goyal and Joshi (2006)'s endogenous tariff model and show that empirical observations partly match with micro-incentives of countries. Although we employ Goyal and Joshi (2006)'s model for our analysis, there are many differences. We just check the micro-incentives of certain countries using their model and depart from this static framework to investigate macro-evolution of FTA network. That is, Goyal and Joshi (2006)'s model is used just as a stage game implied in the macro-evolution model. Finally, by incorporating empirical observations and micro-incentives of countries into the

3) The concept of star countries is closely related to the definition of a star network. A star network consists of one central hub (which is called "star") and peripheral nodes, where every peripheral nodes are directly connected to the star. Here, star countries play a role of central hub in topology like a star in star networks.

mathematical frame of mean-field approximation, we model historic FTA network formation and try to explain the macro-evolution of FTA network. To sum up, we empirically and micro-theoretically find important factors that affect the decision of countries when they form a FTA link. Then we set up the macro-evolution model reflecting those factors. All of these are done to explain how and why FTA networks form and evolve as they do. To the best of our knowledge, this paper is the first trial to explain the macro-evolution of FTA network based on both empirical observations and theoretic micro-incentives of individual countries.

The rest of this paper is organized as follows: In Section 2 we empirically observe the evolution of FTA network, analyze network statistics, and summarize empirical observations. In Section 3 introduces the basic network formation model to check the micro-incentives of individual countries and to match with the empirical observations. And then, based on both empirical observations and micro-incentives, we present a macro-evolution model. Section 4 discusses our model and concludes.

Ⅱ. Empirical Observation

1. Evolution of FTA Network

The empirical evolution of the network structure of FTA links for the period from 1973 to 2015 is examined, focusing on the properties of network structure and the degree distribution. Economic entities represented by nodes in graphs are mainly individual countries, but some are existing PTAs (Preferential Trade Agreements).[4] That is,

4) PTAs stands for Preferential Trade Agreement, and is an economic pact between participating countries to help improve quantity of trade by gradually reducing tariffs between participating countries. PTA is always a

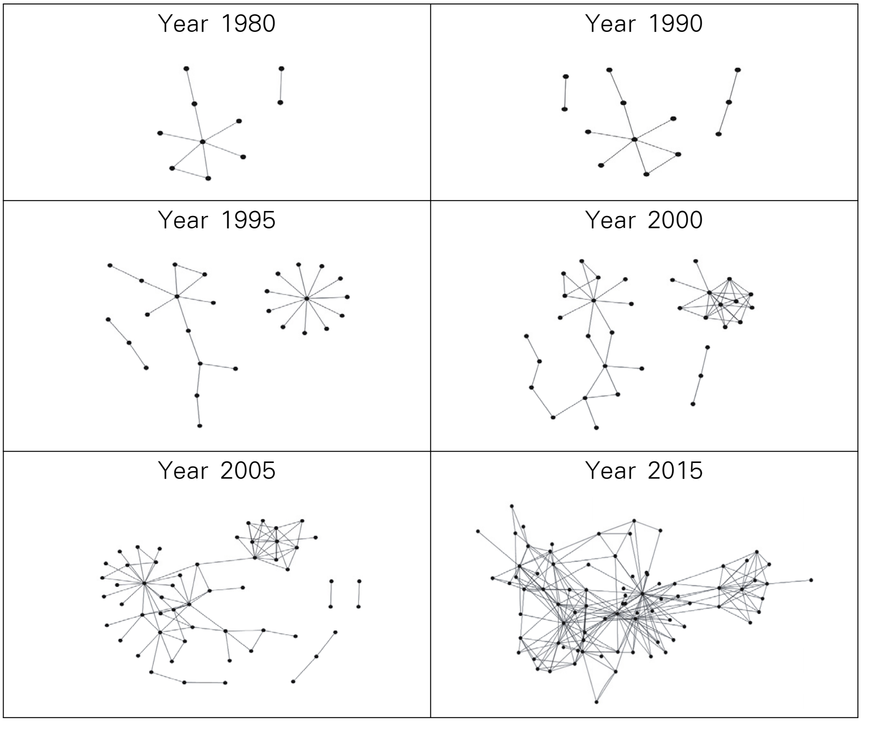
existing PTAs such as the EU (European Union) and the EFTA (European Free Trade Association) are considered as single economic entities because many FTAs are done between them and individual countries. Therefore, FTA links within the EU and the EFTA are not considered, but FTAs between these regional groups and individual countries are included. For simplicity, we just call the economic entities countries. Figure 1 illustrates how the FTA network evolves over time during the time period.

The time period is split into six intervals (1973-1980, 1981-1990, 1991-1995, 1996-2000, 2001-2005, and 2006-2015) according to the development of the network. The networks in Figure 1 are snapshots as of the end of specific years. After the first FTA network among European Community, Switzerland, and Liechtenstein in 1973, the FTA network grows slowly during the 1970-1980s and then proliferates after 1990s. Figure 1 shows that a few components are separated until the early 2000s, reflecting the economic and political separation of the Cold War. All three components are connected one another after the link between Ukraine and the Former Yugoslav Republic of Macedonia (in 2001), the link between New Zealand and Singapore (in 2001) and the link between the EFTA and Singapore (in 2003), among others. The FTA network as of Year 2015 has 82 nodes and 231 links. Note that 82 economic entities cover almost all individual countries.[5)]

starting point and FTA is the final goal of participating countries in a trade block. Whereas PTA aims at reducing tariffs, FTA aims at elimination of artificial barriers and tariffs in trade altogether.

5) Crawford and Fiorentino (2005) show that 145 of the 146 WTO member countries participate in or are actively negotiating RTAs as of 2003.

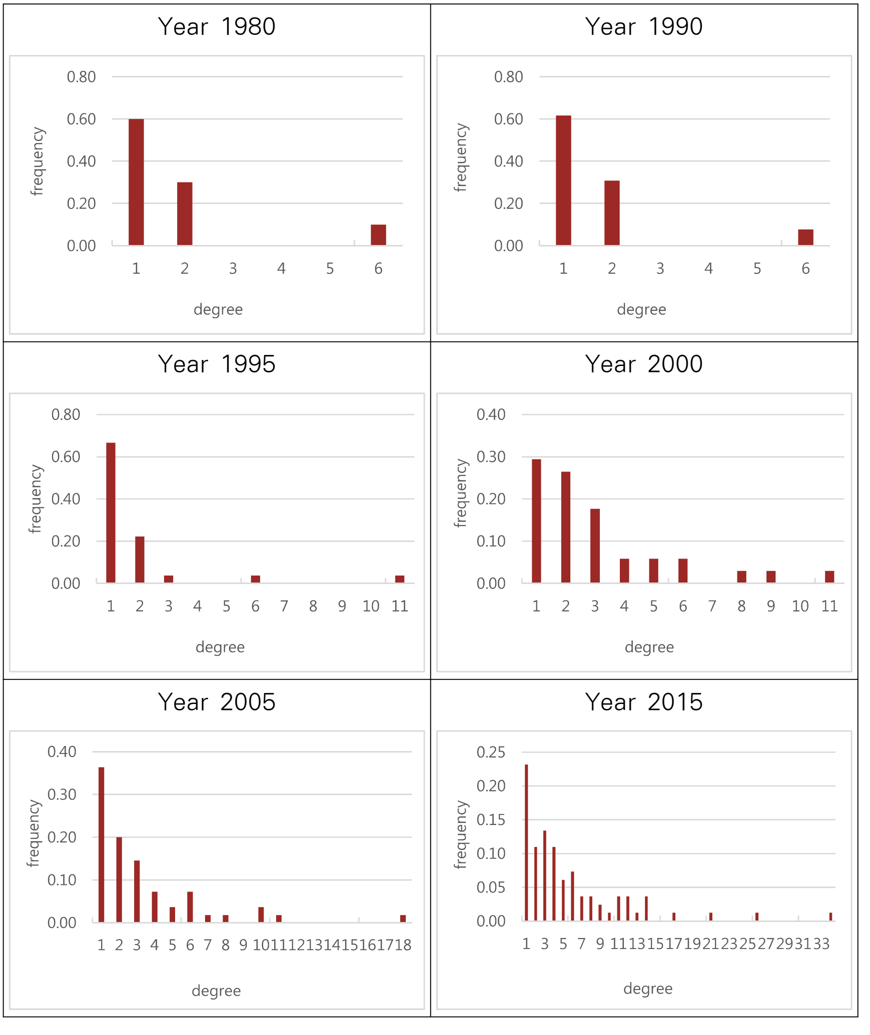
⟨Figure 1⟩ The evolution of FTA network



Notes: 1) Nodes denote economic entities participating in FTAs, and the links represent FTAs.
2) Time period is arbitrarily divided depending on the evolution of the graph structure of networks.
3) The star entities, for instance, are EU in 1980 and 1990, EU and Russia in 1995, EU, Russia, EFTA, Ukraine, Armenia and Kyrgyz in 2000, EU, Russia, EFTA, Ukraine, Armenia, Kyrgyz, Chile and Singapore in 2005, respectively. In 2015, many countries including Japan, Korea and China appear as the stars.

Here some points are noted. Figure 1 illustrates the realization of a real game of FTA network formation among individual countries over the last 40 years. As implicated by the theoretic predictions of Goyal and Joshi (2006) and Furusawa and Konishi (2007), the network structures are far from being complete because of the existence of many types of heterogeneity. However, the network structures have meaningful properties. First, the FTA network is a growing network. Second, there emerge star countries in the middle of network formation process and their status as star countries have been strengthened over time. Without them the network would have remained sparse. Finally, almost all nodes in the network are linked after the mid-2000s. That is, almost all nodes are connected and the distance between any two becomes surprisingly shorter, which making the world smaller. These observations are reinforced by checking the degree distribution of FTA network in Figure 2.

〈Figure 2〉 The evolution of degree distribution of FTA network



Note: In the study of graphs and networks, the degree of a node in a network is the number of links it has to other nodes and the degree distribution is the probability distribution of these degrees over the whole network.

Through the degree distributions, we can easily check the emergence of star countries and the persistence of their status in the growing FTA network. Because of these properties, the distributions have fat tails on the right as shown in the degree distributions in Figure 2.[6] And more importantly, the number of star countries grows and, at the same time, the degrees of star countries are increasing over time. The facts that the number of countries in the network grows and that the degrees of the existing star countries are increasing give a strong evidence of "preferential attachment" in the network formation process, although the exact mechanism of preferential attachment is hard to describe. In the network literature, a link formation process is named "preferential attachment" if the probability that a country gets linked is proportional to the number of links it already has. These features of preferential attachment are essential to obtaining fat-tailed distributions. We summarize the empirical observation as follows:

Empirical observation 1:

1. *The FTA network grows over time so that new countries continue to enter.*
2. *There emerge star countries in the network formation process.*
3. *The number of star countries grows and, at the same time, the degrees of star countries are also increasing over time.*

Based on empirical observations, we perform two tasks as in existing studies on social and economic networks. One is to check

6) A fat-tailed distribution is a probability distribution that has the property that it exhibits large skewness or kurtosis. (Jackson, 2008) This comparison is often made relative to the normal distribution, or to the exponential distribution. Fat-tailed distributions have been empirically encountered in a variety of areas: economics, physics, and earth sciences. Here we can basically check "fat-tailedness" by the persistence of their status of star countries in the growing network.

whether the FTA network as a social network exhibits features of small worlds. The other is to examine whether the degree distributions of FTA network tend to exhibit fat tails and whether the distribution functions follow a power law. For these purposes, we minimally introduce some notations in advance.

2. Basic Network Terminology

We follow Goyal and Joshi (2006)'s notations. Let $N=\{1,2,3,\cdots,n\}$ be a set of countries (economic entities) in the world economy. For two countries $i,j \in N$, define $g_{i,j} \in \{0,1\}$ as the FTA link between them, with $g_{i,j}=1$ the two countries share a (undirected) link and $g_{i,j}=0$ otherwise. The collection of countries and links between them yield a network $g \in G$ of FTA relationships. That is, $g=\{(g_{ij})_{i,j \in N}\}$. For any FTA network $g, g+ij$ is the network obtained by adding an extra link ij to g and $g-ij$ denotes the network obtained by deleting an existing link ij from g.

Let $\mathrm{N}_i(g)=\{j \in N: g_{i,j}=1\}$ be a set of neighbors with whom i has relationships in the network g. The number of neighbors of country i, that is, $\eta_i(g)=|\mathrm{N}_i(g)|$, is referred to as the *degree* of country i in the network g. The *average degree* in the network g is $\eta(g)=\sum_{i \in N}\eta_i(g)/n$. There is a path between countries i and j if $g_{i,j}=1$ or if there is a set of distinct intermediate countries $j_1, j_2,$ $\cdots, j_m$, such that $g_{i,j_1}=g_{j_1 j_2}=\cdots=g_{j_m,j}=1$. If there exists a path between two countries, then they belong to the same component.[7] Components can be ordered in terms of their size, and the network has a giant component if the largest component represents a relatively large portion of population and all other components are

7) A component or connected component of a graph is a subgraph in which any two vertices are connected to each other by paths.

small (typically of order $\ln(n)$).

The *distance* between two countries i and j in the network G, is denoted as $d(i,j;g)$, and is the length of the shortest path between them. If there is no path between two countries i and j in the network g, then $d(i,j;g)=\infty$. For a connected network g, the *average distance* is given by

$$d(g)=\frac{\sum_{i\in N}\sum_{j\in N}d(i,j;g)}{n(n-1)}.$$

The *clustering coefficient* for country i in the network G is a measure of connectivity between his neighbors and given by

$$C_i(g)=\frac{\sum_{l\in \mathrm{N}_i(g)}\sum_{k\in \mathrm{N}_i(g)}g_{l,k}}{\eta_i(\eta_i-1)}$$

for all $i\in N'\equiv\{i\in N:\eta_i\geq 2\}$. This coefficient indicates the percentage of a country's neighbors linked to one another. That is, if country i has a clustering coefficient of unity, then all neighbors of country i are also neighbors of one another. The *clustering coefficient* for the network g is defined by the weighted average of individual clustering coefficients as follows:

$$C(g)=\sum_{i\in N'}\frac{\eta_i(\eta_i-1)}{\sum_{j\in N'}\eta_j(\eta_j-1)}C_i(g).$$

Here the network g is said to exhibit *small world* properties if it satisfies the following four conditions: (1) The number of nodes is very large in comparison to the average number of links, $n\gg\eta(g)$. (2) The network is integrated. That is, a giant component exists and covers a large portion of the population. (3) The average distance between nodes in the giant component, $d(g)$, is small and of order $\ln(n)$. Finally, (4) clustering must be high such that, $C(g) \gg \eta(g)/n$.[8] This definition extends that in Watts (1999) and is taken from Goyal et al. (2006).

3. Small World Hypothesis

Table 1 presents basic statistics on FTA network. We start explanation with the number of nodes in network. This paper counts all economic entities that form at least one FTA link. Therefore, the number increases from 10 in 1980 to 82 in 2015. The problem is that the number of nodes in 1970-2000 period may not capture the population of valid economic entities, therefore network statistics of this time period are not reliable for testing the small world hypothesis. This requires a careful analysis of qualitative properties of the network. Nevertheless, because the number of nodes in the 2000s and 2010s captures almost all valid economic entities, network statistics in these periods are reliable. The 1980s and 1990s are transitional, and therefore both network statistics and qualitative graph structures are evaluated.

〈Table 1〉 FTA network statistics

	1980	1990	1995	2000	2005	2015
Number of nodes	10	13	27	34	55	82
Number of links	9	11	25	52	90	231
Average degree	1.800	1.692	1.852	3.059	3.273	5.585
Average distance	1.862	1.813	2.282	2.908	3.307	2.764
Clustering coefficient	0.207	0.159	0.077	0.359	0.318	0.332

Note: The network structure before 1980 is very similar to that in 1980.

8) This implies that such networks showing small world properties have high clustering coefficients relative to those generated by a random process.

Now the first statistic for the small world, that is, the average degree, is considered. Table 1 shows that the average degree increases from 1.800 to 5.585. Comparing these numbers to the total number of nodes shows that *the average number of FTA links is very small relative to the total number of economic entities.*

Then the existence of a giant component and its share are examined. Figure 1 shows that the largest component in the 1973-1990 period. Given that almost all economic entities are connected in a single network in the early 2000s, it is concluded that *the giant component has grown substantially and the FTA network after the early 2000s is virtually a single giant component.*

Now the third statistic for the small world, namely the average distance, is considered. As in the network literature, the average distance of the giant component is used as a proxy for the average distance of the whole network. Surprisingly, the average distance is no more than four over all time periods. For reference, this number is very small in comparison to that in Goyal et al. (2006), who report about 10.[9] These results suggest that *the FTA network is very small in terms of its average distance.*

Finally, the clustering coefficient for the network is discussed. The clustering coefficients for the FTA network are 0.207 in 1980, 0.159 in 1990, 0.077 in 1995, 0.359 in 2000, 0.318 in 2005, and 0.332 in 2015. Here the point is to check whether these clustering coefficients are higher than those from a random generation process of links. If connections are random, then the probability of a specific link formation is approximately the same as the average number of neighbors divided by the total number of nodes $(\eta(G)/n)$. The clustering coefficients of 0.359 in 2000, 0.318 in 2005, and 0.332 in 2015 are about four, six, and five times those predicted by the

9) The simple comparison of two number requires careful attention, because the absolute size of two networks is different.

random process (0.090, 0.054, and 0.068 respectively). This implies that *the clustering coefficient for the FTA network is high enough throughout the time period*.

In sum, the FTA network satisfies all four criteria over whole analysis period.10) However, as mentioned above, the number of nodes in 1970-2000 period may not capture the population of valid economic entities, any interpretation of the results for the 1970-2000 period should be made with caution. In this regard, it can be concluded that *the FTA network strongly satisfies small world properties at least after the early 2000s*. That is, as an increase in the number of economic entities participating in the FTA network significantly reduces the size of the network.

Empirical observation 2: *The FTA network satisfies small world properties after the early 2000s.*

Although the results look simple, they deliver meaningful implications in the context of international trade literature. We hope this result might throw some hint to the understanding of age-long question of whether the surge in regionalism can facilitate global trade liberalization or a global village. Although the proliferation of regionalism (i.e., bilateral FTAs) may not lead to complete global trade liberalization, it makes substantial contributions to in the establishment of a small world.

4. Power Law Hypothesis

Now we examine whether the degree distributions of FTA network tend to exhibit fat tails and whether the distribution functions follow

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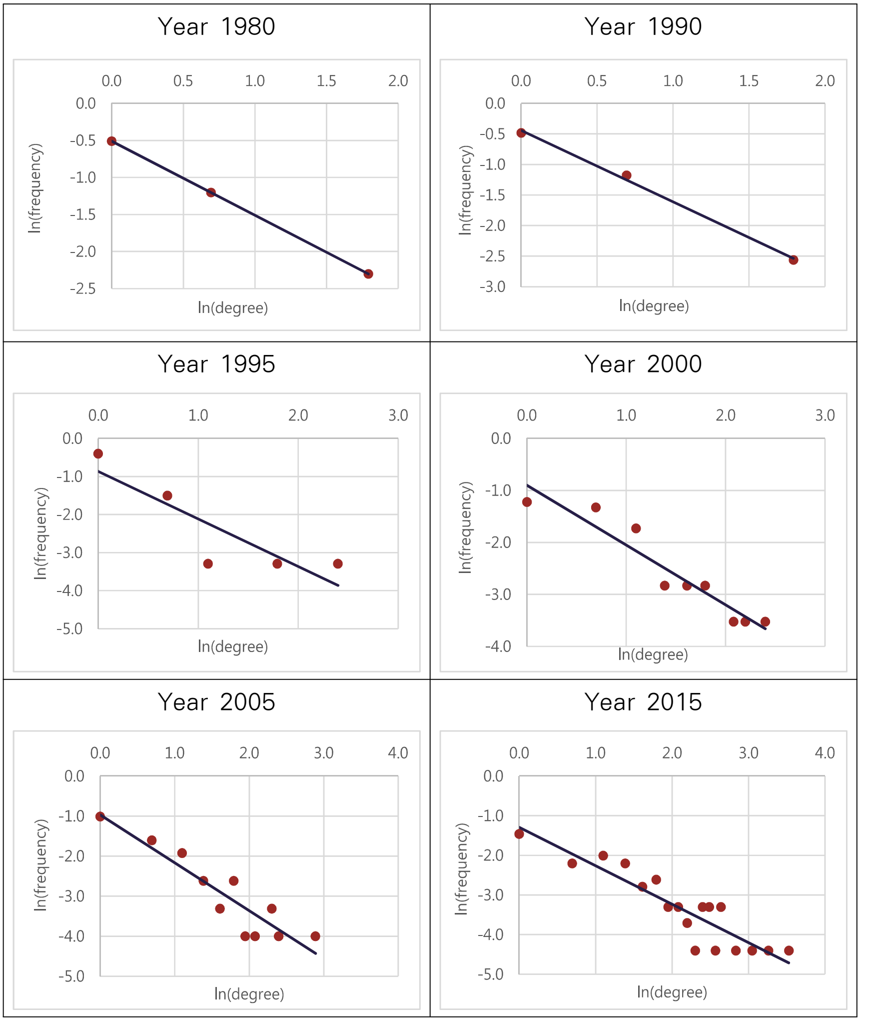
10) If individual countries are defined as nodes and network statistics are calculated, then there is much stronger evidence.

a power law. If the degree distributions satisfy a power law, they are linear when plotted on a log-log plot (i.e., log(frequency) versus log (degree) instead of the raw numbers) as shown in Figure 3.

〈Figure 3〉 The evolution of degree distribution of FTA network: log-log plots



Note: It is well known that fitting to a power law distribution by using only graphical methods based on linear fit on the log-log scale can be biased and inaccurate.

The pure power law distribution, known as the zeta distribution, or discrete Pareto distribution is expressed as the following function:

$$\text{CDF: } F(\eta|\alpha,\eta_0) = 1 - \left(\frac{\eta_0}{\eta}\right)^{\alpha} : \eta_0 \leq \eta < \infty; \alpha, \eta_0 > 0,$$

$$\text{PDF: } f(\eta|\alpha,\eta_0) = \frac{\alpha\eta_0^{\alpha}}{\eta^{\alpha+1}} : \eta_0 \leq \eta < \infty; \alpha, \eta_0 > 0,$$

where η is the degree of nodes in the network. Note that η_0 is a minimum value, called the location parameter.

Considering the number of nodes in the network, we estimate the degree distributions of FTA network after year 2000. When estimated as of the end of 2000, the Maximum likelihood parameter estimation gives $f(\eta|\alpha,\eta_0) = 1.169\eta^{-2.269}$, which follows a power law with statistical significance.

⟨Table 2⟩ Maximum likelihood fit of discrete Pareto distribution: Year 2000

degree	Coef.	Std. Err.	$P > \|z\|$
α	1.169	0.201	0.000

Note: The estimation is performed using a STATA order; ML fit of Pareto distribution.

And, when estimated as of the end of 2015, the Maximum likelihood parameter estimation gives $f(\eta|\alpha,\eta_0) = 0.772\eta^{-1.772}$, which also follows a power law but with a smaller value of α. This means that the degree of fat-tailedness become strengthened after the early 2000s, which is hinted by the degree distributions of Figures 2 and 3.

⟨Table 3⟩ Maximum likelihood fit of discrete Pareto distribution: Year 2015

degree	Coef.	Std. Err.	$P > \|z\|$
α	0.772	0.085	0.000

Note: The estimation is performed using a STATA order; ML fit of Pareto distribution.

Empirical observation 3: *The degree distributions of FTA network follow* *a power law after 2000. And the degree of fat-tailedness is strengthened over time from 2000 to 2015.*

This observation is closely related to the results of Barabasi and Albert (1999). Barabasi and Albert (1999), analyzing random networks, show that a scale-free power law distribution can be a consequence of two generic mechanisms: (i) networks expand continuously by the addition of new vertices, and (ii) new vertices attach preferentially to sites that are already well connected. In the following section, we show that these two mechanisms are consistent with what we have observed in the evolution of FTA network and that these features are also consistent with micro-incentives of strategic countries.

Ⅲ. Theoretic Consideration

Based on empirical findings, we model a growing FTA network where nodes are born over time. Before that, we first examine micro-incentives of individual countries in the context of the network formation game which will be implicitly embedded as a stage game in the macro-evolution model, and show that micro-incentives of countries well match the empirical observations mentioned above.

1. Micro-incentives: Bilateral FTA Network Formation Game

The stage game used here is the same as the endogenous tariffs case developed by Goyal and Joshi (2006). At time t, let $N=\{1,2,3,\cdots,n\}$ be a set of existing symmetric countries. Each country has a single firm producing a homogeneous good at a constant and identical marginal cost γ. The firm in each country chooses how much to produce for its domestic market and how much to export to each foreign country. But each firm's ability to sell in foreign markets depends on the level of tariffs set by different countries. In the market of country i, firms face an inverse linear demand function: $P_i = a - Q_i$, where $a > \gamma$. Let Q_i^j be the export level of firm j to country i. Then $Q_i = \sum_{j \in N} Q_i^j$ is the aggregate quantity in country i. Assume that all firms compete in a Cournot fashion in country i.

Consider the following network formation game. Countries bilaterally discuss free trade and the tariff is set to zero if they sign an FTA. Then each country noncooperatively decides an optimal tariff to levy on those non-FTA countries. Finally, firms determine the outputs to be supplied to their domestic markets and that to be exported to foreign markets. Let T_i^j be the tariff faced by firm j in country i, then $T_i^j(g) = T_i^j(g) = 0$ if $g_{i,j} = 1$ and $T_i^j(g), T_i^j(g) > 0$ if $g_{i,j} = 0$. Because all countries are ex ante symmetric, $T_i^k(g) = T_i(g)$ for all k such that $g_{i,k} = 0$.

A firm must solve different maximization problem in its choices of export level to country i depending on the trade relation between its home country and country i. If $g_{i,j} = 1$, firm j solves $Max_q(a - (\eta_i(g) - 1)Q_i^j(g) - (n - \eta_i(g))Q_i^k(g) - q - \gamma)q$. If $g_{i,k} = 0$, firm k solves $Max_{q'}(a - \eta_i(g)Q_i^j(g) - (n - \eta_i(g) - 1)Q_i^k(g) - q' - \gamma - T_i)q'$. With simple calculation, the Cournot equilibrium outputs in country i are

$$Q_i^j(g) = \frac{(a-\gamma) + (n - \eta_i(g))T_i(g)}{n+1} \quad \text{for } j \in \mathrm{N}_i(g) \tag{1}$$

and

$$Q_i^k(g) = \frac{(a-\gamma) - (\eta_i(g) + 1)T_i(g)}{n+1} \quad \text{for } k \in N \setminus \mathrm{N}_i(g). \tag{2}$$

Given an FTA network g, the social welfare of country i is defined as the sum of consumer surplus, firm's profits and tariff revenues:

$$SW_i(g) = \frac{1}{2} Q_i^2(g) + \left[(P_i(g) - \gamma) Q_i^i + \sum_{j \neq i} (P_j(g) - \gamma - T_j^i(g)) Q_j^i(g) \right] + \sum_{j \neq i} T_i^j(g) Q_i^j(g).$$

Substituting the Cournot equilibrium outputs (1) and (2) into $SW_i(g)$, we obtain the social welfare of country i as a function of tariff rate $T_i(g)$:

$$\begin{aligned} SW_i(g) = \frac{1}{2} \left[\frac{n(a-\gamma) - (n - \eta_i(g)) T_i(g)}{n+1} \right]^2 \\ + \sum_{j \in \mathrm{N}_i(g)} \left[\frac{(a-\gamma) - (n - \eta_j(g)) T_j(g)}{n+1} \right]^2 \\ + \sum_{k \in N \setminus \mathrm{N}_i(g)} \left[\frac{(a-\gamma) - (\eta_k(g) + 1) T_k(g)}{n+1} \right]^2 \\ + (n - \eta_i(g)) T_i(g) \left[\frac{(a-\gamma) - (\eta_i(g) + 1) T_i(g)}{n+1} \right]. \end{aligned} \qquad (3)$$

Here in equation (3), the first term is consumer surplus, the second and the third terms are firm's profit, and the last term is tariff revenues.

Country i noncooperatively sets the optimal tariff level to maximize its social welfare. This gives

$$T_i^*(g) = \frac{3(a-\gamma)}{\eta_i(g)(2n+5) - (n-2)}. \qquad (4)$$

So far the basic model parallels Goyal and Joshi (2006)'s FTA framework. Here we substitute (4) into (3), then each country's welfare is determined by the network g as the following:

$$SW_i(g) = \frac{(a-\gamma)^2}{2}\frac{[\eta_i(g)(2n+1)-(n-4)]}{[\eta_i(g)(2n+5)-(n-2)]}$$
$$+(a-\gamma)^2 + \sum_{j\in \mathrm{N}_i(g)\setminus\{i\}}\left[\frac{2(\eta_j(g)+1)}{\eta_j(g)(2n+5)-(n-2)}\right]^2$$
$$+(a-\gamma)^2 + \sum_{k\in N\setminus \mathrm{N}_i(g)}\left[\frac{2(\eta_k(g)-1)}{\eta_k(g)(2n+5)-(n-2)}\right]^2. \quad (5)$$

Note that country i's welfare is not only determined by the number of its own bilateral links, but also by the number of bilateral links of its FTA partners and non-FTA partners. As a result the FTA network formation game is defined.

Following the tradition of network literature, we also follow the concept of pairwise stability (Jackson and Wolinsky (1996)). An FTA network g is *pairwise stable* if for any $i,j\in N$, (i) when $g_{i,j}=1$, $SW_i(g)\geq SW_i(g-ij)$ and $SW_j(g)\geq SW_j(g-ij)$ hold, (ii) when $g_{i,j}=0$, if $SW_i(g+ij)\geq SW_i(g)$, then $SW_j(g+ij)<SW_j(g)$ hold. In words, if the network is pairwise stable, neither will benefit from severing an existing FTA link unilaterally or establishing a new one bilaterally.

In the previous section, we observed the existence of star countries. Based on empirical observations and the findings of Mukunoki and Tachi (2006), we take the existence of star countries as given and focus on the behavior of star countries. Suppose country i emerges as a star country.

When $g_{i,j}=0$, country i's incentive to form the FTA link ij with country j can be measured by

$$SW_i(g+ij)-SW_i(g)$$

$$=-\frac{9(a-\gamma)^2}{(2n+5)^2\eta_i(g)^2+9(2n+5)\eta_i(g)-(n+7)(n-2)}$$
$$+\frac{3(a-\gamma)^2[4(2n+5)^2\eta_j(g)^3+(2n+5)(2n+53)\eta_j(g)^2-(16n^2+26n-170)\eta_j(g)+20n^2+48n]}{[(2n+5)^2\eta_j(g)^2+9(2n+5)\eta_j(g)-(n+7)(n-2)]^2}$$

The sign of $SW_i(g+ij)-SW_i(g)$ is very important in the definition of pairwise stability.

Theoretical observation 4: *Suppose* $g_{i,j}=0$ *and* $SW_i(g+ij)-SW_i(g)>0$. *Then*

$$\frac{\partial(SW_i(g+ij)-SW_i(g))}{\partial\eta_i(g)}>0.$$

This theoretical observation says that as $\eta_i(g)$ increases, the gain from consumer surplus is larger than the loss of firm i's domestic profit and country i's tariff revenue. And this explains the desire of the star country for the persistence of its status as star country. That is, once country i emerges as a star country in a FTA network, it is advantageous for i to strengthen its role as a hub by increasing its own FTA links. This matched with the empirical observation that the degree of star countries keeps increasing.

Theoretical observation 5: *Suppose* $g_{i,j}=0$ *and* $SW_i(g+ij)-SW_i(g)>0$. *Then*

$$\frac{\partial(SW_i(g+ij)-SW_i(g))}{\partial\eta_j(g)}<0.$$

The intuition behind this result is simple. Less $\eta_i(g)$ means that fewer active firms are operating in country j's market. So FTA will enable firm i gain larger profit. Thus, the incentive for country i to link with a less-linked country is much stronger. That is, the most preferred country as an FTA partner from the side of a star country is a new born country.[11)]

2. Macro-evolution: Mean Field Approximation

Finally, we introduce a well-known macro-evolution model which produces an approximation to FTA network by incorporating empirical observations and individual countries' micro-incentives into the network formation process. What we found from the empirical observations and the micro-incentive model are summarized as follows: (1) The FTA network grows over time so that new countries continue to enter. (2) There exist star countries and their status becomes strengthened. (3) It is advantageous for star countries to strengthen its role as a hub by increasing their own FTA links. Finally, (4) for star countries, the most preferred country for an FTA partner is a new born country. These features ensure the preferential attachment in the process as shown in Barabasi and Albert (1999).

We illustrate a growing network formation model in the frame of mean field approximation[12)] where the network formation game is

11) The limitation of the network formation game is that it is hard to explain the micro-incentives of new born countries, because they also prefer less linked partners from a pure economic point of view. The network formation game literature cannot explain this. At this stage, we simply assume that the new born countries have weak bargaining power as compared to the existing (star) countries, since the FTA link for new countries is beyond the simple economic incentive problem, which is somewhat convincing in the realm of political economics. (Levy (1997))

12) In probability theory, mean field approximation studies the behavior of large populations by studying a simple model. Such models consider a large number of small individual components which interact with each other. The key idea is that the effect of all the other individuals on any given individual is approximated by a single averaged effect, thus reducing a many-body problem to a one-body problem. Please refer to Cardaliaguet (2012) for an introduction.

implied as a stage.

By doing this, we can check that the theoretically derived distribution of the degree of the nodes turn out to match with the empirical estimation of FTA network very well, especially until the early 2000s. The explanatory power of theory, however, somewhat deteriorates after the mid-2000s. When we guess it from the empirical results mentioned above, FTA link formation process changes a lot. This can be seen in Figure 1. Until the early 2000s FTA link formation mainly happens between a new node and existing nodes, but after the mid-200s FTA links are formed between existing nodes. Nonetheless, on the whole, the macro-evolution model significantly explains the historic network formation process over time.

All details are attached in the Appendix.

Theoretical observation 6: *The macro-evolution model which incorporates the features and patterns based on empirical observations and micro-incentives well explains the evolution of FTA network, especially until the early 2000s.*

Ⅳ. Discussion

The study has analyzed and explained the historic evolution of FTA network during the period from 1973 to the mid-2010s. The existing literature on FTA networks are silent about dynamic paths leading to the equilibrium network and, moreover, the equilibrium network structures are far from the real FTA network observed in the real world. Therefore, they fail to explain the real formation of FTA network, regardless of whether they are static or dynamic. Motivated by this, we have tried to propose a model of how and why FTA network forms and evolve as they do. Also, while it is clear that random networks are not always a good approximation for real social and economic networks, this paper shows the possibility that they can produce a fairly good approximation as long as some important patterns and features are incorporated into the network formation process. This paper's specialty is in its pursuit of research which explains how and why FTA networks form and evolve as they do, after observing the real change of FTA network over time and checking individual countries' micro-incentives in the stage of FTA link formation game.

This study complements the existing literature by examining the empirical evolution of FTA network, by characterizing empirical properties of FTA network, and by theoretically explaining the underlying mechanism of the evolution of network based on both the observed empirical properties and micro-incentives of individual countries. From the empirical observations, we find that the FTA network is a growing network, that there exist star countries and their status persist in the growing network, that there is a property of preferential attachment in the link formation between a new country and existing countries, and that the FTA networks evolves to exhibit small worlds and the degree distribution follows a power law. Then we show that these empirical observations are consistent with micro-incentives of strategic countries, using Goyal and Joshi (2006)'s model. Finally, by incorporating empirical observations and micro-incentives of countries into the mathematical tool of mean-field approximation, we analyze historic FTA network formation and explain the macro-evolution of FTA network. To sum up, we, first, empirically and micro-theoretically find important factors that affect the decision of countries when they form a FTA link. Then we set up the macro-evolution model reflecting those factors. All of these are done to explain how and why FTA networks form and evolve as they do. To the best of our knowledge, this paper is the first trial to explain the macro-evolution of FTA network based on both empirical observations and theoretic micro-incentives of individual countries.

Finally, we wish this result might throw some hint to the understanding of whether the surge in regionalism can facilitate global trade liberalization or a global village. Although the proliferation of regionalism may not lead to complete global trade liberalization, it makes substantial contributions to in the establishment of a small world.

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Appendix

Macro-evolution: Mean Field Approximation

Time, t, is discrete and the horizon is infinite. Nodes are born over time and play the FTA link formation game with existing nodes at the time of their birth.13) As nodes are born over time, we index them by the order of their birth. Thus node i is born at time $i \in \{0,1,2,3,\cdots\}$. Although nodes might be born in cluster, for simplicity, think of each period of time as indicating a new node has been born. A node forms FTA links with existing nodes when it is born.14) Let $d_i(t)$ be the degree of node i (born at time i) at a time t. Then $d_i(i)$ is the number of links formed at its birth and $d_i(t) - d_i(i)$ is the number of FTA links formed with the new nodes that were born between time i and time t. For definiteness, start with a pre-existing group of m nodes all connected to one another.

A new node is born at time t, and it meets and discusses free trade with existing nodes. Reflecting the existence and persistence of star countries in the growing FTA network, we assume that the more FTA links an existing node has, the larger likelihood that it will be found as a FTA negotiation partner. So the probability that FTA link is formed is proportional to the existing nodes' degrees. Suppose a new node forms (on average) m links after bilateral FTA negotiations. Thus the probability that an existing node i forms a new link with the newborn node at time t is m times node i's degree relative to the overall degree of all existing nodes at time t. That is,

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13) The link formation between existing nodes will be considered after the basic formula is obtained.

14) Some agreements may fail in the stage of network formation game. Then the node who tried to enter the FTA network stay outside the network and we wait for a new entrant. So there is no loss of generality in the process.

$$m\frac{d_i(t)}{\sum_{k=1}^{t} d_k(t)}.$$

Since there exist total tm links in the network at time t, we have $\sum_{k=1}^{t} d_k(t) = 2tm$. Then, the probability that node i gets a new link at time t is $\frac{d_i(t)}{2t}$.

Now suppose some links are formed with a probability depending on the total time that has already evolved, which includes the possibility of link formation between existing nodes. Then, the mean-field, continuous-time approximation of this process is described by

$$\frac{dd_i(t)}{dt} = \frac{d_i(t)}{2t} + \frac{b}{t}$$

with initial condition $d_i(i) = m$. This equation has a solution

$$d_i(t) = (m+2b)\left(\frac{t}{i}\right)^{\frac{1}{2}} - 2m. \qquad (6)$$

The nodes are born over time and then grow. Hence, the degrees of nodes can be ordered by their ages, with the oldest being the largest. At time t, $1 - F_t(d)$ is then all of the nodes that have degree greater than d. In order to find the fraction of nodes with degrees that exceed some given level d at some time t, we just need to identify which node is at exactly level d at time t, and then we know that all nodes born before then are the larger nodes. Let $i^*(d)$ be such that $d_{i^*(d)}(t) = d$. From (6),

$$i^*(d) = t\left(\frac{m+2b}{d+2b}\right)^2. \qquad (7)$$

Since we know that

$$1 - F_t(d) = \frac{i^*(d)}{t},$$

the distribution function is

$$F_t(d) = 1 - \left(\frac{m + 2b}{d + 2b}\right)^2,$$

with a corresponding density distribution of

$$f_t(d) = 2(m + 2b)^2 (d + 2b)^{-3}. \qquad (8)$$

FTA 네트워크의 진화: 경험과 이론

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논문초록

본 논문은 1973년부터 2010년대 중반까지의 기간 동안 일어난 FTA 네트워크의 역사적 진화 과정을 살펴본다. 먼저, 이 기간 동안 FTA 네트워크 진화에서 나타난 중요한 실증적 특성을 관찰하고, 이러한 특성들이 참여자들의 미시적 인센티브와 부합함을 설명한다. 그리고 실증적 특성과 미시적 인센티브를 반영한 랜덤 거시진화모형이 실제 FTA 네트워크의 진화를 어느 정도 설명할 수 있음을 보인다. 특히 이러한 단순 거시진화모형이 2000년대 초반까지는 FTA 네트워크의 진화를 잘 설명함을 보인다. 또한, 비록 지역주의 무역협정의 확산이 완전한 글로벌 무역자유화에 이르게 하지는 못하지만, 지구촌의 형성에 상당한 기여가 있음을 시사점으로 도출한다.

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