The Technology Diffusion in Patent Transaction Network: An Example of TFT-LCD Industry

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Abstract--**This study investigates several distinctive features of a patent transaction market. Through social network analysis, a patent transaction market can reveal the relationship between portfolio clusters, the position of key market players, as well as the behaviors of patent practicing entities (PEs) and non-practicing entities (NPEs). This study's findings show: first, a mature period for a patent transaction market exhibits clusterization and a small-world structure whereby a limited number of players maintain large technological or patent monetization portfolios. Second, the network evolution of a technology market is asynchronous to technology development. Third, technology diffusion in patent transactions will demonstrate a pattern of cooperation, and the typology of a technological transaction chain. The result not only reveals the IPR strategy of leading technology firms but also demonstrates the social structure of their competitive advantage. This analysis provides insights into patent transaction networks, and also addresses management implications for firms interested in acquiring market competition or market governance.**

I. INTRODUCTION

Monetization of intangible assets is becoming an increasing necessity. Patents have moved into the spotlight during the past couple of years, mainly due to high-stakes litigation and acquisitions involving international giants such as Apple, Samsung, Google and Microsoft. As a result of many recent major patent transactions, more and more investors and companies are now implementing programs which focus on the asset monetization. Patent transactions can be seen in many technology sectors, and every patent can be sold or licensed as long as there is a potential interested party.

The patenting of technological development exists in a multilateral environment. As a result of valid patents in specific areas of technology or design being endowed with exclusivity, patent transactions trade on their respective entities. Because patents in a specific technology or design endow exclusivity, firms try to invent alternatives, or "design-arounds", to patented inventions that do not infringe on a given patent's claims. Design-arounds are not only a defense against patent trolls, but also can invoke technological competition [1, 2]. Therefore, design-around patenting can develop as form of competitive parallel patenting [1, 3, 4]. Furthermore, ever-increasing investments in R&D often become critical issues for resource-limited enterprises, requiring these firms to concentrate on what they do best. Many firms focus their in-house R&D expenditures on core technologies, while externally sourcing other less important technologies [5]. Consequently, firms are increasingly contracting external sources or contracting out their own work to third parties. Technology transaction markets thus emerge. Concurrently, firms commercialize external ideas by deploying outside pathways to market in the form of an open innovation model [6]. A firm holding patents profits from others' use of its technology through licensing, joint ventures and other arrangements. These firms are thus form a collaborative technology portfolio in a patent transaction market, causing the market to evolve as a multilateral environment. However, there are few systematic perspectives that can be applied to observe how patent transactions work in a multilateral environment and what construes a multilateral environment process. Furthermore, there are lots of important factors which have been insufficiently discussed. For example, the relationship between portfolio clusters (*i.e.* PEs and NPEs), and the positional analysis of key market players. Additionally, a behavioral analysis of patent practicing and non-practicing entities remains uncertain.

Several studies have contributed to patent transaction investigation: the behaviors of market players and their effect on transaction markets and technology innovation [7-14], patent value assessment and patent monetization, intellectual property legislation and market governance [15-19], and decisions on the types of technology transactions. However, most previous studies focus on player definition or the activity of capital markets rather than the player's collective behaviors and interaction of patent transaction markets. However, exactly which clusterization structures affect patent transactions remains uncertain.

Although current literature provides valuable insight into a patent transaction market, the above questions remain unanswered. In particular, while these multilateral interactivity-related questions are best understood as network-related, few explicit social network analyses of these questions have been performed. Uzzi and Spiro [20] investigate a how the creativity of a network artists was affected in terms of the financial and artistic performance of the musicals they produced. Moon, Barnett and Lim [21] examine the current structure of an international music trade flow network, revealing an imbalanced network structure. Nam and Barnett [22] explore how the structure of globalization of technology via intellectual property networks has changed longitudinally, becoming decentralized over time. McNerney, Fath and Silverberg [23] study the hierarchical structure of inter-industry relationships using networks of money flows between industries in international economies.

In light of the limitations outlined above, study examines a patent transactions market by using network analysis to explore the structural characteristics of a patent transaction network that is distinctive in construction from other markets. This study aims to make the following contributions to the literature on intellectual property transaction networks: First, this study is the first to employ a multilateral and multi-perspective to examine a patent transaction market. The findings identify a distinctive feature of patent transaction players and the ecology of their collaboration. Second, this study presents a systematic approach rarely adopted in the literature to study a network of patent transactions involving various complex processes. Third, the findings regarding the relationships between network structure and transaction flows conclude that the mechanism to simultaneously achieve an efficient market and technological development. Finally, this study addresses policy implications for firms and authorities interested in acquiring market competition or governance.

The rest of this paper is organized as follows: Section 2 reviews pertinent literature, focusing on the transaction market players, patent value assessment and patent monetization, the activity of intellectual property on transaction networks, as well as changes and technological evolution in the flat panel display industry. Section 3 then introduces the measurements and models of social network analysis used to investigate the cluster of this network. Section 4 briefly presents the results of empirical investigation and discusses theoretical and managerial implications. Finally, conclusions are drawn in Section 5, along with recommendations for future research.

II. THEORETICAL BACKGROUND

A. Patent value assessment and patent monetization

A valid patent not only can contribute to practicing entities but can also accommodate financing assets and technological development. In terms of patent collateralization and value assessment, Fischer and Ringler [15] point out the lenders of technology-related characteristics use patents to collateralize high-quality technology that can be redeployed to ventures in similar technology fields. However, patent-related characteristics like scope, which are related to patent value and are particularly important for non-practicing entities (NPEs), do not matter. Furthermore, the relationship between the patent forward citations and the patent family size can have an effect on patent valuation and collateralization [16].

The determinant of what types of technology transactions in a market is another central issue. Jeong, Lee and Kim [17] indicate that firms in technology markets tend to prefer licensing their patents when uncertainty is low, whereas firms in other markets tend to sell their patents when uncertainty is high. Therefore, the uncertainty of a given technological environment is a critical factor which affects firms licensing or selling their patents. However, a network of technological development can relieve environmental uncertainty for technology mobility. Jensen, Palangkaraya and Webster [18] point out trust in a technology partnership can affect the decision to enter the market for immature technology; parties with high levels of trust are more likely to conclude transactions compared with those with low levels of trust. Meanwhile, patents can effectively substitute for a lack of trust, and that trust is more important in upstream stages. Thus, the formation of a technology sector might influence technology mobility. Furthermore, research conducted by Mowery and Ziedonis [19] indicates that technology flows through market transactions are more geographically localized than those operating through nonmarket spillovers.

B. The ecology of patent transaction market

Several studies have contributed investigations into patent transaction markets and provide valuable insight into intellectual property management. Hytönen, Jarimo, Salo and Yli-Juuti [7] point out three types of companies taking part in the transaction market: First, Patenting and Manufacturing Companies (PMCs) contribute strongly to technology and standards development, and they also manufacture and sell related products. PMCs drive the creation of new technologies. They invest heavily in R&D and have a strong influence on emerging standards. Usually, they are the first to introduce new products, giving them first-mover advantage, which is how they obtain the most value from technology development. PMCs have a two-fold objective in licensing: on one hand, they seek to minimize the costs of licensing from third parties. On the other hand, they seek income from companies that have no patents by licensing their own patents to these companies. Second, Manufacturing Companies (MCs) manufacture and sell their own products, but make small investments in technology and standards development in comparison with the size of their product sales. MCs adopt a follower strategy as they let others develop the technology and focus on the implementation of the open technology. Their R&D investments are much lower than those of PMCs. MCs extract value only through product sales, and seek to minimize the compensation to the patent owners. Third, Patenting Companies (PCs) contribute to technology and standards development, but have small or negligible product sales in comparison with their patent portfolios. PCs specializing in R&D with no product sales have been important in many industries [8, 9]. They protect the results of their R&D work and contribute to the standardization process with the aim of making profits by licensing their patents to PMCs and MCs. These companies usually seek to maximize the value of the technology in product markets, as well as their own share of this value.

Additionally, Shrestha [13] proposes the viewpoint of litigation and market activity by investigating patent transaction markets consisting of Practicing Entities (PEs) and Non-practicing entities (NPEs). NPEs are firms that rarely or never practice their patents, instead focusing on earning licensing fees. NPEs may have patented inventions on their own or bought the patents from other inventors. Critics of NPEs have labeled them "patent trolls", and claim that they use weak and vague patents to extract excessive licensing fees or to engage in frivolous infringement litigation against product manufacturers. Meanwhile, Pénin [10] points out NPEs can be broken down into three types: Technological firms, Patent brokers, and Patent trolls. Larson [11] indicates that NPEs, entities which purchase or acquire patents only to enforce them to generate revenues, have taken advantage of a business opportunity in creating various business models centered solely on the exploitation and enforcement of patent rights. Hemphill [12] empirically studies the business model of patent assertion entities (PAEs) and indicates that some PAEs are having an adverse impact on innovation and technology commercialization activities of US firms. However, NPEs and their supporters claim that these firms enhance innovation and competition by providing capital to independent inventors and creating an efficient market for trade in technological information [13]. Finally, Surdeanu and Jeruss [14] states that NPEs in transaction markets potentially act as patent monetization entities (PMEs).

C. Intellectual property on transaction networks

Activities on intellectual property transaction markets not only involve technology or knowledge trading but also focus on multilateral behaviors which interact as a network. Several studies concerning this market structure have provided valuable insights. Moon, Barnett and Lim [21] examine the current structure of international music trade flow networks, revealing an imbalanced network which demonstrates a core-periphery network structure. Their findings showed that the international music trade network remained relatively stable. A country's economic development and culture are influential factors which contribute to determine the global structure of international music flows. Nam and Barnett [22] explored how the structure of globalization of technology via intellectual property networks has changed longitudinally, and compares the structures of global trademarks and patents. The result empirically confirmed that both the trademark and patent networks have become decentralized over time. McNerney, Fath and Silverberg [23] demonstrated the hierarchical community structure of inter-industry relationships using networks of money flows between industries in international economies.

Given the studies above, the development of a sector as capital intensive as technology is well-suited for investigation as a patent transaction network. Flat panel display (FPD) manufacturing emerged as the first sector to fully develop in a global economy defined more by trade in knowledge than in physical products [24]. However, the FPD industry is characterized by large-scale capital investment and accelerated technological development [25], resulting in a technological advantage held by limited number of firms. While stressing the critical role of organizational co-location in FPD development of both technology and industry, previous studies [24, 26] have posited that a new class of global, knowledge-driven manufacturing industries has emerged in which learning, continuity, and speed define competition. Therefore, the patenting of TFT-LED technology can be viewed as activing trade in the transaction market. This study thus selects the patents of TFT-LCD technology for closer examination.

D. FPD industry evolution and TFT-LCD technology

Over the last decade, the FPD industry has distinguished itself largely due to its combination of high technology and enormous capital expenditures. As a result, many FPD applications have become linked directly to daily consumer life, making it a highly promising industry for future growth. The accelerated development of TFT-LCD technology has provided advantages such as slim, lightweight, and compact shapes, energy saving features, high image quality, enhanced visual effects, as well as a modern communication interface [27, 28]. Development of the FPD industry ranges from IT devices to entertainment applications, and from industrial applications to consumer electronics. With its revolutionary development, TFT-LCD technology has demonstrated its strong global potential [24]. Other than a previous study demonstrating FPD industry passing through several phases [29], the industrial evolution of FPD has seldom been explored in the literature. Jang et al. [30] undertook patent data research to divide the evolutionary process of FPD industry into three stages. From the pre-dominant design stage beginning in around 1976, the FPD industry that has emerged in the recent decade can trace its origin back to the 1970s and 1980s in both Japan and the United States [24, 31, 32]. The dominant design stage may also be viewed as a technological transition stage around 1987, which witnessed the establishment of the dominant design mode. The transition stage confirmed the position of TFT-LCD as the dominant design in FPD industry, with the number of TFT-LCD patents granted worldwide more than doubling during this stage. The post-dominant design emerged around 1997, in which triple the number of TFT-LCD patents was granted than in the dominant design stage.

Meanwhile, in terms of network evolutionary studies, Koka, Madhavan and E.Prescott [33] indicate that the network formations can churn, expand, strengthen or shrink. Each network change is created by a specific combination of changes in an actor's "portfolio size" and "portfolio range". Then the type of formation change subsequently presented as: "a network churning period" reflects the formation of new alliances and the elimination of current alliances. While the average portfolio remains stable in terms of the number of partners, an increasing variety of partner identification is available. "A network expands period" by increasing its number of new alliances without eliminating old ones (implying a larger average portfolio), together with an increasing portfolio range (more different partners). "A network strengthens period" by increasing the number of new alliances while eliminating old ones (implying a larger average portfolio), together with a decreasing portfolio range (i.e. fewer different partners).

Previous studies [27, 30, 34] have focused on technological transition more than technology market and transaction networks. Given that the FPD industry and TFT-LCD technology has passed through several development phases, their technology trajectory can provide abundant information for patent transaction network studies.

Furthermore, exactly what the evolutionary processes of technology transaction market are synchronous with technology development remains uncertain.

III. DATA AND METHODOLOGY

A. Data

In addition to providing strategic background information regarding sector-specific factors in domestic and global science-technology linkages and knowledge flows [35], patent citation network analysis demonstrates technological transactions regarding industry-specific development. This study thus utilizes the key term TFT-LCD related technology in patent searching records in the United States Patent and Trademark Office (USPTO) database. This procedure yielded a base sample of 59,855 FPD patent documents from 1976 to 2012. This study then compiled the patent samples to obtain 18,166 patent assignment records from 1978 to 2012. “Corporate Tree Data” was then merged with patent traders for their branch and subsidiary companies. Finally, patent transaction data as then employed to empirically examine network relationships.

B. Methodology

This investigation employs cluster perspective to analyze a patent transaction network. Utilizing the core-periphery analysis, small world analysis, K-core and N-clique analysis explore a collective behavior to reveal the technology mobility. Furthermore, Ego network analysis utilizes degree centrality, and betweenness centrality to examine core position actors.

1) Core-periphery analysis

Several researchers have argued that technological networks typically display core/periphery structure [36, 37]. To test the technological network may actually be form of central and periphery, we employ a core/periphery model proposed by Borgatti and Everett [38] and defining the core/periphery structure as follows: The core/periphery model consists of two classes of nodes, namely a cohesive subgroup (the core) in which actors are connected to each other in some maximal sense and a class of actors that are more loosely connected to the cohesive subgroup but lack any maximal cohesive with the core. In other words, the cohesive group is characterized by a high density of interrelations in contrast to a more loosely connected class of actors forming the periphery of the network [39]. The model iteratively compares an observed network with a perfect core/periphery structure by simultaneously varying the rows and columns of the network’s adjacency matrix. However, it would be unrealistic to expect that observed networks completely match an idealized pattern. We can readily appreciate that observed structures will only approximate idealized pattern. The measurement of how well the observed structure approximates the ideal structure is proposed by Borgatti and Everett [38] as follows:

$$\rho = \sum_i \sum_j a_{ij}\varepsilon_{ij} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where:

$$\varepsilon_{ij} = \begin{cases} 1, & \text{if } i \in core \text{ or } j \in core \\ 0, & \text{otherwise} \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

In the equations, a_{ij} indicates the presence or absence of a tie between any two actors i and j in the observed network. Moreover, ε_{ij} indicates the presence or absence of a corresponding tie in the ideal core/periphery structure. It is obviously that the value of ρ is maximum if the observed network (matrix of a_{ij}) is identical to the ideal core/periphery structure (matrix of ε_{ij}). Hence, if the value of ρ is sufficiently high for that the observed network shows core/periphery structure.

2) Network density

Network density can be categorized into measurement of an actor and a group or network. This study utilizes group density to analyze network interactivity. In a directed network, density is represented as D, the ratio of number of lines or arcs present to the maximum possible number that could arise [40]. Each line or arc is given a value of 1, and pairs of nodes forming absent lines are given a value of zero. To generalize the notion of density to a value graph or digraph, one can average the values attached to the lines/arcs. Wasserman and Faust [41] indicate that the density of a directed network is equal to the proportion of arcs present in the network. This is calculated as the number of arcs, L, divided by the possible number of arcs. Since an arc is an ordered pair of nodes, there are $n(n-1)$ possible arcs. The density for directed network is expressed below:

$$D = \frac{L}{n(n-1)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

The density of a network is a fraction that goes from a minimum of zero (no arcs present) to a maximum of 1 (all arcs are present). If the density is equal to 1, then all dyads are mutual.

This study utilizes Freeman’s centrality measurement [42], which is based on two conceptual foundations. The first measurement is based on the degrees of points and indexes communication activity. The second measurement is based on the betweenness of points and indexes potential for control of communication. Furthermore, each set of these measures includes two indexes of point centrality - one based on counts and one on proportions - and one index of overall network or graph centralization. Together, these measures seem to cover the intuitive range of the concept of centrality. They specify distinctive structural characteristics of network interaction. These measures of overall network centrality agree on the assignment of extremes; that is, one of the main applications of network analysis is the identification of the “important” nodes in their network. The most prominent nodes generally occupy strategic locations within a network. The idea of the centrality of individuals in their network is one of the earliest to be pursued by network analysts [43], and is used to acquire the positional features of individual nodes within networks.

3) small-world analysis.

Watts [44] proposed the “small world network” to interpret a social network structure in which nodes are people and links are acquaintance relationships between people. It is easy to see that people tend to form communities, i.e., small groups in which everyone knows everyone (one can think of such community as a complete graph). In addition, the members of a community also have a few acquaintance relationships to people outside that community. Some people, however, are connected to a large number of communities. Those people may be considered the hubs responsible for the small world phenomenon. Therefore, a small world structure can accelerate information flow [45, 46]. To determine whether a network is a small world, Watts’s model compares the actual network’s path length (L_{actual}) and clusterization coefficient (C_{actual}) to a random graph of the same size, where random graphs have both very low path lengths (L_{random}) and low clusterization (C_{random}). To determine whether a network is a small world, Watts’s model compares the actual network’s path length and clustering coefficient to a random graph of the same size, where random graphs have both very low path lengths and low clustering. Therefore, Kogut and Walker [47] propose the small world quotient (Q_{sw}) expressed as:

$$Q_{sw} = (C_{actual}/L_{actual}) * (L_{random}/C_{random}) \quad \ldots\ldots\ldots\ldots..(4)$$

$$\begin{cases} Q_{sw} > 1, \text{Small world network} \\ Q_{sw} < 1, \text{otherwise} \end{cases}$$

Then, a network is a “small world” when Q_{sw} is substantially greater than one [48].

4) N-clique and K-core

The idea of a clique is relatively simple. At the most general level, a clique is a sub-set of a network in which the actors are more closely and intensely tied to one another than they are to other members of the network. In terms of friendship ties, for example, it is not unusual for people in human groups to form "cliques" on the basis of age, gender, race, ethnicity, religion/ideology, and many other things. The smallest "cliques" are composed of two actors: the dyad. But dyads can be "extended" to become more and more inclusive -- forming strong or closely connected regions in graphs. A number of approaches to finding groups in graphs can be developed by extending the close-coupling of dyads to larger structures.

N-cliques: recall that the geodesic distance between two nodes, denoted by d(*i, j*), is the length of a shortest path between them. Cohesive subgroups based on reachability require that the geodesic distances among members of a subgroup be small Thus, we can specify some cutoff value, n, as the maximum length of geodesics connecting pairs of actors within the cohesive subgroup. Restricting geodesic distance among subgroup members is the basis for the definition of an n-clique [49, 50]. An n-clique is a maximal subgraph in which the largest geodesic distance between any two nodes is no greater than n. Formally, an n-clique (η) is a subgraph with node set N_s such that:

$$\eta = \begin{cases} 1, & \text{if } d(i,j) \le n \text{ for all } n_i, n_j \in N_s \\ 0, & \text{otherwise} \end{cases} \quad \ldots\ldots\ldots...(5)$$

and there are no additional nodes that are also distance n or less from all nodes in the subgraph. When n = 1, the subgraphs are cliques, since all nodes are adjacent. Increasing the value of n gives subgraphs in which longer geodesic distances between nodes are permitted. A value of n = 2 is often a useful cutoff value. 2-cliques are subgraphs in which all members need not be adjacent, but all members are reachable through at most one intermediary.

K-cores: a k-core is a maximal group of actors, all of whom are connected to some number (k) of other members of the group. To be included in a k-plex, an actor must be tied to all but k other actors in the group. The k-core approach is more relaxed, allowing actors to join the group if they are connected to k members, regardless of how many other members they may not be connected to. By varying the value of k (that is, how many members of the group do you have to be connected to), different pictures can emerge. K-cores can be (and usually are) more inclusive than k-plexes. And, as k becomes smaller, group sizes will increase. Seidman [51] proposed *k*-core that is a subgroup based on nodal degree. A *k*-core is a subgraph in which each node is adjacent to at least a minimum number, *k*, of the other nodes in the subgraph. In contrast to the *k*-plex, which specifies the acceptable number of lines that can be absent from each node, the k-core specifies the required number of lines that must be present from each node to others within the subgraph. As before, we define the degree of node *I* within a subgraph, $d_s(i)$, as the number of nodes within the subgraph that are adjacent to *i*. We then define a *k*-core in terms of minimum nodal degree within the subgraph. The measurement of how well the observed structure approximates the k-core (δ) structure is proposed by Seidman [51]as follows:

$$\delta = \begin{cases} 1, & \text{if } d_i \ge k \text{ for all } n_i \in N_s \\ 0, & \text{otherwise} \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots..(6)$$

A k-core is thus defined in terms of the minimum degree within a subgraph, or the minimum number of adjacencies that must be present. Seidman [51] notes that although k-cores themselves are not necessarily interesting cohesive subgroups, they are "areas" of a graph in which other interesting cohesive subgroups will be found.

5) Degree centrality and betweenness centrality.

Degree centrality is the simplest and most intuitive, which measures the centrality of an individual in terms of the number of nodes with a particular node connects. Knoke and Kuklinski [52] argue that while direct networks, degree centrality can distinguish between the in-degree and the out-degree of each node to measure its in-degree and out-degree centrality respectively. The degree centrality (C_D)

of a given node is formally defined as:

$$C_D^{in}(n_i) = \sum_{j=1}^{l} r_{ij,in} \text{ , } C_D^{out}(n_i) = \sum_{j=1}^{l} r_{ij,out} \quad i \neq j, \;\; i,j,l = 1,2,3... \quad ....(7)$$

where r_{in} and r_{out} respectively denote one of the inward and outward connections of node i, and l within the network. In-degree centrality of a node i is the sum of the number of nodes j in the network (1 to l) that connect inwardly (from node j to node i); out-degree centrality of a node i is the sum of the number of nodes j in the network (1 to l) that connect outwardly (from node i to node j). The use of these two indicators corresponding to the investigation of the network characteristics of international technology diffusion as inward and outward technological linkages of a country represents international technology acquisitions and exportations, respectively.

Second concept of node centrality is betweenness centrality, which measures the extent to which a particular node lies between the various other nodes in the set of nodes [43]. This betweenness centrality is another global measurement that elaborates the ability of a given node to control interactions between pairs of other nodes in the network. The betweenness centrality (C_{be}) of a node defines as:

$$C_{be}(n_i) = \sum_{j=1}^{l}\sum_{k=1}^{l} \frac{g_{jk}(n_i)}{g_{jk}}, \quad i \neq j \neq k, \;\; i,j,k,l = 1,2,3... \quad ...(8)$$

where g_{jk} denotes the number of geodesics between nodes j and k, and $g_{jk}(n_i)$ denotes the number of geodesics linking the two nodes that contain node i. Betweenness centrality of a node i is the sum of the node i's estimated probabilities of standing along any geodesic that all pairs of nodes (nodes j and k, excluding node i) in the network have selected. Marsden and Lin [53] suggest that betweenness of a node measures the extent to which can play the role of a broker or gatekeeper with a potential for control over others. Betweenness centrality is an appropriate indicator measuring the extent which nodes broker indirect connections between all other nodes in a network. However, increasing redundant connections in a network decreases the efficacy of the brokerage advantage of nodes; increasing non-redundant connections would improve. Applying this indicator to the network of international technology diffusion, a particular country with high betweenness centrality represents more opportunities to broker the flows of diffusion among other countries since most technology diffusion will pass through this country, and thus it should possess competitive advantages in terms of brokerage opportunities.

IV. RESULTS AND DISCUSSION

This study regards a trader as a node and the patent as a linkage between traders. From a network perspective, network nodes could express a firm's status in the marketplace as well as network linkage to observe the activity of a firm. This study has compiled 18,166 patent assignment records to obtain 2,949 patent traders. After "Corporate Tree Data" merging and sampling the node where linkage is greater than 2 degrees (excluding any isolated, internal-trade, and single trade actors), this study tabulates samples of each period as Table 1.

From a cluster perspective, a patent transaction network utilizes a core-periphery analysis, small world analysis, K-core analysis, and N-clique analysis to explore a collective behavior of market. The results are shown in Table 1.

A. Core-periphery analysis and dissemination structure

The core-periphery analysis can not only identify a node located in a core or periphery position but can also identify their interactive behaviors. Therefore, in patent transaction networks, a firm with frequent transactions would be located in a core position. The results demonstrate that only a few firms are located in core positions with a low percentage ($C_{\%}^{I}$=7%, $C_{\%}^{II}$=2%, $C_{\%}^{III}$=5%). In comparing periphery positions, a large proportion of firms remain at a peripheral status ($P_{\%}^{I}$=93%, $P_{\%}^{II}$=98%, $P_{\%}^{III}$=95%). This implies that a patent transaction market is high structuralized. However, through a network density outcome, this study reveals that patent transaction markets do not exhibit heavy embeddedness. On the contrary, the markets demonstrate a closed network pattern. In terms of density analysis, a higher internal density of core positioning (D_C^{I}=0.25, D_C^{II}=0.833, D_C^{III}=0.110) accompanies a lower density of peripheral positions. Therefore, most major transactions occur in a core position. Specifically, core positions seldom provide their resources to the periphery vis-à-vis their interaction ($D_{C\text{-}P}^{I}$=0.000, $D_{C\text{-}P}^{II}$=0.003, $D_{C\text{-}P}^{III}$=0.006, and $D_{P\text{-}C}^{I}$=0.004, $D_{P\text{-}C}^{II}$=0.005, $D_{P\text{-}C}^{III}$=0.004).

Furthermore, network density demonstrates a reciprocity or complicity of in-group and out-groups, where theories of interdependence support mutual interdependence between partners resulting from close interactions that lead to interfirm reciprocity and complicity [54, 55]. Hence, when a firm determines its market policy, its decisions depend not only on its own situation [56], but also on the advice or experience of other firms [54]. Therefore, core and periphery groups exist in different proximities; a core group demonstrates high reciprocity, whereas a periphery group shows low reciprocity. This result reveals that members of core and periphery positions are rear transactional in terms of their technology. However, this result is conform to Wallerstein [57] argument that a core-periphery structure, an exploited system, often demonstrates a core position actor acquiring resources from the periphery. Thus, this distinctive feature implies a patent transaction market is not similar to a product transaction market. Patent transactions work for a firm to enlarge their patent portfolio, and not necessarily for reinvention or modification.

TABLE 1. CLUSTERIZATION ANALYSIS

Periods	*I.1978-1989*	*II.1990-2001*	*III.2002-2012*
Firms numbers (N)	60	273	411
Transaction amount (T)	22	219	420
Core- Periphery analysis*			
Core Numbers (C_N)	4	6	22
Core Percentage ($C_{\%}$)	7%	2%	5%
Periphery Numbers (P_N)	56	267	389
Periphery Percentage ($P_{\%}$)	93%	98%	95%
Core Density (D_C)	0.250	0.833	0.110
Core to Periphery Density ($D_{C\text{-}P}$)	0.000	0.003	0.006
Periphery to Core Density ($D_{P\text{-}C}$)	0.004	0.005	0.004
Periphery Density (D_P)	0.006	0.003	0.002
Small world analysis			
Actual clustering** (C_{actual})	0.000	0.498	0.645
Actual length (L_{actual})	2.094	9.587	6.171
Random clustering** (C_{random})	0.007	0.003	0.008
Random length (L_{random})	4.641	4.228	2.985
Small world quotient (Q_{sw})	0	732.083	38.999
K-Core analysis			
0 $_{(D<3)}$	47%	25%	23%
K1$_{(D=3)}$	53%	55%	34%
K2$_{(D=4)}$		17%	36%
K3$_{(D=5)}$		1%	7%
K5$_{(D=7)}$		2%	
Type (K_T)	1	4	3
N-Clique analysis			
N3	8	62	77
N4	2	21	46
N5		3	58
N6		3	34
N7			17
N8		1	6
N9		1	2
N10		1	3
N11		1	4
N12		1	1
N14			1
N15			1
N17			1
N18			1
Numbers of subgroups (*G*)	10	94	252
Max N-Clique (*Max N*)	N4	N12	N18

* Appendix I exhibits a specifically result in node name and numbers.
**Actual network refers to a patent transaction network and Random network refers to a random simulation network the same scale as the actual network.

Consequently, this study finds several distinctive features: first, a patent transaction market is a highly structured market, where a minority core of firms representing the majority of patent transactions. Second, core and periphery firms are rear transaction actors. Third, core firms develop as a social closure cluster to trade their technology. Fourth, patent transaction markets work for patent portfolios rather than reproduction.

B. Small world analysis and technology diffusion

In terms of small world analysis, the small world quotient reveals transaction networks undergoing evolutionary development (Q^{I}_{sw}<1, Q^{II}_{sw}>1, Q^{III}_{sw}>1). During the first period, the patent transaction network has not yet developed as a small world. During the second and third periods, the small world structure arises. This implies that the patent transaction network experiences qualitative changes in terms of information mobility [45, 46]. During the first period, the transaction market is in the initial stage and a small world structure remains premature (Q^{I}_{sw}<1); there are few market players to interact with. Thus, the clustering coefficient is zero (C^{I}_{actual} =0), but the network's path length (L^{I}_{actual} =2.094) is short, which implies that patent transactions are constrained to some specific technology clusters. As to the second and third periods, a small world structure emerges (Q^{II}_{sw}>1, Q^{III}_{sw}>1), and the transaction market exhibits clustering and connecting. However, there are differences between these two periods. During the second period, the patent transaction market demonstrates looser clustering (C^{II}_{actual} =0.498< C^{III}_{actual} =0.645) and more information closure (L^{II}_{actual} =9.587> L^{III}_{actual} =6.171) than the third period does. Therefore, in the second period, the patent transactions market presents many structural holes [58, 59].

From a cluster analysis standpoint, the FPD industry is undergoing the technological transition stage. Firms are chasing a dominate design, thus companies strategizing alliance or collaboration re-shape market clustering. During the third period, the patent transaction market exhibits firming clusters and more information, (C^{III}_{actual} =0.645, L^{III}_{actual} =6.171) as well as a mature market. Despite the clusterization coefficient (C^{III}_{actual}=0.645) being significantly high, the network's path length (L^{III}_{actual}=6.171) remains long (compared with random length (L^{III}_{random}=2.985)).

This distinctive feature reveals structural holes remaining in the market. The third period of the patent transaction network significantly develops as clusters form with a long network path length. Restated, network clusters act as patent pools in technological portfolios or patent monetization portfolios, along with a few hub-nodes in brokerage positions controlling the entire network and acting to control technology mobility.

In conclusion, a mature period of patent transaction market develops clusterization and a small-world structure whereby a limited number of players maintain large technological or patent monetization portfolios.

C. K-core, N-clique analysis and market evolutionary stage

K-core and N-clique analysis can investigate the quality of a network transmission. However, there are differences between these analyses: K-core analysis is based upon the perspective of a network linkage, and N-clique analyzes a network through the network node [41]. Therefore, K-core analysis can reveal network portfolio size and N-clique analysis can reveal network portfolio range. Koka, Madhavan and E.Prescott [33] indicate that each network change is created by a specific combination of changes in an actor's "portfolio size" and "portfolio range". Then the type of a network formation change can subsequently be presented as: a churning period, an expanding period, and a strengthening period. Specifically, the evolutional process of portfolio size gradually increases through all periods (size I < size II < size III). Meanwhile, the change of portfolio range increases at first, then decreases (range I < range II > range III). Empirical results are shown as Table 1 and discussed below.

In terms of K-core analysis, in the Table 1 shows an increasing tendency of a K-core cluster (K_T^{I}=1, K_T^{II}=4, K_T^{III}=3). Specifically, during the first period, there is only one type of cluster in a patent transaction market. The K1 shows a cluster as a connected subgroup with three firms (D=3), and over half of the market players (K1, 53%) keep their group to three members. During the second period, transaction clusters reveal expansion; most clusters remain as a K1 type (55%). This result implies technology diffusion in the first and second periods are not widely dispersed. However, as to the third period, a majority of clusters extend to K1 and K2 types (34% to 36% respectively). Thus, technology diffusion is significantly wider than in earlier periods. From the perspective of a technology portfolio, this network formation change implies that a patent transaction market is gradually increasing in diversification.

Meanwhile, the result of N-clique analysis can reveal the range of transaction clusters. An increasing subgroup implies members more actively trade with others. According to Table 1, the number of subgroups sharply increased from the first to the third periods (G^{I}=10 < G^{II}=94 < G^{III}=252). The types of maximum N-Clique simultaneously enlarged (*Max* N^{I}=N4, *Max* N^{II}=N12, *Max* N^{III}=N18,). Restated, a market with large subgroups represents market players who trade with more members.

To sum up K-core and N-clique analysis, when the size of a technology portfolio and the range of a technology portfolio persistently increase, a patent transaction market is undergoing a network expansion period. However, previous studies [25, 30, 60] have shown that the FPD industry stepped into a network strengthening period from 2002-2012.

Consequently, the evolutionary processes of technology transaction markets lag behind technology development. Technology development and technology transaction are not synchronous processes.

D. Analysis of core actors' ego network

Because patent transaction networks are extremely large and lose, this study is based on a core-periphery analysis (refer to Appendix I.) to select core position actors as ego network investigation and firm level analysis. Thus, in the first period are 4 actors, the second period has 6 actors, and the third period consists of 22 actors. The analysis results are shown in Table 2.

1) First period ego network

During the first period, the FPD industry originated in the United States and emerged in the last decade. At the beginning of this period, more than 50% of FPD patents were filed in the United States, explaining why it is the principal technology forerunner of the FPD industry [30]. However, there were few core actors in the transaction market, and most of them were patent practicing entities (PE). Only one actor, USGO (U40), was non-practicing entity (NPE). In USPTO assignment records, "United States of America as represented" refers the patent assigned by several governmental institutions. For instance, the national aeronautics and space administration (NASA), the department of energy, and the department of the Air Force are governmental organizations. In a national innovation system, the non-practicing entity of governmental organization (GO'NPE) plays a critical role to balance any market failure [61]. The high value of in-degree centrality and zero out-degree centrality ($C_{in}^{I,U40}$=14, $C_{out}^{I,U40}$=0) implies governmental organizations acquiring lots of patents for technology control. On the other hand, most actors were patent practicing entities. Hughes Aircraft Company (H83), RCA (R1), and TRW, Inc. (T197) are electrical equipment manufacturers. However, at the dawn of FPD industry, the patent transaction amount was small and the betweenness centrality of every actor was shown as extremely low.

TABLE. 2 EGO NETWORK OF CORE ACTORS

Code, Name (Country, PE/NPE)			In-degree centrality(C_{in})	Out-degree centrality(C_{out})	Betweenness centrality(C_{be})
Period I.					
H83	Hughes	(US, PE)	2	1	2
R1	RCA [1]	(US, PE)	1	1	2
T197	TRW, Inc.	(US, PE)	0	3	0
U40	USGO [2]	(US, NPE)	14	0	0
Period II.					
I88	International Rectifier	(US, PE)	7	14	258
H54	Hitachi	(JP, PE)	14	15	84
H62	Hokkaido Electric	(JP, PE)	4	6	10
F88	Fujikura	(JP, PE)	4	5	0
N59	NEDO [3]	(JP, NPE)	22	0	0
T144	Tokyo Gas	(JP, PE)	4	5	0
Period III.					
N44	NEC [4]	(JP, PE)	6	419	1,875
H54	Hitachi	(JP, PE)	30	91	1,685
I44	ITRI [5]	(TW, NPE)	489	537	1,557
C62	Chimei	(TW, PE)	172	73	1,452
S15	Samsung	(KR, PE)	136	10	1,367
S74	Seiko	(JP, PE)	29	56	1,171
K55	Royal Philips [6]	(NL, PE)	62	175	1,075
S266	Sumitomo	(JP, PE)	7	19	997
K75	Kyocera co.	(JP, PE)	11	8	935
A215	AUO [7]	(TW, PE)	293	64	690
M39	Matsushita	(JP, PE)	3	125	341
T168	TPO Displays	(TW, PE)	128	65	253
T152	Toppoly Optoelectronics	(TW, PE)	77	2	209
F90	Fujitsu	(JP, PE)	1	438	128
I105	IPG [8]	(UK, NPE)	7	12	76
I88	International Rectifier	(US, PE)	4	6	72
C80	Chunghwa Picture	(TW, PE)	67	94	68
S26	Sanyo	(JP, PE)	1	78	61
H11	Hannstar Display	(TW, PE)	71	64	43
I82	IBM [9]	(US, PE)	0	392	0
N59	NEDO [3]	(JP, NPE)	10	0	0
U5	U.S. Philips	(US, PE)	0	77	0

1. **RCA**: Radio Corporation of America
2. **USGO**: United States of America as represented by NASA, government offices, and military
3. **NEDO**: New energy and industrial technology developı Organization, Japan
4. **NEC**: Nippon Electric Company, Limited
5. **ITRI**: Industrial Technology Research Institute, Taiwan
6. **Royal Philips**: Koninklijke Philips electronics
7. **AUO**: AU Optronics
8. **IPG**: IPG Healthcare 501 Ltd, IPG Electronics 502 Ltd, IPG Electronics 503 Ltd, IPG Electronics 504 Ltd
9. **IBM**: International Business Machines Corporation

2) Second period ego network

As to the second period, the technologies of TFT-LCD became the dominant design in the FPD industry. Japan accounted for more than 50% of all FPD patents granted, giving it the dominant edge in FPD technology over the US. Therefore, most core actors were Japanese corporations. However, International Rectifier (I88), a U.S. company, played an important role in the transaction market. High betweenness centrality ($C_{be}^{II,\ I88}$=258) implies International Rectifier acted as a gatekeeper in the transaction market. Meanwhile, higher out-degree centrality ($C_{out}^{II,I88}$=14 > $C_{in}^{II,I88}$=7) suggests that this firm acted as a technology provider. International Rectifier (I88) is a power management firm engaging in technological manufacturing of analog and mixed-signal ICs, advanced circuit devices, integrated power systems, and high-performance integrated components for computing. As to the other companies, most of the core actors were Japanese companies, which acted as a diversification ecology. Hitachi (H54) is an integrated electrical equipment manufacturer. Hokkaido Electric (H62) is an integrated power systems manufacturer. Fujikura (F88) is an electrical components company manufacturing flexible printed circuits, membrane switches, and connectors. Tokyo Gas (T144) is a smelter technology company manufacturing glass substrates used in TFT-LCD. However, NEDO (N59) was a non-practicing entity (NPE) in this core group. High in-degree centrality and zero out-degree centrality ($C_{in}^{II,N59}$=22, $C_{out}^{II,N59}$=0) show NEDO acted as a technology controller and integrator in the transaction market, along with U40 (U.S.G.O.). The New Energy and Industrial Technology Development Organization, (NEDO) is a governmental organization for Japanese industrial policy management, the largest public research and technology development. Finally, Hitachi (H54) was the most important actor in this transaction market. With high in/out-centrality ($C_{in}^{II,H54}$=14, $C_{out}^{II,H54}$=15) Hitachi plays the role of a technology intermediate, and a high betweenness centrality ($C_{be}^{II,H54}$=84) reveals Hitachi was a core hub in the transaction market. Hitachi, Ltd. is a multi-business company involved in electrical industries, with patent assignment records in areas such as cable, chemical, device engineering, display technologies, storage technologies, home and life solutions, energy, metals, plasma, and printing solutions.

3) Third period ego network

In the third period, there are 22 core actors in this investigation. While Japan still retains its position as the leader in the FPD patent transaction market (9 actors: NEC, Hitachi, Seiko, Sumitomo Chemical, Kyocera Co., Matsushita, Fujitsu, Sanyo, NEDO), Taiwan (7 actors: ITRI, Chimei, AUO, TPO Displays, Toppoly Optoelectronics, Chunghwa Picture, Hannstar Display) and Korea (1 actor: Samsung) have caught up with the United States (3 actors: International Rectifier, IBM, U.S. Philips).

Meanwhile, from the perspective of patent transaction players, 3 NPE actors have emerged during this period. They are ITRI (I44), IPG (I105), and NEDO (N59). However, there are some differences in the types of these NPEs. Firstly, NEDO (N59) is Japanese GO'NPE and has consistently acted as a technology controller and integrator in the transaction market ($C_{in}^{III,N59}$=10, $C_{out}^{III,N59}$=0, $C_{be}^{III,N59}$=0). Secondly, ITRI (I44) is another type of Taiwanese GO'NPE. The Industrial Technology Research Institute (ITRI) is a nonprofit R&D organization engaging in applied research and technical services. With extremely high in-degree and out-degree centrality ($C_{in}^{III,I44}$=489, $C_{out}^{III,I44}$=537), ITRI occupies a key hub position in the technology market as well as maintaining an extremely high betweenness centrality ($C_{be}^{III,I44}$=1,557). ITRI acts as an intermediary, broker, and gatekeeper in the transaction market. However, IPG (I105) acts as a typical

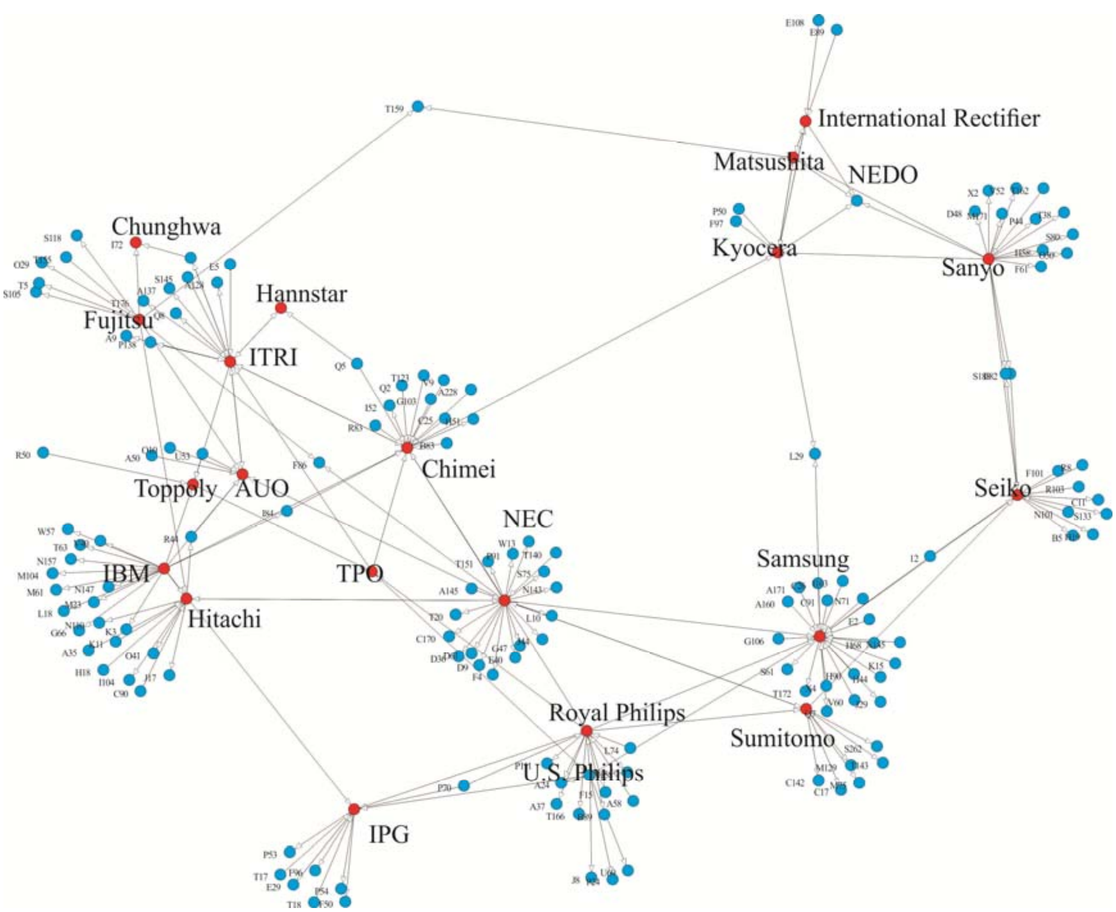

Figure 1. The third period of a patent transaction market

patent monetization company or commercial NPE (Co'NPE). Coller Investment Management Ltd. (a subsidiary of Coller Capital) is the manager and general partner of two stealth patent funds: IPG Healthcare and IPG Electronics that use the corporate names IPG Healthcare 501 Ltd, IPG Electronics 502 Ltd, IPG Electronics 503 Ltd, and IPG Electronics 504 Ltd. Though Coller has yet to assert IPG patents in court, these funds generate revenue from patent licensing and sales to entities that later assert IPG patents [62]. Furthermore, through in/out-degree centrality ($C_{in}^{III,\ I105}$=7 < $C_{out}^{III,\ I105}$=12) and betweenness centrality ($C_{be}^{III,\ I105}$ =76) shows that IPG plays a broker role in the technology transaction market.

Small world analysis (Table 1) shows that the patent transaction market in the third period maintains a mutual market structure. The network clusters form a patent pool in technological or patent monetization portfolios, along with a few hub-nodes in brokerage positions controlling the entire network and acting to control technology mobility. Therefore, in/out-degree centrality comparison and betweenness centrality observation can reveal distinctive features of the core actors.

By investigating the countries involved in patent practicing entities (PE), most Japanese firms (N44, H54, S74, S266, M39, F90, S26) act as technology providers (C_{in}^{III} < C_{out}^{III}), except Kyocera ($C_{in}^{III,\ K75}$=11 > $C_{out}^{III,\ K75}$=8). As to the others, the high betweenness centrality actors are NEC (N44), Hitachi (H54), and Seiko (S75). NEC and Hitachi are a multi-business conglomerates in the electrical industry, and Seiko is an instrument and electronics manufacturer. High betweenness centrality ($C_{be}^{III,\ N44}$=1,685, $C_{be}^{III,\ H54}$=1,685, $C_{be}^{III,\ S74}$=1,171) shows them acting as core hubs in the transaction market. In terms of middle and low betweenness centrality actors, Sumitomo Industry (S266) is a multi-business company serving in several industries including chemical and electric, ceramics, metal, rubber and heavy industries, as shown in patent assignment records. Kyocera Corporation (K75) is an electronics and ceramics manufacturer, providing small and middle size display panels for consumer electronic device applications. With middle betweenness centrality ($C_{be}^{III,\ K75}$=935), Kyocera is an important actor in the small and middle size display panel market. Matsushita (M39), Fujitsu (F90), and Sanyo (S26) are electrical equipment, component and consumer electrics device manufacturers.

However, Samsung (S15), a South Korean company, is a different type of core actor. With high in-degree centrality and low out-degree centrality ($C_{in}^{III,\ S15}$=136 > $C_{out}^{III,\ S15}$=10), Samsung is a technology absorber. Simultaneously, Samsung acts as a gatekeeper because of its extremely high betweenness centrality ($C_{be}^{III,\ S15}$=1,367). Samsung has been the world's largest manufacturer of LCD panels since 2002, and the world's largest television manufacturer since 2006.

In terms of Taiwanese firms (C62, A215, T168, C80, H11), Chimei (C62) is similar to Samsung, with an extremely high betweenness centrality ($C_{be}^{III,C62}$=1,452) and an in-degree centrality greater than its out-degree centrality ($C_{in}^{III,C62}$=176 > $C_{out}^{III,C62}$=73). Therefore, Chimei plays technology absorber and gatekeeper. As to the other core actors, AUO (A215), TPO Displays (T168), Toppoly Optoelectronics (T152), Chunghwa Picture (C80), and Hannstar Display (H11) occupy middle and low betweenness centrality ($C_{be}^{III,A215}$=690, $C_{be}^{III,T168}$=253, $C_{be}^{III,\ T152}$=209, $C_{be}^{III,\ C80}$=68, $C_{be}^{III,\ H11}$=43). More specifically, these firms are major TFT-LCD panel manufacturers. However, the Taiwanese FPD industry has rapidly changed since 2005. The TPO was formed in 2006 as a synergistic merger of Toppoly Optoelectronics and Philips Mobile Display Systems. In 2010, Chimei and TPO Displays were merged by Innolux Display Corp. and began operating under the new name Chimei Innolux Corporation (CMI).

Another critical core actor is Royal Philips (K55). High betweenness centrality ($C_{be}^{III,\ K55}$=1,075) indicates Royal Philips as core hub and technology provider ($C_{in}^{III,\ K55}$=62 < $C_{out}^{III,K55}$=175) in the transaction market. The Dutch company Koninklijke Philips Electronics (also name as "Royal Philips" in English) is similar to NEC, Hitachi, and Samsung in that it is a multi-business company in several electrical industries. In 1990, Royal Philips Electronics and the Korean electronics company LG Electronics signed a joint venture agreement to form LG. Philips LCD, but Philips sold off all its shares in late 2008. However, during this period Royal Philips provided lots of display technology to the transaction market and acted as a critical hub in the network.

In conclusion, a patent transaction network is composed of several types of actors. Most core actors are patent practicing entities and a few are NPE actors. However, NPEs act in various roles in the transaction market. Governmental organizational NPEs (GO'NPE) are notable in that USGO and NEDO are technological controllers and integrators. ITRI, another type of GO'NPE, plays a role as a technology provider, integrator and intermediator. Furthermore, commercial NPE (Co'NPE) core actor the IPG Company, has emerged in the third period and acts as an arbitrager in the transaction market. On the other hand, in terms of a technology transaction chain, core actors of patent practicing entities act as technology providers, intermediators, and absorber during certain periods. The major upstream technology providers are NEC, Royal Philips, Seiko, Sumitomo, Hitachi, and International Rectifier. The major downstream absorbers are Chimei, Kyocera, and Samsung.

V. CONCLUSION AND REMARKS

The central purpose of this study is to explore the relationship between portfolio clusters, the positional analysis of key market players, and a behavioral analysis of patent practicing entities (PEs) and non-practicing entities (NPEs). Thus, this study utilizes a cluster perspective to explore patent transaction market networks, investigate the collective behaviors of transaction networks to reveal technology diffusion in a market, and finally examines the ego network of core position actors.

Cluster analysis utilizing core-periphery analysis, small world analysis, K-core analysis, and N-clique analysis explores a collective behavior to reveal technology mobility. Furthermore, Ego network analysis utilizes degree centrality, and betweenness centrality to examine core position actors. Through this framework, this study demonstrates the applicability of network analysis to illustrate the distinctive features of the TFT-LCD patent transaction network. The empirical findings of this study are summarized below.

Firstly, this study finds four distinctive features: first, a patent transaction market is a high structuralize market, with a minority of core firms holding large patent transactions. Second, core firms and periphery firms are rear transactional. Third, core firms have developed as social closure clusters to trade their technologies.

Secondly, in terms of technology diffusion, a mature period in a patent transaction market is exhibited as clusterization and a small-world structure whereby a limited number of players maintain large technological or patent monetization portfolios. Furthermore, the network evolution of a technology market is not synchronous to technology development; a technology transaction market lags behind technology development.

Thirdly, the role of governmental organization NPEs (GO'NPEs) are notable in each period. They play the roles of technology provider, integrator and intermediator. Although commercial NPEs (Co'NPEs) can act as arbitrager, they can also promote transaction. On the other hand, most transaction actors are patent practicing entities (PEs) and act as technology providers, intermediators, and absorbers in a technology transaction chain.

Despite its contributions, this study has certain limitations, which should be acknowledged to identify future research directions. The first limitation of this study is that it only takes into account information on patents granted by the U.S. Patent and Trademark Office. Since data has not been obtained for patents granted by non-U.S. organizations, this study is overly reliant on U.S.-granted patent transactions. Future studies could include information on patents granted by other international patent organizations to eliminate this bias. A further limitation is the insufficient discussion of industrial network evolution and meso analysis. Future studies can utilize an evolutionary perspective to examine what macro or micro mechanisms that evoke network evolution. The third limitation of this study is sector bias; this study examines data from a limited TFT-LCD technology and FPD sector, and thus the relative technology or crossover application cannot be traced. Future works can trace these related technologies and applications using the same methodology, which may demonstrate any potential policy implications.

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APPENDIX.1

position	**Period I: 1978-1989**	**Period II: 1990-2001**	**Period III: 2002-2012**
Core	H83, R1, T197, U40	F88, H54, H62, I88, N59, T144	A215, C62, C80, F90, H11, H54, I105, I44, I82, I88, K55, K75, M39, N44, N59, S15, S26, S266, S74, T152, T168, U5
Periphery	A170, A18, A184, A224, A80, A92, B127, B37, B42, B52, B99, C122, C123, C132, D72, E123, E2, E46, E5, E60, F17, F31, F48, F58, G100, G27, H33, H67, I118, I55, I82, I88, K45, K67, K78, L34, L48, M116, M148, M15, M25, M71, O28, O77, S136, S169, S171, S206, S219, S232, S288, U19, U5, U54, U71, X8	12, 2, 6, A129, A130, A135, A143, A154, A157, A161, A166, A167, A176, A179, A204, A240, A29, A32, A41, A48, A53, A58, A6, A60, A64, A65, A82, A91, A92, A98, B1, B106, B109, B113, B115, B127, B140, B21, B24, B34, B69, B7, B73, B88, C115, C127, C134, C14, C15, C152, C167, C169, C35, C36, C49, C55, C6, C7, C82, C88, C89, D100, D17, D21, D30, D31, D41, D44, D56, D9, D94, D95, E112, E2, E30, E43, E46, E5, E54, E60, E61, E70, E72, E78, E96, F11, F36, F37, F49, F51, F55, F63, F65, F8, F82, F86, G103, G19, G22, G25, G27, G28, G60, G78, G82, H12, H25, H4, H44, H57, H61, H67, H70, H83, H84, H98, I118, I2, I21, I30, I34, I43, I44, I70, I93, I98, J14, K27, K28, K51, K59, K69, K7, L1, L29, L30, L39, L51, L52, L59, L62, L69, L79, M116, M12, M123, M131, M146, M160, M3, M30, M36, M39, M4, M46, M51, M58, M67, M75, M97, M99, N105, N120, N128, N24, N31, N34, N43, N44, O23, O33, O39, O49, O62, O66, P104, P109, P11, P134, P22, P59, P7, P72, P78, P82, P9, P93, P98, Q10, Q11, Q5, R20, R36, R41, R47, R54, R81, R83, R84, R86, R95, S105, S135, S15, S18, S188, S19, S199, S204, S212, S231, S236, S248, S266, S27, S280, S290, S291, S32, S45, S61, S68, S74, S80, S94, T14, T143, T146, T158, T202, T32, T42, T56, T58, T66, U1, U14, U23, U30, U31, U37, U40, U41, U46, U5, U55, U70, U73, U76, V37, V46, V69, V7, W11, W17, W36, W37, W38, W40, W56, W67, W70, X10, Y1, Y11, Z12, Z5	12, 2, 9, A101, A11, A111, A115, A132, A143, A145, A150, A153, A154, A158, A161, A172, A179, A187, A188, A189, A196, A201, A223, A228, A231, A234, A24, A243, A33, A35, A38, A40, A41, A50, A53, A54, A57, A58, A89, A9, A98, B106, B109, B112, B124, B128, B19, B36, B79, B85, B90, B93, B95, B99, C107, C117, C119, C128, C135, C139, C141, C146, C152, C165, C169, C17, C170, C175, C189, C26, C29, C32, C33, C36, C50, C61, C65, C90, C92, C94, D30, D36, D38, D48, D58, D7, D70, D76, D8, D85, D9, E109, E124, E15, E16, E17, E2, E29, E34, E40, E45, E46, E5, E50, E60, E62, E80, E82, E98, F101, F32, F34, F35, F4, F50, F58, F6, F7, F70, F76, F85, F86, F87, F96, F97, G106, G15, G18, G27, G60, G66, G67, G71, G85, H12, H23, H44, H49, H51, H66, H68, H81, H86, H93, H94, I103, I104, I17, I20, I21, I30, I47, I49, I50, I52, I53, I61, I62, I70, I72, I74, I79, I83, I84, I90, I91, I97, J17, J22, J24, J32, J37, J41, J44, J45, K13, K25, K26, K28, K58, K71, L1, L11, L18, L29, L30, L49, L51, L60, L73, L76, L9, M1, M103, M108, M11, M118, M119, M123, M124, M130, M135, M142, M144, M152, M156, M159, M161, M171, M18, M19, M35, M37, M53, M59, M68, M75, M83, M84, M99, N103, N109, N11, N110, N114, N115, N122, N128, N138, N142, N143, N156, N157, N158, N2, N33, N54, N61, N70, N71, N89, N96, O1, O2, O27, O33, O36, O43, O5, O53, O74, P106, P111, P114, P13, P145, P152, P17, P20, P29, P49, P51, P53, P70, P81, P83, P89, P90, P91, P98, Q11, Q2, Q5, Q7, R103, R105, R12, R20, R24, R35, R36, R40, R44, R50, R56, R69, R8, R83, R87, R88, R89, S1, S100, S105, S118, S123, S128, S13, S135, S145, S147, S148, S151, S155, S166, S173, S188, S19, S199, S203, S204, S214, S228, S233, S238, S269, S27, S275, S276, S28, S285, S288, S293, S299, S30, S306, S35, S50, S55, S61, S68, S77, S80, S82, S86, T101, T118, T123, T132, T136, T141, T145, T151, T159, T161, T162, T163, T17, T176, T180, T181, T187, T20, T201, T202, T39, T4, T43, T45, T46, T5, T50, T65, T66, T90, T91, U30, U47, U48, U53, U69, U8, U83, V30, V32, V37, V46, V50, V63, W10, W30, W37, W39, W55, W57, W69, X4, Z10, Z9