Analyzing the Impact of Social Contagion and Technological Diffusion Mechanisms on National Innovation Performance

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Abstract – The purpose of this research paper is to analyze the impact of social contagion and technological diffusion mechanisms on the national innovation performance in relation to trade flows and patent citations. The objective is to elucidate how these mechanisms can promote cross-country technology transfer and innovation. While using trade and patent data as numeric measures, we complement it with the qualitative analysis of the selected case studies in order to assess the suitability of the cohesion and structural equivalence mechanisms in the context of technological diffusion. The results support social contagion effects as strongly enhancing national innovation through collaboration, while trade and citations enhance technology transfer. Therefore, this study proves that social contagion's strength and high patent citations lead to the progress of innovation and improved R&D outcomes in nations. Therefore, this study intends to help enhance knowledge about how to enhance national innovation strategies and how foreign technological knowledge can be utilized to enhance global competitiveness.

Keywords – Social Contagion, Technological Diffusion, National Innovation Performance, Global Competitiveness, Research and Development Performance.

I. INTRODUCTION

Global competitiveness has exerted a lot of pressure to both developing and developed nations. In particular, developing countries are faced with the challenging task of addressing the massive challenges that are associated with technical development and innovation from the more advanced countries. Innovation means the conversion of existing and new ideas into business ventures. It entails the discovery, acquisition of knowledge and application of new technologies and strategies from various sources. It has a significant function in the activation of economic and productivity development, which in turn result in improvement of living standards. Probably, the most popular and accepted theory among policy makers and academicians is that competition leads to innovation. The driving factor behind significant policy changes, such as the deregulation of various sectors in OECD nations and economic reforms in Eastern Europe, is acknowledged.

Technological innovation is a necessary tool for enhancing national competitiveness, regardless of the country's present level of development. Howells and Michie [1] emphasize and enhance comprehension of the issue of technical innovation and worldwide competitiveness as it relates to corporate development. In a diverse range of views in order to provide an integrated but comprehensive viewpoint on the issue. Weck, et al. urge researchers, politicians, and others to uncover pertinent insights on technological innovation and global competitiveness to facilitate well-informed decision-making for their firms in an increasingly unpredictable and dynamic environment. The academic interest in the relationship between technologically-oriented innovations and competitive positioning is increasing. Coccia investigated the relationship between technological innovation and competitive advantage. Ruttan found that the factors that contribute to technological innovation include Research and Development (R&D) activities, techniques for designing new products and services, and improving existing products.

Suarez-Villa propose that national inventive capacity is influenced by underlying factors that drive the innovation process. They suggest that nations may use this understanding to actively shape their national innovative ability. National inventive capacity refers to the ability of an economy, both in economic and political terms, to generate a continuous flow of commercially significant inventions. National Innovative Capacity (NIC) is a concept that captures the institutional framework that sustains innovation in a particular nation. Numerous efforts have been devoted to the research on this concept, which can be traced back to Furman, Porter, and Stern who provided a clear definition and measure following the patenting rates. There is no doubt that the rate at which patents granted by the US Patent and Trademarks Office (USPTO) are adopted is one of the most unambiguous measures of innovation success. Patents are generally `accepted as a reliable and objective indicator of innovation quantity being offered by a nation.

The creativity of an economy and its people is determined by the level of technology, investments and/or policies that have been and continue to be made in the economy and the workforce by the government and private sectors. Innovative capability can be viewed as intertwined with, but different from, the scientific and technological developments that do not necessarily entailing their economic application. This argument means that innovative capacity is not the same as the current industrial competitive edge or productivity of a country. This capacity, therefore, may not solely depend on the development and deployment of new technologies but could be influenced by several other factors [2]. These differences in NIC are due to differences in economic geography, for example the extent of knowledge spillovers between firms, and innovation policy, such as the level of public funding for basic research or the strength of patents protection. These interactions between countries have effects on the cultural, political, and economic factors of the countries because of the enhancement of information technology.

The knowledge of the concepts of social contagion and technology adoption is the key to improving national innovation capabilities in the context of globalization. This research paper fills this gap by identifying how these mechanisms, in combination with trade flows and citation links, impact on technology transfer and innovation capabilities across nations. In this regard, the present research examines the relationships between social contagion effects and technological diffusion mechanisms to offer practical recommendations for policymakers and organizations interested in enhancing innovation and capitalizing on technological breakthroughs worldwide. Thus, it is apparent that the mentioned factors should be managed to enhance technological advancement both at the national and international levels.

The rest of the paper has been organized in the following manner: Section II reviews related works on national innovative capacity, international technology diffusion, and contagion effects. Various hypotheses regarding cohesion mechanisms, and structural equivalence mechanisms have been provided in Section III. The data and methods employed in the research have been described in Sectio IV. Section V presents a detailed account of the findings and discussion for this research, which integrate contagion impacts, embodied and disembodied forms of technology. Lastly, Section VI provides a summary of the findings obtained in this research.

II. RELATED WORKS

This section provides an introduction to the concept of national inventive capability and explains the process of International Technology Diffusion (ITD), which may occur via two different mechanisms: These can be categorized into two forms of diffusion; the embodied diffusion and the disembodied diffusion. The last sub-section looks at the implications of social contagion, and looks into previous works that address Social Network Analysis (SNA).

National Innovative Capacity

Hu and Mathews use the term long-term technological accumulation capacity to describe a country’s ability to continuously develop and introduce new technologies to the market. Hence, the notion of NIC goes beyond the sheer number of inventions produced and attempts to embrace all the factors that underlie the innovation process. The concept of NIC seeks to explain the variations in innovation capacities across different countries. Indeed, the inherent disparities of NIC also extend across the member countries of the European Union [3]. Empirical data on patent volume, which is commonly used as a measure of innovative performance, indicates a growing disparity in the innovative outcomes of different countries. This disparity is characterized by the presence of “innovation followers,” “innovation leaders,” “modest innovators,” and “moderate innovators,” as key players in this competition. Countries such as Germany, Sweden, Denmark, and Finland constantly maintain and strengthen their dominant position in this rivalry, while the other countries are unable to catch up.

Dakhli and De Clercq have contended that the ability of a country to embrace innovation is impacted by more than just the number of financial resources and human capital dedicated to innovation. Other factors at the national level, such as the level of technological advancement, the innovation ecosystem in industrial clusters, and the connection between the overall industry groups and innovation infrastructure, also play a significant role. While previous research has identified a limited number of factors that influence a nation's capacity of innovation, these studies often view NIC as a self-contained system and focus solely on the domestic economy. However, this perspective fails to acknowledge the fact that countries can enhance their innovative capacity by engaging in international trade and attracting foreign investments, which provide access to foreign technological advancements [4]. The increasing economic integration in the 21st century, driven by frequent international trades, market openness to Foreign Direct Investment (FDI), and advancements in information and communication technology, renders the traditional approach of analyzing NIC as a closed system less significant.

International Technology Diffusion

The phenomenon of International Technology Diffusion (ITD) is extensively examined in the economic literature.Despite ongoing disagreements, particularly regarding measurement, academics generally concur on two key facts. Primarily, the majority of nations have reaped the advantages of technical innovations originating from other countries. A compelling rationale for this is that a small number of industrialized nations carry out the bulk of global R&D, but the resulting increases in productivity are seen around the globe. Moreover, it should be noted that there are certain challenges associated with the process of ITD and the effects it has on the production of the receiving country are not instantaneous and are not guaranteed. In addition to a set of natural adversities, there are also artificial ones that must be surmounted, and knowledge acquisition and absorption. In present the findings of a systematic review of the global diffusion of ITD technologies which is also referred to as Artificial Intelligence (AI). In proposed a new approach to identify patterns of ITD in Artificial Intelligence (AI) based on the patents data generated between 1970 and 2019. In order to achieve this objective, construct a connection between the capacity for technological innovation (TI) and the extent of ITD, and classify regions/countries into three distinct categories such as backward, intermediate, and leading.

Technological knowledge in [5] refers to the specific design or blueprint used to create a novel intermediate product. Direct global knowledge transfer of such knowledge implies that the blueprint is not only accessible to the business in the country where it was first produced (or companies, if there are domestic technologies), but it also becomes accessible to enterprises in other nations. Learning in this context is said to have a positive externality, also known as a spillover, if the acquisition of technical knowledge costs less than what the innovator originally paid. The international technology diffusion occurs via the utilization of foreign intermediary products. The concept is that using the global intermediate good entails the implicit use of the design technology that was generated via R&D investments of the international creator. The technical skillset of the blueprint is manifested in the intermediate good. There is a benefit to accessing foreign intermediate products as long as their cost is lower than their opportunity expenses that include the expenses of R&D for product creation.

Contagion Effects

Kimmerle, Cress, and Held assert that the generation and dissemination of novel information takes place via the collaborative acquisition of knowledge by individuals, which in turn facilitates the advancement and dissemination of innovative technologies. Social contagion, in the perspective of SNA, is sometimes used synonymously with peer influence. It refers to the phenomenon where individuals are influenced by their peers and exhibit similar behaviors, which are transmitted via their social connections [6]. Social contagion effects in information spread are influenced by two primary factors: number of exposures and interaction. The hypothesis of interaction posits that the likelihood of a person sharing message from each other is contingent upon the social connections between them. Interacting with others and engaging in conversation may bring people closer together socially, leading to a greater impact from peers.

Cohesion Mechanism

Communication that is influenced by social factors includes direct interaction between an individual and another person. Cohesion is the predominant method for managing a communication process in the field of SNA. Preliminary studies offered initial evidence for the correlation between communication and cohesiveness in teams. Further studies have directly connected some aspects of communication to team cohesiveness, such as cooperative communication, open communication, and suitable communication. Certain social network researchers analyze cohesiveness from a collective standpoint. Social cohesiveness is a term that has been used with many interpretations in the field of social sciences. According to Sage, it may be seen as a resource that impacts both individual actors and the whole group or society. Cohesion in the cultural, economic, and political domains has been linked to trust, identification, commitment, reciprocity, and shared ideals. In the domain of social network analysis, cohesiveness has also been linked to the formation of close relationships , since connections with similar individuals tend to be transitive.

Structural Equivalence Mechanism

The structural equivalence, which refers to the similarity in network interactions or being linked to the same individuals, may also contribute to peer influence. Structural equivalence impact is partially dependent on the competition, which arises when individuals assess new and unique situations. The degree of similarity in the relationships between individuals, known as ego and alter, with other people determines the extent to which alter can replace ego. Consequently, the stronger the sense of competition ego feels towards alter; the more inclined ego is to swiftly embrace any innovation. The process of networking via structural equivalence is influenced by social contrast such as role playing and imitation [7], as well as rivalry between alter and ego. The actors that are structurally equivalence are individuals who have the same network position and may be interchanged with one another. Actors in this context exhibit structural equivalence, leading them to rely on one other to assess their beliefs, attitudes, and actions, perhaps causing the activation of egos' behaviors.

III. HYPOTHESES

This research investigates the impact of social contagion effects on national inventive ability. It analyzes the structural equivalence and cohesion mechanisms, as well as the worldwide spread of embodied and disembodied technology. The cohesion mechanism influences actors within a cohesive group is a substantial change that directly affects those who have direct touch with each other. On the other hand, the structural equivalence mechanism posits that changes in the similarity of networking position may affect players who might not have a direct connection with each other. Therefore, the assumption in this research used contagion mechanisms to investigate the spread of both physical and virtual technologies.

Cohesion Mechanism

The mechanism focuses on the dynamic relationship between the alter and ego. The alter ego–connection axis pertains to the cultivation of an individual's capacity to express emotions to important individuals, establish close relationships, and integrate into broader social groups and institutions. The typical progression of this axis is shown via a sense of affiliation and interconnection, as well as a perception that one's attributes, objectives, and principles are understood and embraced by others. The policy formulation of a particular nation swiftly aligns with that of another nation, since both countries share a mutual evaluation of the advantages and disadvantages resulting from their contact. Therefore, this research may posit that nations belonging to the same group might exert effect on the creative capacity performance of a specific country via cohesiveness mechanisms. Therefore, the proposed assumptions are:

H1: The performance of a focus country's national inventive ability is favorably and substantially impacted by other nations within a cohesive category established by the global transmission of embodied innovation.

H2: The performance of a focus country's national inventive ability is favorably and substantially impacted by other nations within a cohesive category established by the global transmission of disembodied innovation.

Structural Equivalence Mechanism

The conduct of ego is more accurately predicted by its place in the structural network rather than its interactions with others. Recent examinations [8] of the structural qualities of famous Online Social Networks (OSNs), such as Twitter and Facebook, have shown that online ego networks exhibit the same characteristics as offline ego networks. These online networks have comparable size and follow a similar hierarchical model. The characteristics of ego-networks are essentially identified by the cognitive limitations of the human brain and are not affected by certain communication tools, such as smartphones and OSNs. Twitter and Facebook do not seem to enhance our social aptitude; rather, they just serve as extra social channels at our disposal.

Furthermore, these investigations not only confirm the presence of familiar characteristics in human ego networks inside OSNs, but also uncover novel qualities [9] that were previously anticipated but never confirmed owing to limited access to large-scale data sources. This illustrates that OSNs may also serve as a "social microscope" for studying new and important element of human social behaviors. The structural equivalence mechanism reveals that participants inside it are in a state of competition with one another. The notion of structural equivalence in analyzing industrial systems. A participant's adoption of conduct is influenced by others who hold a similar position within a network. Thus, this research posits the following hypotheses:

H3: The national inventive potential of a focus country is favorably and substantially impacted by other nations at structurally equal levels, as determined by the international transmission of embodied technology.

H4: The national inventive ability of a focus country is favorably and considerably impacted by the performance of other nations that are structurally analogous, as indicated by the international transmission of disembodied technology.

Comparison

Irrespective of the specific way in which cohesiveness is defined, it is generally accepted that actors who have direct relationships may be considered cohesive, as long as these relationships are deemed to be good. Although these relationships may not be favorable, they may nonetheless be considered coherent [10]. The operational definition of structural equivalence is a subject of contention, as discussed. Structurally analogous actors, in theory, are those who have identical or similar relationships with other players in the network. Considering a network consisting of five players and excluding self-connections, as suggested by prominent academics such as Merelo and Molinari and Carayol and Roux actors A and B will be considered structurally equal if they have identical relationships with actors C, D, and E.

Theoretical differences in processes are seen in the social contagion impacts of the structural equivalence and cohesion theories. While there are two distinct ways in which contagion may spread in social proximity, several scientists agree that an individual's conduct is more likely to be influenced by others who occupy a similar network position rather than by direct interactions with those individuals [11]. Therefore, the influence of the structural equivalence mechanism on the spread of infection should be more powerful compared to the cohesion mechanism. The theories about the comparison of national inventive capacity performance are investigated as follows:

H5: The performance of local innovative ability in nations with a social closeness structural equivalence is more comparable on the basis of global dissemination of embodied technologies compared to countries with social closeness of cohesiveness.

H6: The performance of local innovative ability in nations with a social closeness structural equivalence is more comparable on the basis of global dissemination of disembodied technologies compared to countries with social closeness of cohesiveness.

IV. DATA AND METHODS

Data

This study utilizes a sample of 42 nations from 1997 to 2023. The countries are rated based on the World Competitiveness Databank (WCD) and the Global Competitiveness Index (GCI). The set of data on social contagion impacts comprises four various classes: bilateral commerce in imports and exports, patent citation frequency, combined R&D cost, and global patents awarded in period (year) $t + 3$. The primary source of trade flow statistics is Global Trade Information Services (GTIS) Inc. Nevertheless, imports data is more precise compared to the statistics concerning exports [12]. Trade data include details about the movement of material or product streams via exports or imports. In several nations, including the United States, general exports are categorized into two types: domestic exports, which originate in the exporting nation, and re-exports, which originate in a different nation. Official trade databases record and track the monetary worth, and in some instances, the amount or weight, of products that are brought into and taken out of a country.

In measuring trade-based spillover using trades in capital products is more advantageous than measuring it using total trade. Developing nations significantly depend on imported high-end capital goods, such as powerful computers and complex industrial machines, since they have limited access to indigenous sources. It has been noted that these technologies that are brought in from wealthy nations tend to come with a bias towards improvements that favor skilled workers in the indigenous economy. Therefore, most researchers concentrate their studies on the changes in the need for skills that are brought about by the importation of capital goods, and the subsequent impact on the additional compensation received by skilled workers. Some researchers, relying on the concept of capital-skill complementarity [13], develop quantitative trade mechanisms that include capital imports to analyze the effects of skill premiums caused by capital imports. Patents dataset by the NSPTO as well as the patent citation frequency are gathered from the NBER Patent Citations Database for analysis of patent citation frequencies.

Due to technological challenges in interpreting unprocessed data, this study collects data from 1997 to 2023 and includes the frequency of patents being referenced and citing amongst different countries. To assess the overall R&D spending of every nation, data from the World Competitiveness databank, IMD has been used in this analysis. The variable "Patents" captures the total number of patents approved by the USPTO in period $t + 3$. This is due to the fact that it depends on the time it takes for the USPTO to take in patent applications and the correlation between measures of creative capacity and the actual flow of innovation. The USPTO examines patent applications to determine their suitability for patent protection.

The USPTO has the power to reject a patent application for many reasons; for example, due to lack of novelty, if the invention is obvious, if it does not meet the subject matter criteria, and if it is not useful. The mean approval rate of a patent usage by the USPTO from the year 2011 to 2020 is 52.8 %. Approval depends on the type of patent and the year of filing and it also varies from time to time [14]. Patent applicants should be made aware of the fact that it would take the USPTO in many months to review and evaluate a patent application. For instance, the patent application of a product that received its approval in 2020 could have been filed in 2018, or even earlier. In the years between 2011 and 2020, the USPTO has received a total of 5,814,517 application for patents and granted 2,990,695 patents.

We selected 42 countries because there are no data materials of some countries in order to have a complete data collection. These countries include United States, United Kingdom, Hungary, Hong Kong, South Africa, Japan, Ireland, South Korea, Brazil, India, Indonesia, Italy, Netherlands, Turkey, New Zealand, Philippines, Mexico, Denmark, Chile, Argentina, Belgium, Colombia, Greece, Finland, China, Canada, Iceland, Norway, Portugal, Sweden, Taiwan, Malaysia, Austria, Australia, Poland, Singapore, Switzerland, France, Thailand, Spain, Russia, Hungary, and Germany. The beginning periods of innovative productivity and the historical circumstances of every nation have distinct impacts on national innovativeness. This innovativeness was gauged using various variables identified in **Table 1**.

Table 1. Definitions and Variables

Variables	Complete variable name	Definitions	Sources
Innovative outputs			
Patents $_{j, j+3}$	Global patents issued in $t + 3$	Different patents provided by USPTO in j during the $t + 3$	USPTO patent database
ITDs			
R&D$_{j, t}$	Aggregated R&D cost	R&D costs	IMD World Competitiveness Reports
Contagion impacts[1]			
Embodied Cohesion	Engagements within cohesive groups via diffusion	Engagements within cohesive groups through trade flow	GTIS

Disembodied Cohesion	Interactions within cohesive groups via disembodied type of diffusion	Engagements within cohesive groups through patent citations	NBER Patent Citations Database
Embodied structural equivalence	Relations in Structural Equivalence via embodied diffusion Relations in structural equivalence via embodied diffusion	Relations within structural equivalence through trade flows	GTI
Disembodied structural equivalence	Relations in structural equivalence through disembodied type of diffusion	Relations in structural equivalence through patents citations	NBER Patent Citations Database

*** The trade flow data is derived from the importation of capital products, whereas patents are issued by USPTO.*

International Technology Diffusion

This study utilizes the perception of social contagion impacts to investigate the transmission of technological knowledge across international borders. By examining the diffusion process from the perspective of the interactions between individuals who have adopted a particular behavior or idea and those who have not, one may see diffusion as a temporal phenomenon of social contagion. There are two benefits to using this lens. First, it makes it possible for one to analyze the process through which the diffusion of technology occurs [15]. Moreover, it goes a step further than merely analyzing the characteristics of the adopting entity to analyzing the relationships between them. ITD can be measured by multiplying the national R&D spending by a weighted coefficient. This is because previous findings have revealed that there is a positive and strong correlation between the total national expenditure on R&D and ITD.

We investigate the cross-country disparity by including the overall R&D spending of the countries in the mechanism. The mathematical representation that has been used to represent the process of worldwide technology diffusion is Eq. (1). In this context, ITD_{ij} denotes the extent to which technical information is transferred from nation i to country j. RD_i indicates the amount of money spent on R&D by country i, whereas r_{ij} reflects the proportion of knowledge that travels from i to j. To distinguish between disembodied and embodied forms of technology dissemination, it is necessary to create two weighing formulas: $r_{E,ij,t}$, and $r_{D,ij,t}$. This work has presented a definition to the embodied type of diffusion as $r_{E,ij,t}$, as described in Eq. (2).

$$\boldsymbol{ITD_{ij} = r_{ij} \times RD_i} \tag{1}$$

$$\boldsymbol{r_{E,ij,t} = \frac{M_{ij,t}}{\sum_{i=1}\sum_{j=1} M_{ij,t}} \quad i \neq j, \quad i,j,l = 1,2 \dots, 42} \tag{2}$$

where $M_{ij,t}$ denotes the flow of capital products that are imported by j to i in year t. The index l ranges from 1 to 42 and indicates the total number of countries. In this study, trade flows are determined by multiplying the amount of equipment and machinery imports in one nation by the total R&D spending in another country. Additionally, the country in question buys from 42 countries and exports to these same 42 countries, resulting in a 42 by 42 matrix. Therefore, this research posits that if a particular country increases its capital goods imports from another country, the nation that is importing will gain advantages via the spread of technology that is embedded in those commodities. During the process of technology diffusion, patent citations serve as a connection to previous knowledge. In other words, the frequency at which a particular nation cites patents from a different nation indicates the level of knowledge transfer between the two nations. Disembodied technology dissemination weight is denoted as $r_{D,ij,t}$ and is defined in Eq. (3).

$$\boldsymbol{r_{D,ij,t} = \frac{C_{ij,t}}{\sum_{i=1}\sum_{j=1} C_{ij,t}} \quad i \neq j, \quad i,j,l = 1,2 \dots, 42} \tag{3}$$

The variable $C_{ij,t}$ shows the frequency of nation j mentioning patents from i in year t. The nations are identified by numbers from 1 to 42. Citations are quantified based on frequencies. In this context, a particular nation mentions patents from 42 different nations, while also being mentioned by these nations. This relationship may be represented as a 42 by 42 matrix. This research proposes that when a nation cites a higher number of patents from other nations, it will experience the benefits of technological diffusion without the need for physical transfer.

Contagion Effects

Many scholars are studying the process of how innovations spread and become contagious. While the significance of network structure on contagion processes has been shown in [16], our understanding of the social network itself is often restricted due to the concealed nature of its structure and dynamics. The digital era has provided unparalleled prospects in terms of online social networks and Voice over Internet Protocol services, which gather extensive data on the relationships and actions of its users. These services serve as proxies for the actual social connections between people, partly revealing the social structure. Additionally, they provide precise records of users' adoption behavior.

This research utilizes the social contagion mechanism developed to predict the spread of technology across different nations. y_i is the quantification of patent production in country i, reflecting the actual implementation of creative activity inside that country. In this context, y_i^* refers to the anticipated patent production in nation i, taking into account the reactions of other countries. The term ε reflects the residual component. The weight w_{ij} plays a pivotal role in this study as it determines the extent of contagion impacts between structural equivalence and cohesion mechanism. By manipulating w_{ij}, it quantifies the social proximity of nation i to nation j on the basis of its social closeness to other nations. Additionally, it reflects the level of proximity between nations i and j in comparison to other nations with the network. The equation for contagion impacts is as shown in Eq. (4).

$$\boldsymbol{y_i = \rho\left[\sum_j w_{ij} y_j\right] + \epsilon\, j \neq i \quad or\; y_i = \rho(y_i^*) + \epsilon, j \neq i} \tag{4}$$

Here,

$$\boldsymbol{y_i^* = \rho\left[\sum_j w_{ij} y_j\right] + \epsilon\, j \neq i} \tag{5}$$

$$\boldsymbol{w_{ij} = \frac{(proximity\;\; i\; to\; j)^v}{\sum_k (proximity\;\; i\; to\; j)^v}, k \neq i} \tag{6}$$

The value of v may be quantified as the extent to which nation i depends on other countries, indicating its level of reactionary behavior [17]. This study examines the contagion impacts of the structural equivalence and cohesion mechanisms using the variable w_{ij}. Consequently, equations Eqs. (4) and (5) may be used to quantify the social closeness of these contagion effects. The cohesiveness mechanism is represented by w_{ij} when measuring social closeness via frequency or trade flows of patent citations between nations i and j. Alternatively, if we gauge social closeness by comparing the relationship between nation i and nation j, then w_{ij} denotes the mechanism of structural equivalence. Given that $y_i^* = \sum_j w_{ij} y_j$, it is important to note that the interpretation of y_i^* differs from the interplay among actors. If w_{ij} is assessed using the cohesiveness mechanism, then y_i^* measures the extent to which nation i reacts to the performance behaviors of citation partners or trade. In contrast, when measuring w_{ij} using the mechanism of structural equivalence, y_i^* represents the reaction of nation i to the efficiency of its rivals. The link between y_i and y_i^* signifies the extent to which contagion mechanism impacts the dissemination of foreign technology.

Cohesion Mechanism

This research utilizes two kinds of diffusion mechanisms, namely the structural equivalence and cohesion mechanisms. In the later mechanism, the weight variable W is calculated based on the data, which reflects the impact of the mechanism on the local innovative capability of nations that import or cite patents. Here, the variable ITD_{ij} signifies the dimension and speed at which technological knowledge travels through the frequency or export value of patent citations from i to j. On the other hand, if w is computed from the standardized column dataset, this process shows the impact of contagion on the local innovation efficiency of cited nations. The level of technical information transfer between country i and country j using patent citation frequency or imported values is represented as ITD_{ji}. We will be able to find out how the performance of a country's inventive capacity is influenced by the extent of technical information diffusion through trade or citing partners by summing up the data in the row ITD_{ij} and column ITD_{ji}.The exponent v shows how the process of influence impacts the self-identity with higher values suggesting contact with close friends. The effect weight w_{ij} is determined in Eq. (6).

$$\boldsymbol{w_{ij}^C = \frac{(ITD_{ij} + ITD_{ji})^v}{\sum_k (ITD_{ik} + ITD_{ki})^v}, k \neq i} \tag{7}$$

Structural Equivalence Mechanism

The structural equivalence mechanism quantifies the relationships between actors based on trade or patent citations. The Euclidean distance equation incorporates both column data and row data. In this context, R_i represents the total amount of technological knowledge that is spread to every nation in row i through patent citation frequency and export values. Similarly, C_i represents the total amount of technological knowledge that is spread to each country in column i through import values or patent citation frequency.

If $\frac{ITD_{ik}}{R_i} = \frac{ITD_{jk}}{R_j}$ and $\frac{ITD_{ki}}{C_i} = \frac{ITD_{kj}}{C_j}$, then i and j are considered structurally equivalent. This proves the fact that how much their technological knowledge is incorporated with others through exports or patents is directly proportional to the result faced by each nation. In the same way, the spread of technological knowledge through their imports or patents is also in proportion with the input they received from every country. It is therefore used to quantify the Euclidean distance as shown in Eq. (7).

$$d_{ij} = \left[\sum_k \left[\frac{ITD_{ik}}{R_i} - \frac{ITD_{jk}}{R_j}\right]^2 + \sum_k \left[\frac{ITD_{ki}}{C_i} - \frac{ITD_{kj}}{C_j}\right]^2\right]^{1/2}, \quad i \neq k \neq j \tag{8}$$

This research employs the Euclidean distance value d_{ij} to assign weight w_{ij} after identifying the structural equivalent between nations i and j The weight w_{ij} is the measure of structural equivalence as described. $dmax_i$ denotes the maximum distance that nation i can reach out to any other country in the world network [18]. The sector proximity between sector i and sector j may be captured by the degree of difference between d_{ij} and the maximum value of $dmax_i$. Similarly, if the value is small for d_{ij} compared to $dmax_i$ then it means that country i is nearby the country j.

V. RESULTS AND DISCUSSION

We examine the national innovation capabilities within the context of the social contagion impacts, the structural equivalence and cohesion mechanism on the globalization of embodied and disembodied technologies. This section contains the evaluation of the global extent of technological contagion.

Contagion Impacts

This section discusses how cohesion mechanism, structural equivalence mechanism, and contagion effects affect the performance of NICs, in this case, measured by the number of patents generated. It is a technology for the distribution of embodied and disembodied technology around the world. This research examines 42 nations from 1997 to 2023. Due to the delay in implementing new ideas, this research only examines the number of patents issued between 2000 and 2005. **Table 2** indicates that all mechanisms are statistically relevant. In regards to the correlation between the spread of contagion and the number of patents produced in each nation, as shown by Mechanisms 1 and 3, the cohesion approach unexpectedly demonstrates detrimental impacts via the spreading of both embodied and disembodied technology.

Concerning the structural equivalency approach, Mechanisms 2 and 4 show that there are strong and statistically significant connections between the NIC performance and contagion impacts in every nation. This research suggests that nations are more inclined to enhance their national inventive capability by imitating the actions of rivals rather than those of communication partners. In addition, the analysis of contagion impacts in **Table 2** indicates that structural equivalence, via the dissemination of embodied technology, has a greater impact on national inventive capacity compared to the cohesion mechanism.

Table 2. Findings of the Regression Analysis

Dependent variables (Patent)$_{j,\ t+3}$						
Mechanisms	1	2	3	4	5	6
Embodied spillover through cohesion approach	-.462 (-8.272)				-.189 (-3.58)	
Embodied spillover through structural equivalence approach		.516 (9.57)			.518 (9.804)	
Disembodied spillover through cohesion approach			-.642 (-13.26)			-.12 (-3.84)
Disembodied spillover through structural equivalence approach				.917 (36.53)		.844 (27.08)
Sig.	.000	.000	.000	.000	.000	.000
R^2	.214	.268	.412	.842	.304	.851

***Note: The numbers provided are standard beta coefficients*

This finding supports *H5*. In relation to the spread of technology without physical form, structural equivalence has a substantial and a more positive impact compared to the cohesion mechanism on the national capacity for innovation, therefore confirming *H6*. Therefore, the results of the research confirm *H3*, *H4*, *H5*, and *H6*, while rejecting *H1* and *H2*. According to our study, the contagion effect, which is measured in this study, is not entirely consistent with the previous empirical literature [19]. This research will examine the factors that lead to these outcomes before presenting a broader view of how to study the effects of a country's inventive capability through two mechanisms referred to as the contagion impact.

Contagion Impacts on NIC Performance

Embodied

Innovation diffusion theory provides a vast pool of ideas and an extensive database of empirical evidence that can be applied to the study of technology assessment, adoption, and application. Diffusion theory provides both the actual and potential methodologies for establishing the likely rate at which a given technology will spread as well as several factors that promote or hinder the uptake and implementation of technology. These are the attributes of the technology, the attributes of the individuals using the technology, and the ways through which these individuals get informed and persuaded to adopt the technology. Thus, it is not surprising that the theory of innovation dissemination is emerging as a framework for empirical research on Information Technology (IT).

Knowledge encompasses the information that is stored in the minds of people and may include judgement, observations, ideas, interpretations, concepts, procedures, facts etc. It is a process involving professional judgment, context, norms, assumptions, values, technique, knowledge, and information. This combination serves as a conceptual map for evaluating and integrating novel experiences, knowledge, and information. Knowledge is closely associated with individuals' beliefs and convictions, which are fundamentally connected to human activity in a manner that enhances the worth of the organization. Information is transformed into individual knowledge when a person acknowledges and remembers it as a correct comprehension of what is true and a legitimate interpretation of reality. Subsequently, the acquired knowledge is transformed back into information when it is expressed and conveyed by means such as text, pictures, language, or other symbolic representations.

In contrast, the use of embedded technology in the structural equivalence mechanism has a large and favorable impact on NIC performance. Mechanism 2 portrays nations that are more likely to imitate the conduct of structurally similar rivals by exchanging technology products. This process illustrates that ego nations and alter countries are rivals. In other words, while they may not directly engage in technological transfers, their comparable network positions result in indirect communication via trade with other parties [20]. Due to the presence structural equivalence, a nation has the ability to imitate the technology of a rival country that has a comparable network location. This imitation might then have an impact on the country's national inventive capability. Countries that have comparable positions in networks tend to use similar talents to get new technology.

Alternative method to quickly comprehend the economic relationships between nations based on their goods is to create a projection graphical illustration using the initial collection of bipartite connections represented by the matrix $\widehat{M}$. The concept is to establish connections between other nations based on the strength of their mutual production of goods. The information contained in $\widehat{M}$ is anticipated onto the system of nations. The country network may be described by the $(NC \times NC)$ nation-nation matrix $\hat{C} = \widehat{M}\widehat{M}^T$. The non-diagonal components $C_{cc'}$ represent the intersection of goods produced by nations c and c', indicating the quantity of items that are common to both countries. The diagonal components C_{cc} represent the number of items designed by nation c and serve as a measurement of c diversity. To determine the competitiveness level between two nations, we may set up the similarity matrix of the countries using Eq. (8).

$$\boldsymbol{S^{C}_{CC'},= 2\frac{C_{CC'}}{C_{CC}+C_{C'C'}}} \tag{9}$$

We note that the value of $S^{C}_{CC'}$ varies between 0 and 1, which points to the relationship between the products of nations c and c'. Lower values indicate negative association, while higher values indicate positive association and the extent of the association. As has been noted in earlier works on complex networks, authors constructed the relation between the vertices or analyzed the distance between them using similar methods [21]. These techniques have been used in various situations, for example, for determining the correlation between proteins or for studying the interrelations within the clinical characteristics of the orofacial system. The first major issue in working with big correlation networks is the identification of the best approach to display the significant structure. One of the efficient ways of illustrating the most similar vertices can be done by creating a Minimal Spanning Tree (MST). This approach involves creating a new graph and connecting nodes (c, c') following an order to reducing similarity until all the nodes have been linked. To form a tree, any leads that would form a cycle is omitted. Similarity, such as equivalent correlation indicators, may be used to identify the internal network structure. Although several approaches for societal recognition differ in their specific applications,they often provide the same qualitative outcomes whenever indicators include similar data.

We examine the impact of two different contagion approaches, structural equivalence, and cohesion, on the similarity of national innovation capacity performance between nations. The objective is to determine if nations with structural equivalence and social proximity reveal more similarity in their innovation capacity performance compared to countries with cohesive social proximity, as depicted in *H5*. The Standard Error (SE) is computed to measure the variation between standard coefficient approximation of cohesion and structural equivalence mechanisms. The t-test is then used to determine the relevance of this variation. The standard coefficient approximation obtained from structural equivalence is much higher than the one obtained from cohesion mechanism. Additionally, the R^2 value of the former mechanism is greater than the R^2 value of the latter mechanism.

Disembodied

The cohesion's standard coefficient is significant and negative for the spread of disembodied forms. Disembodied technology, similar to embodied technology, is widely spread in accordance with global stratification trends. This worldwide analysis included both emerging and developed nations, and it may demonstrate a counteractive impact on the cohesiveness mechanism as a result of the significant disparities in inventive potential between these two types of countries. Furthermore, because to their limited ability to innovate and lack of intellectual property, developing nations need to rely on the disembodied technology of more advanced partners in order to utilize their R&D efforts and enhance their technical progress [22]. Therefore, at a worldwide scale, the robust correlation among cohesive groupings has repercussions for the ability to innovate. Consequently, the spread of technology without physical form among nations in a united group has a detrimental impact on their ability to innovate.

In the context of structural equivalence, the standard coefficient exhibits a positive and statistically significant relationship. The structural equivalence mechanism has more explanatory power as a result of the multi-collinearity between patent citation and patent production. Nevertheless, the dissemination of the structural equivalency mechanism continues to be a significant matter that requires more study. A nation that is equivalent not only has the same networking state to a rival but also has similar technical skills to learn the skillset of their rivals. Disembodied technologies may be more easily diffused via a structurally identical mechanism. Disembodied technology diffusion refers to the active transfer of technology, when the acquisition of foreign technical knowledge entails the explicit use of patent applications as a means of accessing disembodied information [23].

An Analysis of the Dissemination of Technology

Empirically, it is challenging to distinguish between disembodied and embodied diffusion. However, by employing empirical data, it is possible to quantify and discriminate between the two types of diffusion. When comparing the first and the third mechanisms, which include the coefficient of cohesiveness approach, or Mechanisms 2 and 4, which use the coefficients of structural equivalence, it is evident that disembodied form of diffusion has a substantially greater impact on national inventive ability compared to embodied diffusion. This outcome suggests a disparity in the level of inflexibility in the transfer of technology between physical and non-physical forms. Rent spillover from embodied technological diffusion exhibit more inflexibility compared to pure spillover of knowledge from disembodied type of technological diffusion. The use of sophisticated and advanced intermediate products developed abroad illustrates the implicit use of technical expertise embedded in foreign intermediate products for generating final outputs. In addition, domestic innovators do not have access to the technical expertise contained in commercial intermediaries.

Embodied technology diffusion refers to the passive transfer of technology that largely affects improvements in production efficiency. Marvel and Lumpkin examine the significance of technology that is included in intermediate inputs, challenging the common notion that technology is only found in capital. They also assess the productivity benefits that result from the spread of this technology across different sectors. Consequently, two possibilities are explicitly examined, drawing on Romer's mechanism of input diversity. *H1* suggests that technical advancements are incorporated into high-tech inputs, whereas *H2* posits that the spread of technology improves overall sector output by using high-tech inputs. Baldwin and Gellatly. demonstrates that there is a clear tendency for technical advancements to favor high-tech inputs.

VI. CONCLUSION

This paper provides a systematic review of the literature in understanding the multivariate relationship between social contagion, technology adoption, trade, and patents as factors that shape the innovation performance of nations. This indicates that social contagion is a key factor that affects the rate of diffusion of new technologies by creating appropriate networks for work and the flow of information to support diffusion of innovations within and across organizations. Technological diffusion mechanisms on the other hand facilitate the use of these innovations across industries, and trade flows; and citation of patents are some of the ways through which the transfer of technology takes place. The paper also demonstrates how these elements improve the innovation capabilities and points out that policy interventions are required for these processes. The process of knowledge sharing, technological support and international cooperation involves some strategies that may be important to the countries in order to enhance their technologies. With the help of the mentioned aspects, the countries can enhance their information systems and contribute to the necessary competence for further development of the economies.

CRediT Author Statement

The author reviewed the results and approved the final version of the manuscript.

Data Availability

No data was used to support this study.

Conflicts of Interests

The author(s) declare(s) that they have no conflicts of interest.

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