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Master Thesis

技術主路徑中融合與發散階段的合作人才表現：以減緩氣候變遷技術爲例

The Technology Convergence, Divergence, and Talent Collaboration in Climate Change Mitigation through Key-Route Main Path Analysis

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誌謝

在台大已經接近七年，終於要正式踏出社會啦！碩士這幾年真的不好過，踏入新領域的不安感、疫情帶來的低氣壓、沒辦法回家的兩年，這些種種都讓休學的念頭三天兩頭就出來一次。感謝俊傑老師的鼓勵，允許我回馬來西亞充電，在很多卡關的時候給予了很多意見，也給了未來人生的很多指導。

有辦法唸書接近七年，我很幸運有一直都是最愛我的媽媽，跟我說休學也沒關係，不管怎麼樣都給我最多的愛。研究所最大的收穫就是認識一群很棒很棒的朋友，特別感謝柏毅、玫瑄、心璇！我很感謝有柏毅，陪我三餐、一起寫作業、在研究室熬夜看日出、一起撐到口試。玫瑄在研究室的陪伴，一起米聽，還幫我跑了很多程序；心璇的溫柔常常鼓勵我，都是我非常珍惜的回憶。還有 Jordan, thanks for always being there for me. 研究所給我最大的寶藏就是讓我認識這些很棒很優秀的人，希望以後的人生都能夠一直有你們在。

在口試前幾個月很迷茫的時刻，多虧有育豪每天打來跟我 sync 人生盯論文和人生進度。有大家溫暖的陪伴，讓我慢慢對迷茫的 25 歲重燃信心，可以不再害怕地過每一天。在這裡想給未來的自己一個期許，不管多麼的害怕迷茫，在往後的日子裡，走一步算一步，不用快樂也可以很自在。畢業以後要加油耶！

林禕雯 謹誌

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中文摘要

氣候變遷仍是當今世界面臨的最重要全球挑戰之一，需要緊急而有效的緩解策略。解決這個複雜的問題需要多方面的方法，包括創新技術的開發和應用、政策調整以及個人行為的改變。在眾多分析方法中，關鍵路徑主要路徑分析成為一種強大的工具，可用於識別技術或系統實現成功所必須走的最重要途徑或路線。本論文旨在通過關鍵路徑主要路徑分析，針對氣候變遷緩解中的技術融合與發散問題填補重要的研究空白。本論文致力於為氣候變遷緩解領域做出重要的貢獻，並探索該領域的人才合作。通過分析在主要路徑上的人才與不在主要路徑上的人才之間的關係，以更清晰地了解人才合作。本研究使用了普遍性和原創性來探索主路徑中的不同階段，雖然未見明顯的差異，但是配合主路徑中的分合還是可以分辨得出不同的階段。最後，通過不同階段內，人才合作的模式，我們更能瞭解在氣候變遷緩解領域內，合作類型要依據所在的階段，第二階段中非主路徑上的組合最能產出第三階段中主路徑上的人才，而第三階段則是要仰賴主路徑上的人才，才能產出第四階段中主路徑上的人才。

關鍵字：減緩氣候變遷、技術融合與發散、關鍵主路徑分析、人才合作

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Abstract

Climate change remains one of the most critical global challenges of our time, necessitating urgent and effective mitigation strategies. Addressing this complex issue requires a multifaceted approach, involving the development and deployment of innovative technologies, policy adjustments, and changes in individual behavior. Among various analytical methods, Key-Route Main Path Analysis emerges as a powerful tool to identify the most crucial pathways or routes that a technology or system must traverse to achieve success. This thesis aims to address a significant research gap by specifically examining technology convergence and divergence in the context of climate change mitigation through the lens of Key-Route Main Path Analysis. By analyzing the relations between talent-on-the-main-path and talent-off-the-main-path to see a clearer view of talent collaboration. In conclusion, by examining the patterns of talent collaboration across different stages, we can better understand that in the field of climate change mitigation, the types of collaboration should be aligned with the respective stage. In the second stage, talent combinations that diverge from the main path are most likely to produce talents that contribute to the main path in the third stage. Meanwhile, the third stage relies on talents from the main path to generate talents for the main path in the fourth stage.

Keywords: climate change mitigation, technologies, convergence and divergence, key-route main path analysis, talent collaboration

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Chapter 1: Introduction

1.1 Background

Climate change has generated significant consequences on environmental and human systems over the last three decades, long-term effects of climate change include further ice melt, ocean warming, sea-level rise, and rain acidification have been occurring (IPCC, Summary for Policymakers, 2014). One of the alarming effects caused by climate change, heat waves, have put more than 100 million people under various heat alerts (CNN, 2022). Not only are there heat waves that have haunted the United States, Europe and other countries, in the exact summer of 2022, the capital city Seoul of Korea faced the heaviest rain in decades and caused serious floods that took several lives (BBC, 2022). According to the Korea's Meteorological Administration (KMA), Seoul's Dongjak district recorded the highest rate since 1942 with 141.5 mm of rain per hour (KMA, 2022). We could see the distressful consequences caused by climate change by all these changes that happened over this decade.

To reduce risks of climate change impacts, both adaptation and mitigation are compulsory approaches to face the Climate Change (Ayers & Dodman, 2010; IPCC, 2014). Moreover, climate change affects several fields including agriculture, forestry, fisheries, health and water resources, development of CO2 emission reduction or offsetting solutions is urgently needed in emerging nations (Lal, 2003). Also, the development of the Climate Change Mitigation Technology (CCMT) is an important topic to discuss. Subsequently, in 2022 August, the Senate Democrats of the United States have decided to resurrect the core of their election-year agenda, enacted a budget plan that would seek to address climate change, over $300 billion would be invested in

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energy and climate reform, making it the greatest federal clean energy investment in US history (The White House, 2022).

Mitigating the effects of climate change requires a multifaceted approach, including efforts to reduce greenhouse gas emissions and increase the use of renewable energy in different areas (Mac Kinnon, Brouwer, & Samuelsen, 2018). Technology plays a critical role in this effort (Wright & Fulton, 2005), as the development and deployment of new technologies can help to reduce emissions and increase the use of renewable energy. Accordingly, the European Patent Office (EPO) collaborated with the United Nations Environmental Program (UNEP) and the International Centre on Trade and Sustainable Development (ICTSD) to conduct a study on Patents and Clean Energy and created the Y02 patent classification to organize the findings of the study (Veefkind et al., 2012).

However, the development and deployment of new technologies is a complex and dynamic process, and understanding how different technologies evolve over time is crucial for effective climate change mitigation (Hung, Lai & Liu, 2022). Key-Route Main Path Analysis is a method that can be used to analyze the development and deployment of new technologies and understand the factors that drive technology convergence and divergence (Yu & Sheng, 2020; Hung et al., 2022). Understanding how technology convergence and divergence affect the development and deployment of new technologies is also very important for effective climate change mitigation.

After understanding the technology convergence and divergence of the main path, the convergence and divergence that happened in an organization is worth our attention. Roco (2016) draws a clear image of how an organization can have different stages under the different phases in convergence and divergence. From a series of knowledge convergence happening in the beginning of the development of a technology, to

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incorporating new inventions and entering the divergence phase, and increasing their businesses from 1 billion to 4 billion. Therefore, we think that it is a must to not only analyze the development of the main path but to enter the assignee level to take a look at the convergence and divergence in the organization level, given that in different phases, organizations took different approaches to develop the technology. When using Patentometricss on analyzing the organization level, we use originality and generality, since the significance of patented research has been linked to both originality and generality, which are considered as metrics for assessing its fundamental value (Lerner, Sorensen & Strömberg, 2011).

It is important to analyze the talent on the main path since the knowledge flow in a main path that is full of collaborations is mainly affected by the type of the collaborators (Liu, Mihm & Sosa, 2018). By seeing the result, a firm could improve the cultivation of potential talents, can enhance a firm's design competitiveness and bring about favorable shifts in its focus and direction (Liu et al., 2018). Therefore, in our study we hope to understand if a talent-on-the-main-path has been collaborating with another talent-on-the-main-path to make it appear on the path.

1.2 Motivation

Previous researchers have used Key-Route Main Path Analysis to study the technological changes in various fields, such as blockchain domain and thin-film solar cell technology (Yu & Sheng, 2020; Lai, Bhatt, Kumar, Chen, Chang, & Su, 2021). They have identified divergent-convergent patterns in understanding the implications of the development process of the technology (Hung et al., 2022). Hung et al. (2022) also mapped the main path development of printers and found that main path is a directed knowledge flow and that the global structure is a combination of divergence and

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convergence. This understanding of the divergence and convergence of knowledge flow can provide a better view of the different phases of innovation development (Verspagen, 2007). By doing such, Hung et al. (2022) also identified the different lead inventors/companies in different phases of development. Based on this study, we thought that by applying the Key-Route Main Path Analysis on analyzing the development of CCMT would give us a better view of the innovations.

Previous studies have not reviewed the main path of CCMT using Key-Route Main Path Analysis, and there are no clear instructions on how to identify the specific periods of each stage that contain divergence-convergence dynamics. This is an important area of research as it can provide valuable insights into the factors that drive technology convergence or divergence and identify opportunities for innovation. In previous studies, none have reviewed the main path of CCMT (Climate Change Mitigation Technologies) using key-route main path analysis and also, there were no clear instructions for identifying the specific periods of each stage containing the divergence-convergence dynamics. Given that previous studies on divergence-convergence dynamics have pointed out that the convergence phase contains new conceptions and creative synthesis, while the divergence phase is more likely to involve branching out into exploratory outreach (Roco, 2016), we can see similarities in important patent indicators such as originality and generality.

Understanding the technological divergence and convergence can provide valuable insights into the factors that drive technology development, we can gain valuable insights into the different stages of technology development and the role of different actors in each stage. Besides, doing such research could also improve the technology road mapping, we could differentiate the flow of knowledge in a more accurate way, and each stage of the junction of convergence and divergence, can also

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help in developing more accurate and effective technology roadmaps and plans.

Last but not least, it would also provide a better understanding of collaborations, by understanding the divergent and convergent dynamics, we identify the different types of collaborations that exist within a technology field and how they drive technology development. Other than the understanding of the technological divergence and convergence in the main path, our study has identified a distinctive factor that influences knowledge transfer in collaborative efforts - the quality of collaborators, to see whether the quality of the collaborator will lead to a better development. This finding holds significant implications for companies interested in enhancing their ability to nurture promising talent. By doing so, they can elevate their design competitiveness and potentially even drive positive shifts in the company's priorities and trajectory.

1.3 Purpose

Based on the above, we could gain a brief understanding of how important the CCMT is, and also the lack of attention has been paid on discussing the technology divergence and convergence in CCMT. Even though Hung (2022) had done the research and found out the divergent–convergent patterns in understanding some important implications of the development process of the technology, they did not provide a clear indication of how to slice out the exact stage of the junction using clear indicators. Yet, no researchers have done the research in the patent of CCMT using key-route main path analysis. After understanding the roles of assignees, it is important to analyze the talent, because collaborations within certain talents would not be the same as compared to other collaborations.

Therefore, we have two questions to answer:

1. In the whole main path, how could we understand each stage of the path and

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differentiate the phases?

2. According to Liu et al. (2018), collaborating with key talent raise the possibility of being a key talent itself, since main path is all about collaborating, could we find out this phenomenon in main path of CCMT?

According to these two questions, we have two purposes to achieve:

1. The first purpose is to differentiate the stages of main path of the CCMT into four phases, which is convergence: creative phase, integration/ fusion phase, and divergence: innovation phase and spin-off phase according to Roco (2016).
2. To find out in the different stages, whether collaborating with talent-on-the-main-path is increasing the possibility of talent-off-the-main-path to involve into a talent-on-the-main-path.

In this paper, we examine the technological trajectories of CCMT through the lens of the convergence-divergence cycle. Our goal is not only to gain a deeper understanding of the dynamics of knowledge flow, but also try to differentiate the stages in main path and discover the possible talent that will lead others into the main path and even dive deeper into the talent that would be needed in the future.

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Chapter 2: Literature Review

In this section of the paper, we will focus on a literature review of relevant research on CCMT, main path, and Patentometrics. The literature review will begin by discussing research on technology used for climate change mitigation. Then, it will move on to discussing research on the main path, specifically, the analysis of technology trajectories and main path, convergent-divergent patterns of main path, and the role of talents and organization in the evolution of technology trajectories. Finally, it will delve into the field of Patentometrics, which involves the analysis of patent data to understand the evolution of technology. Specifically, the literature review will look at research on patent data, generality and originality, and organization and talents in technology convergent and divergent phases.

2.1 Climate Change Mitigation Technology (CCMT)

CCMT have been extensively discussed in the scientific literature over the past few decades (Szulczewski, MacMinn, Herzog & Juanes, 2012; Dechezleprêtre, Glachant & Ménière, 2013). A comprehensive review of the literature reveals a variety of technological solutions that are being employed to reduce or eliminate the impacts of climate change. These solutions include renewable energy sources, carbon dioxide capture and storage, energy efficiency measures, nuclear power, and carbon capture storage and utilization (Fawzy, Osman, Doran & Rooney, 2020).

The importance of the CCMT could be seen both academically and politically. The international proliferation of CCMT is at the forefront of current post-Kyoto regime debates (Dechezleprêtre et al., 2013). The current US President Joe Biden vowed to return to the Paris Climate Agreement as soon as he took office, and emphasized that

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climate change is one of the main axes of US administration in the next few years (Biden, 2020). Since the President of the United Nations Framework Convention on Climate Change forced the commitment of technology transfer in 1992, how to fulfill the commitment and effectively promote the international transfer of climate-friendly technologies in reality has been the theme of debate (UNFCCC, 2016). Since the Bali Roadmap (2007) further emphasized the importance of clean energy technology transfer (UNFCCC, 2008), the "Cancun Declaration" held in Mexico in 2010 placed more emphasis on climate change mitigation and adaptation, and responded to the technology transfer requirements of developing countries. The Technology Mechanism (TM) was adopted to promote reinforced actions on technology development and transfer (UNFCCC, 2011).

In addition, there has been significant attention given to the development of innovative technological solutions that could help to reduce and eliminate the impacts of climate change. The discussion around CCMT has been a key topic at recent United Nations climate conferences, including the Conference of the Parties (COP) meetings. These meetings bring together governments, businesses, and other stakeholders to negotiate international agreements and policies to address the global climate crisis.

The Paris Agreement, signed in 2015, set a new course in global efforts to tackle climate change. Under the Paris Agreement, countries committed to limiting global temperature rise to well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the increase to 1.5 degrees Celsius (UNFCC, 2016). According to the Paris Agreement (UNFCC, 2016), to achieve these goals, countries must significantly reduce their greenhouse gas emissions and transition to a low-carbon, sustainable future.

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At COP21 in Paris, governments emphasized the importance of technological solutions for mitigating climate change, including the development and deployment of low-carbon and zero-carbon energy sources, energy efficiency measures, and carbon capture and storage (CCS) technologies (UNFCC, 2016). There was increased recognition of the need for international cooperation in research, development, and deployment of these technologies, as well as the financing and transfer of these technologies to developing countries (UNFCC, 2016).

Prior to the Paris Agreement, the Kyoto Protocol, signed in 1997, was the main international agreement for addressing climate change (UNFCC, 1997). Under the Kyoto Protocol, industrialized countries committed to reducing their greenhouse gas emissions. The protocol was updated by the Doha Amendment (UNFCC, 2012), which extended the commitment period to 2020 and established new emissions targets for some countries. At COP18 in Doha, the amendment was adopted and entered into force in 2013.

In the context of the Kyoto Protocol and the Doha Amendment, discussions at COP meetings focused on the need for developed countries to take the lead in reducing emissions and the need for technology transfer to developing countries. There was also a strong emphasis on the importance of complementary policy measures, such as carbon pricing, renewable energy mandates, and energy efficiency standards, to drive emissions reductions (UNFCC, 1997; UNFCC, 2012).

Overall, the discussion around CCMT at COP meetings reflects the evolving international response to the global climate crisis and the recognition of the critical role that technology will play in meeting the goals of international climate agreements. We could see the importance of discussing climate change mitigation technologies and understanding its trajectories, since climate change has now become a really urgent

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topic. Given that there are different kinds of technologies in climate change mitigation technologies, we would like to have a peek at each roadmap and also the organizations in each technology, and understand how the technology develops.

CCMT is one of a newly emerging technologies that are developing very fast (Veefkind, Hurtado-Albir, Angelucci, Karachalios, & Thumm, 2012). In the CCMT, there are different technologies such as technologies to adapt climate change, CCMT that related to buildings and includes the technology of the capture, storage, sequestration or disposal of greenhouse gas, and also the reduction of greenhouse gas emission, related to energy generation, transmission or distribution, CCMT in the production or processing of good, CCMT related to energy generation, transmission or distribution, CCMT in the production or processing of goods, CCMT related to transportation, CCMT related to transportation, last but not least, CCMT related to wastewater treatment or waste management (USPTO, 2023).

Given that CCMT has a variety of different technologies and it is a newly growing technologies that is escalating quickly (Veefkind et al., 2012), it is suitable to use to analyze the convergence and divergence since technological convergence and divergence have been used in analyzing technology that is newly emerged (Roco, 2016).

2.2 Main Path

This paragraph gives a brief introduction of the main path by going through technology trajectories to the analysis of the main path. After the brief understanding of the main path, it will discuss the convergent-divergent patterns of the main path. Last but not least, we will have a go through about technology convergence-divergence in organization and also how talent plays roles in the collaboration.

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2.2.1 The Analysis of Technology Trajectories and Main Path

The concept of technological paradigms and trajectories, as first defined by Dosi (1982), can provide an explanation for the processes of incremental and disruptive innovation, considering the roles that social and economic factors play as selective criteria. This paradigm allows for a model and pattern of solutions to be created from a large set of possible directions of technology development and for a normal problem-solving activity to be repeated, forming a trajectory (Nelson and Winter 1977; Dosi 1982). Additionally, researchers have argued that technological trajectories are shaped by a variety of factors such as the availability of resources and capital, the knowledge base of the industry, and the interests of the actors involved (Dosi, 1982).

The study of technological trajectories is a complex and multifaceted field, with researchers taking a variety of approaches to understanding the forces that shape technical change and its consequences (Kim & Shin, 2018). Previous research on technological trajectory has focused on the effects of different components of the trajectory on the development of technology and the resulting economic and social implications (Werfel & Jaffe, 2013). Technological trajectories are important drivers of innovation, economic growth, and global competitiveness and that the success of such trajectories depends on the ability of firms, governments, and other stakeholders to identify and develop the appropriate trajectory for their context (Verspagen, 2007). There have been a number of approaches used to trace technological changes and identify technological trajectories; these approaches range from qualitative to quantitative methods (De Marchi, Napolitano & Taccini, 1996; Verspagen, 2007; Hung, Liu, Lu & Tseng, 2014).

To trace the technology trajectories and the knowledge diffusion in between, main path analysis is an excellent method to use since investigating these main paths will

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provide researchers with more understanding and also insights of the field (Rejeb, Rejeb, Zailani & Abdollahi, 2022). Main path analysis is one important approach of tracking developmental technology trajectories, known as Patent-Based Knowledge Network Analysis, which uses quantitative methods to examine the economic and social implications of technological changes (Kim, Yoon, Raghavan, Le, & Park, 2021). Kim et al. (2021) used knowledge persistence (KP) based main path analysis to analyze the developmental trajectories of blockchain technology using a patent database and citation network. Their goal is to identify trends, discover new opportunities and develop roadmaps for the technology. Since patent citations will reveal knowledge flows within the technology, patents are a reliable source for technological knowledge.

Fu et al. (2019) used the main path analysis method, to trace the growth of IoT (Internet of Things) studies, and conducted a survey on the development trajectory. On the other hand, Rejeb et al. (2022) used main path analysis to examine the knowledge diffusion routes in IoT studies, by discovering the interrelationships within the IoT domain. By using global main path analysis, the researchers found the most influential path and the role of certain technology in the domain, and stated that the position of the papers in the main path reflects certain roles in the citation network (Rejeb et al., 2022). Nevertheless, analyzing the main path of key routes can provide a better understanding of how the IoT domain was formed, revealing more detailed information (Rejeb et al., 2022).

The proposed method of Hung et al. (2014) examining technological changes involves using key-route main paths, which are multiple main paths constructed based on key-routes, significant links in a citation network. This approach differs from previous methods, such as the main path suggested by Hummon and Doreian (1989) which is single sequence of citation and multiple main paths by Verspagen (2007), as

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key-route main paths guarantee inclusion of top significant citation links in multiple sequences, revealing the governing structure of knowledge diffusion paths and potential divergent-convergent patterns. According to Lucio (2018), main path techniques examine the connectedness in acyclic networks, especially when the nodes are time-dependent; these techniques are useful in selecting the most important nodes at different points in time, which helps in capturing the evolution of the network over time. The main-path approach provides a way to summarize the most representative sequences of events in a network, making it relevant in a variety of fields where time-evolution of relationships is important.

Methodologically, main path analysis is applied to a lot of research in technology trajectories (Hung et al, 2014; Liu, Lu & Ho, 2019; Hung et al., 2022). Through main path analysis, Hung et al, (2014) also present two complete stages of divergent-convergent cycles, each starting with a breakthrough and ending with another breakthrough, plus a divergent half cycle, differentiate them into three stages: 1st, 2nd and 3rd stages. According to Hung et al. (2014), the divergent phase is the period of design competition and the convergent phase is characterized by the development of a dominant design; the peak of the chaotic period is also the time when the dominant design starts to emerge and marks the transition from the divergent phase to the convergent phase. Hung et al. (2022) using key-route main path analysis and differentiate the knowledge flow into three stages: Early Period, Growth Period and Maturity Period. Xu, Hao, An, Pang, & Li (2020) observed three different development stages according to convergence-divergence patterns in the main paths: the emergence, exploration and development stages, but they did not make clear indicators about how to differentiate each stage.

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In this paper, the main path fits perfectly with our research purpose because it pictured the most representative citation chains in the whole citation network. It allows us to get a clearer roadmap of a technology and also find the significant links within them. Also, the main path allows researchers to see a bigger picture of every node and their relations on the path. Many researchers also differentiate stages in the main path, by looking at their transitions and drawing a picture out of it.

2.2.2 Convergent-divergent Patterns of Main Path

The convergence-divergence cycle is a repetitive link, cyclical model of technological change, with full stages of the cycle, each beginning with a breakthrough and ending in another breakthrough (Hung et al., 2014). The convergence-divergence cycle is a theoretical framework that describes the development of science and technology over time (Roco, 2016). It consists of two main stages: convergence and divergence, and a total of four phases are in the two main stages.

According to Roco (2016), the author illustrated Figure 1 which shows that the stage of convergence contains two phases: creative phase and integration/fusion phase; while the stage of divergence contains two phases: innovation phase and spin-off phase.

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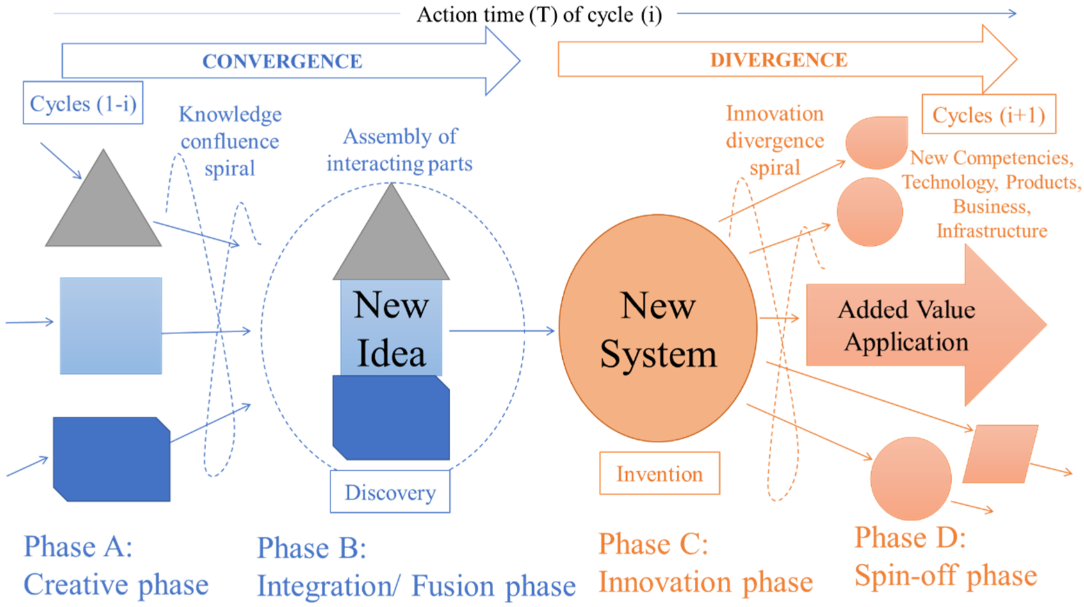

Figure 1. Four phases of the convergent-divergent cycle (Roco, 2016)

Roco (2016) explained the different characteristic in each phase as below:

a. Creative phase (Phase A): During this phase, ideas and knowledge from multiple fields are combined and integrated, leading to new insights and breakthroughs. This is often described as the "knowledge confluence spiral" because of the way that ideas from different disciplines come together to create something new and innovative.

b. Integration/ Fusion phase (Phase B): In this phase, newly gained knowledge is applied and used to develop new products and technologies. This is the phase where inventions are made and new products are designed to meet specific needs and requirements.

c. Innovation phase (Phase C): During this phase, new technologies are commercialized and integrated into existing business practices. This is where the potential for new businesses and markets is realized and the products of innovation are brought to market.

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d. Spin-off phase (Phase D): This is the phase where the products of innovation lead to new competencies, tools, and uses. This can lead to the creation of new businesses and infrastructure, as well as the development of new applications for the original technology, into different new areas. The spin-off phase often results in a new cycle of convergence-divergence, as new knowledge and innovations are generated and integrated into the existing system.

Therefore, we could classify convergence into (1) Science convergence, which involves the merging of various scientific disciplines into a unified body of knowledge, (2) Technology convergence, which combines technologies from different areas into a single unity of technology, and (3) Market/Industry convergence, which brings together companies from different technology backgrounds, applications, and target markets into a unified market or industry (Jeong, Kim & Choi, 2015). In this paper, we are focusing on technology convergence. To sustain competitive advantage, technology convergence affects a firm by increasing new core competence, learning new knowledge and skills (Lei, 2000). In other words, the convergence stage involves the creative combination and harmonization of information and technology from various distinct fields, industries, and levels of complexity and structure; it encompasses examination, linking disparate concepts, and combining these new links into cutting-edge scientific theories and technological expertise (Roco, 2016)

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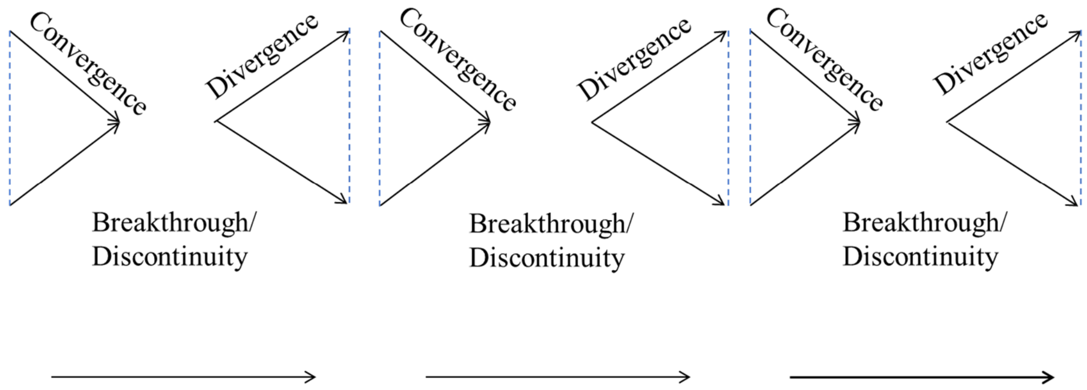

Figure 2. Technological cycle as a divergent-convergent linkage (Hung et al., 2014)

On the other hand, technological divergence arises from a disruptive innovation, signaling the start of a period of intense activity during which multiple technologies emerge and gradually improve (Hung et al., 2014). According to Hung et al. (2014), the chaotic or disruptive phase is characterized by an abundance of new information branching off from the initial innovative idea and can lead to further advancements, causing a rapid growth of new knowledge. This results in a divergent pattern as the knowledge spreads widely until a design standard is established (Hung et al., 2014). In Figure 2, Hung et al. (2014) also illustrated how divergence and convergence occurs, we could observe that there's a breakthrough or discontinuity happens and divergence will continue by convergence until the next cycle.

The knowledge flow in technological trajectories can be represented by a combination of local divergent branching structures and convergent fusing structures, which form multiple patterns that make up the global structure, subsequent extensions, and cyclical patterns of trajectories (Hung et al., 2022). Patent data is a rich source of information that can be used to study knowledge flow and identify patterns of convergence and divergence in knowledge sharing (Liu & Lu, 2012; Hung et al., 2014; Hung et al., 2022; Rajeb et al., 2022). This study will examine the current state of research on convergent-divergent patterns of knowledge flow using patent data.

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Numerous studies have been conducted on the convergent-divergent patterns of knowledge flow using patent data. Liu & Lu (2012) used key-route main path analysis on patent citation data and eventually found out a convergent-divergent structure that summarizes the development of Hirsch index; they also confirm the usefulness of the key-route approach in hinting the structure. Rajeb et al. (2022) analyze the domain of the Internet of Things (IoT) by applying main path analysis on patent data, they discovered multiple divergence-convergence patterns on the main path. By looking at the timing of the path diverges and converges, researchers found that in the development of secure and energy-efficient IoT systems, there is a specific examination of the potential of IoT and blockchain technology in the textile and automotive sectors, but other vital industries have been overlooked (Rajeb et al., 2022).

In governance of S&T development, Roco (2016) stated an example of how an organization/ corporate goes through the convergence and divergence stage. The R&D program conducted under the auspices of the US National Nanotechnology Initiative (NNI) has been through the four phases of convergence and divergence stage, leading the development of significant new nanotechnologies (Roco, 2016).

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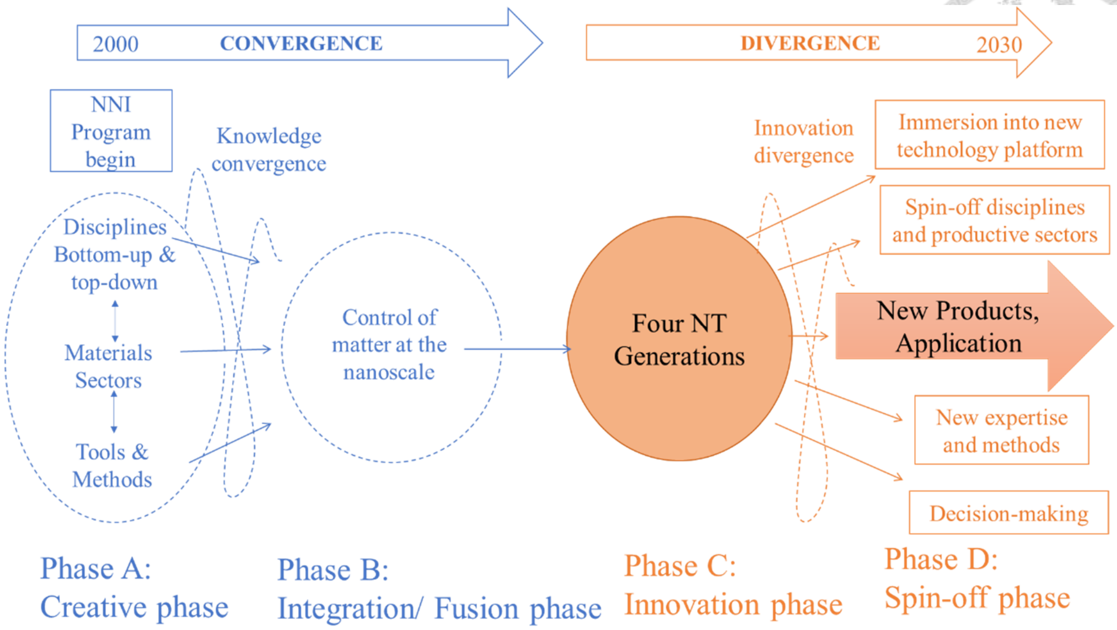

Figure 3. The 2000–2030 convergence–divergence cycle for global nanotechnology (Roco, 2016)

Roco (2016) used four stages to describe the development for the nanotechnology development:

(1) Phase A (convergence): Knowledge convergence happens within different S&T areas, such as bottom-up and top-down disciplines, various sectors of relevance, different tools and methods of investigation, and nanostructure synthesis; it leads to understanding and control of matter at the nanoscale.

(2) Phase B (convergence): Four generations of nanotechnology products (passive nanostructures, active nanostructures, systems of nanosystems, molecular nanosystems) have integrated, and incorporated into new system designs and inventions.

(3) Phase C (divergence): New product and business opportunities which are worth about $1 billion and to increase to $4 billion from 2013 to 2020, leading by the spiral of innovation.

(4) Phase D (divergence): Immergence with other technologies (such as biological, information, and cognitive sciences and technologies) and socioeconomic

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projects happened, and are expected to be the most abundant phase from 2020 to 2030.

2.2.3 Technology Convergence-divergence in Talent

While a technology is developing, talents in the development flow are very important (Liu & Pearson, 2014). In an organization or cooperation, creative stars and non-stars employees are differentiated in driving the team towards creativity performances (Li, Li, Li & Li, 2020). Li et al. (2020) identified stars and non-stars by their highest creativity rating scores and leader nomination scores, and found out that stars contributed the most to the team creativity. Consequently, we could understand that a star refers to talent who is highly skilled, experienced, or well-known in their field, and whose contributions to the project are particularly valuable, who might be a recognized expert or a leader in the field, and may have a strong reputation or following (Liu et al., 2018; Li et al., 2020).

On the other hand, a non-star collaborator is someone who may not have the same level of expertise or recognition as a star collaborator, but who still contributes meaningfully to the project (Liu et al., 2018; Li et al., 2020). Moreover, Liu et al. (2018) also stated that collaborating with a star will bring more creative performances, and a higher possibility to become a star themselves. A hypothesis has been proved that when an innovator collaborates with a creative star more than a non-star, the innovator will have a higher chance to become a star (Liu et al., 2018).

Collaborations with non-star talents greatly benefit individuals by fostering divergent idea generation, potentially leading to transformative break throughs (Liu et al., 2018). Conversely, partnering with established stars not only enhances idea

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generation but also imparts creative synthesis skills, these advantages extend beyond immediate collaboration, equipping aspiring innovators with a skill set that fosters continuous breakthroughs and propels them into star (Liu et al., 2018). Consequently, an innovator's sustained creative performance, and their prospects of achieving stardom, hinge on the caliber of their collaborators.

Contrariwise, in our study by using main path analysis, we are able to track connections between the key intellectual developments in the field (Carley, Hummon & Harty, 1993). The citation chains that represent in a main path are the most representative chains in a network (Hung et al., 2022), which means that the talent appearing in a main path is the "star" or so-called "key talent" of the field. Therefore, we will like to find out when collaborate with "star" or in later we called "talent-on-the-main-path", will it emerge its performance to becoming a "star". Contrarily, when collaborates with a non-star talents, the benefits they got will or not emerge its performance to becoming a "star".

2.3 Patentometrics Analysis

Patentometrics is a field of study that uses patent data as a means of measuring scientific, technological, and innovation outputs (Baglieri & Cesaroni, 2013). The main goal of Patentometricss is to extract information and insights from the vast amounts of patent data that are generated every year (Kim & Bae, 2017). The data sources include patent databases, patent applications, and patent grant information, among others (Kim & Bae, 2017). Patents serve as a reliable indicator of technology development and innovation, as they represent a specific technique that has passed a thorough

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examination to ensure its novelty, quality, and potential industrial utility (Guan & He, 2007).

2.3.1 Patent Data in Main Path Analysis

There are few different path search paths: the local main path, the global main path, backward main path, forward main path, single main path, multiple main path and the key-route main path (Liu & Lu, 2012). For the local and global main path, the global main path refers to the path that has the highest number of overall traversals, indicating its significance in the flow of knowledge; while the local main path emphasizes the increasing importance of a specific path, the global main path highlights the overall importance of the path in the knowledge flow (Liu & Lu, 2012). Secondly, for the backward and forward main path, the process of searching forward involves identifying the offspring of significant contributions, while searching backward entails tracing the roots of current works (Liu & Lu, 2012). When using the main path algorithm to search forward, papers that have attracted the most followers are given priority in the main path (Liu & Lu, 2012). Conversely, when searching backward, papers that have incorporated ideas from a wide range of sources are given greater importance (Liu & Lu, 2012). For single and multiple main paths, single path allows to search only the most significant path while multiple main paths select more paths on the top overall traversal counts, more details will be revealed (Liu & Lu, 2012). Last but not least, for key-route main path,

Traversal weight is a key concept in main path analysis, and several different types of traversal weight have been proposed. Hummon and Doreian (1989) suggested three types: search path link count (SPLC), search path node pair (SPNP), and node pair

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projection count (NPPC). Batagelj (2003) later proposed the search path count (SPC). These different types of traversal weight measure different aspects of the main path, such as the number of links or nodes visited, or the frequency of visits to a particular node pair. The SPLC and SPNP are determined by considering all potential search paths starting from a particular node, while the NPPC is computed for a subset of the network defined by both a start and an end node (Liu & Lu, 2012). The rationale behind using these traversal counts as a measure of significance is that a citation link that lies on a route through which a significant amount of knowledge flows must be essential to the knowledge-dissemination process (Liu & Lu, 2012). Moreover, the nodes located on these significant routes can be inferred to hold valuable knowledge (Liu & Lu, 2012).

In a citation-link network, the SPC value of a citation link represents the total number of times that the link is traversed when all possible citation paths from sources (nodes that are cited while referring to no other nodes) to sinks (nodes that are referred to while citing to no nodes) are considered (Xu, Hao, An, Pang & Li, 2020). The SPLC value of a citation link is the total count of times the link is traveled when all possible citation paths from ancestors (including themselves) of the tail nodes to sinks are taken into account (Xu et al., 2020). The SPNP weight is a more complex measure, representing the total number of times that a citation link is traveled when all possible citation paths from ancestors (including themselves) of the tail nodes to descendants (including themselves) of the head nodes are considered (Xu et al., 2020). The NPPC method, on the other hand, computes the number of times that each link is involved in connecting all node pairs within all subgraphs derived from the network (Xu et al., 2020). In our study, we use the SPLC algorithm to compute the traversal count since it is closer to an actual knowledge diffusion scenario (Hung et al., 2022).

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Patent information is a rich source of data that can provide insights into technological innovations, trends, and competition (Baglieri & Cesaroni, 2013). This information can be useful for a variety of purposes, including technology research and development, market analysis, competitive intelligence, and legal and policy analysis (Zhang et al., 2021). According to Kim & Shin (2018), patents are commonly used in technological trajectory literature due to their benefits. Patent data that represent the key technologies could be found in the main trajectory (Huang, Zhu, Porter, Zhang, Zhu & Guo, 2020).

Firstly, patents allow for the construction of a technological trajectory at a knowledge level, providing insights into the development and evolution of a technology (Hung et al., 2022). Secondly, patents are readily available for a long period, making it possible to track the history of a technology over time (Pilkington & Dyerson, 2006; Kang, Kim, Seo & Park, 2017). Lastly, patents provide detailed technological information, including descriptions of the invention, how it works, and how it can be used (Hung et al., 2022). This information can be useful for researchers, innovation managers, and policy makers.

Baglieri & Cesaroni (2013) arranged the three broadly defined sets of activities that being mentioned by Bonino, Ciaramella & Corno (2010), and arranged them into:

1. Patent search: The objective of retrieving relevant patent information is to reduce the risk of infringing others' existing patents when filing a new patent application. Methodologies like semantic patent maps using multi-dimensional scaling can help visualize similarities between a firm's patent application and other granted patents, minimizing the risk of infringement. This activity is important for firms converting a new technology into product applications.

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2. Patent analysis: Patent analysis is a broad activity that can involve a single patent or a portfolio and can serve different goals. It can be used for business purposes, such as estimating patent or portfolio value for licensing deals, mergers, and acquisitions. It can also be used for technical purposes, to understand the connections among patents in a technological domain or the inner characteristics of a specific technical solution.
3. Patent monitoring: An intelligence activity that involves tracking the technological landscape and competitors' innovation behavior to assess evolving technological trends and identify their technological profiles.

As mentioned above, patent data is a valuable resource for a variety of studies, as it provides insights into the state of innovation and technological development in various industries and regions, such as technology assessment, technological prospecting, innovation analysis, technologies trajectories mapping and others (Marmor, Lawson & Terapane, 1979; Kim & Bae, 2017; Zhang et al., 2021). Patent data can be used to identify emerging trends and technologies, as well as to assess the competitiveness of different industries as a technology assessment (Marmor et al., 1979; Zhang et al., 2021). Zhang et al. (2021) used patent data that are blockchain-related to perform a technology analysis, by dividing the patent data subsets and performing a topic analysis using the LDA topic model, and eventually could identify the existing trends.

Besides, researchers used patent data to examine the technology development and develop a framework that predicts the effectiveness of different regulations based on their ability to promote technological capabilities (Pilkington & Dyerson, 2006). Likewise, patent data is also used for technological prospecting, Rodrigues & Junior (2019) analyzed the worldwide patent documents of carbonization kilns for the

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production of charcoal, and was able to find out some characteristics and understand the advantages for the preparation to adopt new technology in the future.

Patent data also used as technological trajectories mapping, by using main path analysis to trace the citation network of patent data (Liu & Lu, 2012; Hung et al., 2014; Hung et al., 2022; Rajeb et al., 2022). Main path analysis helps to identify the key technological routes that have led to the development of a particular field, and to track the flow of knowledge and ideas over time, the approach can be used to understand the evolution and dynamics of technological systems, and to identify the actors and technologies that are driving innovation in a particular field (Liu & Lu, 2012; Hung et al., 2014; Hung et al., 2022; Rajeb et al., 2022). In the process of using patent data in mapping technology trajectories, researchers start by collecting patent data from a specific field, then construct a citation network by analyzing the citations within the patent data, and use main path analysis to identify the key technological routes within the network (Liu & Lu, 2012; Hung et al., 2014; Hung et al., 2022; Rajeb et al., 2022). Using the main paths as a guide, researchers can map the trajectory of technology development within the field, they can identify the emergence of new technologies, the evolution of existing technologies, and the key actors that have driven innovation within the field (Liu & Lu, 2012; Hung et al., 2014; Hung et al., 2022; Rajeb et al., 2022).

In our study, we are using patent data as a tool to map the CCMT, by using main path analysis, since patent data provides a valuable resource for understanding technological trajectories and can be a useful tool for companies, researchers, and policymakers to inform decision-making and strategic planning.

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2.3.2 Originality and Generality

Originality and generality first suggested by Trajtenberg, Henderson & Jaffe, (1997), according to Shih, Liu & Hsu (2010), originality is a measure of a patent's level of innovation, and a higher value of originality corresponds to greater innovation value of a patent, also means that the patent cites previous patents that belong to a wide variety of fields of technologies. Originality could be used to analyze the aspect of convergence, the combination of diverse emerging technologies (Lee & Lee, 2021). The idea behind originality is that patents are considered more original when they are based on a wider range of technological knowledge (Lee & Lee, 2021). In other words, the broader the technological foundation of the knowledge underlying a patent, the higher its level of originality (Lee & Lee, 2021).

Generality, on the other hand, is a measure of the scope of cross-field applications of a patent and a higher value of generality corresponds to a greater economic value of a patent (Shih et al., 2010; Lee & Lee, 2021), this means that a patent is considered to have higher generality when it is cited in several different technological fields. The higher the generality is, the wider the patent is citing, and in other words, it represents that the impacts of the patent are on wider fields of technologies. It would be beneficial to identify stages according to an exact indicator and also the roles of each assignee on the main path, which haven't been done by previous researchers.

Originality and generality have been used in different kinds of research, in different fields. Lee & Lee (2021) used generality and originality to find out that technology is highly dependent on scientific knowledge and involves combining insights from a wide range of fields, which leads to greater originality but longer development cycles; however, the impact of these technologies may be less diverse, with lower generality, not just in a few specific areas associated with the Fourth

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Industrial Revolution (4IR), but across various technological domains. Lee (2021) used originality, generality, along with longevity, to compare the levels of international technological competitiveness and rank them accordingly; they found out that industries with higher originality and generality are more competitive in technological innovation.

As the description of the characteristic of convergence and divergence stage above, in this paper, we found out that we could use generality and originality as an indicator of measuring the convergent-divergent juncture. Kim & Shin (2018) stated to use generality to analyze the technology juncture, which is a starting point of a new derivative path, divergence. The higher generality of a patent indicated that the patent cited by patents that spread over several technological fields (Shih et al, 2010; Kim & Shin, 2018), which indicated the characteristic during the innovation phase and spin-off phase of divergence, which will spin off to new technologies (Roco, 2016). For convergence, it is the merging of different markets (Borés, Saurina & Torres, 2003; Roco, 2016), and contains the creative synthesis (Roco, 2016), therefore it is compatible with originality which have a meaning of measuring the innovation of a patent, the higher the value of a patent's originality, the greater the patent's innovation value (Shih et al., 2010).

Table 1. Relationship of each phases in convergent-divergent cycle and the generality and originality

Stage	Convergence		Divergence	
Phase	Phase A: Creative Phase	Phase B: Integration/ Fusion Phase	Phase C: Innovation Phase	Phase D: Spin-off Phase
Generality	Low	Lowest	High	Highest
Originality	High	Highest	Low	Lowest

Based on the above, we arranged a table to show the relation between the convergent-divergent phase and the indicators: generality and originality. During

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convergence stage, different ideas and knowledges started to combine during the creative phase (Roco, 2016), and infer to have high originality, but to have low generality; while in the integration/ fusion phase, ideas are integrated into new products, innovations and invention (Roco, 2016) so that in this specific stage will have the highest originality, but since it focusses in integration into innovations, it will also be predicted to have lowest generality. During the divergence stage, in the innovation phase, new innovations have been brought into market (Roco, 2016), predicted to have high generality and low originality. Lastly, in the spin-off phase, where the innovation goes to new different areas, and having a new derivative path (Roco, 2016; Kim & Shin, 2018), which should have the highest generality and the lowest originality.

At the corporate level, Roco (2016) used figure 3 to illustrate the same four phases that one firm will go through, it also includes the four phases: creative phase, integration/ fusion phase, innovation phase and spin-off phase. According to Roco (2016), the convergence stage involves the integration of different ideas and knowledge resulting in high originality but low generality, while the integration/fusion phase has the highest originality but low generality since it focuses on incorporating ideas into new products and innovations; during the divergence stage, the innovation phase brings new opportunities into the market with high generality and low originality, and finally, the spin-off phase involves the innovation going into new areas resulting in the highest generality and lowest originality.

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2.3.3 Talents in technology Convergent-divergent Phases

Talent plays a huge role in the development of technology, and also in organization. Researchers identified talents or so-called stars by analyzing the popularity index, if an inventor's popularity index is within the top 2% of all inventors, they are regarded as a star designer during the time of evaluation (Liu et al., 2018). Liu et al. (2018) differentiate stars and nonstars as stars are individuals who are highly skilled and also well-known in the field compared to nonstars. The more the researchers looked into, it was discovered that working together with a star inventor resulted in more exceptional creative outcomes and an increased probability of achieving stardom, however, this also posed the risk of adverse effects such as being overshadowed by the said star (Liu et al., 2018).

Hung, Lai, & Liu (2022) only focus on top 12 assignees when doing the cross-citation network analysis, they use two criterias which are sample size and market share. Therefore, researchers treated these 12 assignees as the most influential talent in the market, and found out that they each play different roles in the industry (Hung et al., 2022). Hung, Lai, & Liu (2022) rated the corporation that owned the greatest number of patents as a rising star in the printer industry, and stated that it has been considered as a key innovation both traditional and new innovations. When investigating the relations between these inventors, Hung, Lai, & Liu (2022) named them as knowledge absorber and knowledge creators as they have knowledge flows between them.

In this paper, we recognize talent on the main path as key talent, as the main path highlighted the most significant links of the field (Hung et al., 2014), therefore the talents appeared on the main path are called talent-on-the-main-path, and those are not on it are talent-off-the-main-path.

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Chapter 3: Methodology

3.1 Research Steps

Our research process is shown in Figure 4, including data collection, key route main path analysis to process main path, differentiate stages and calculate the collaboration

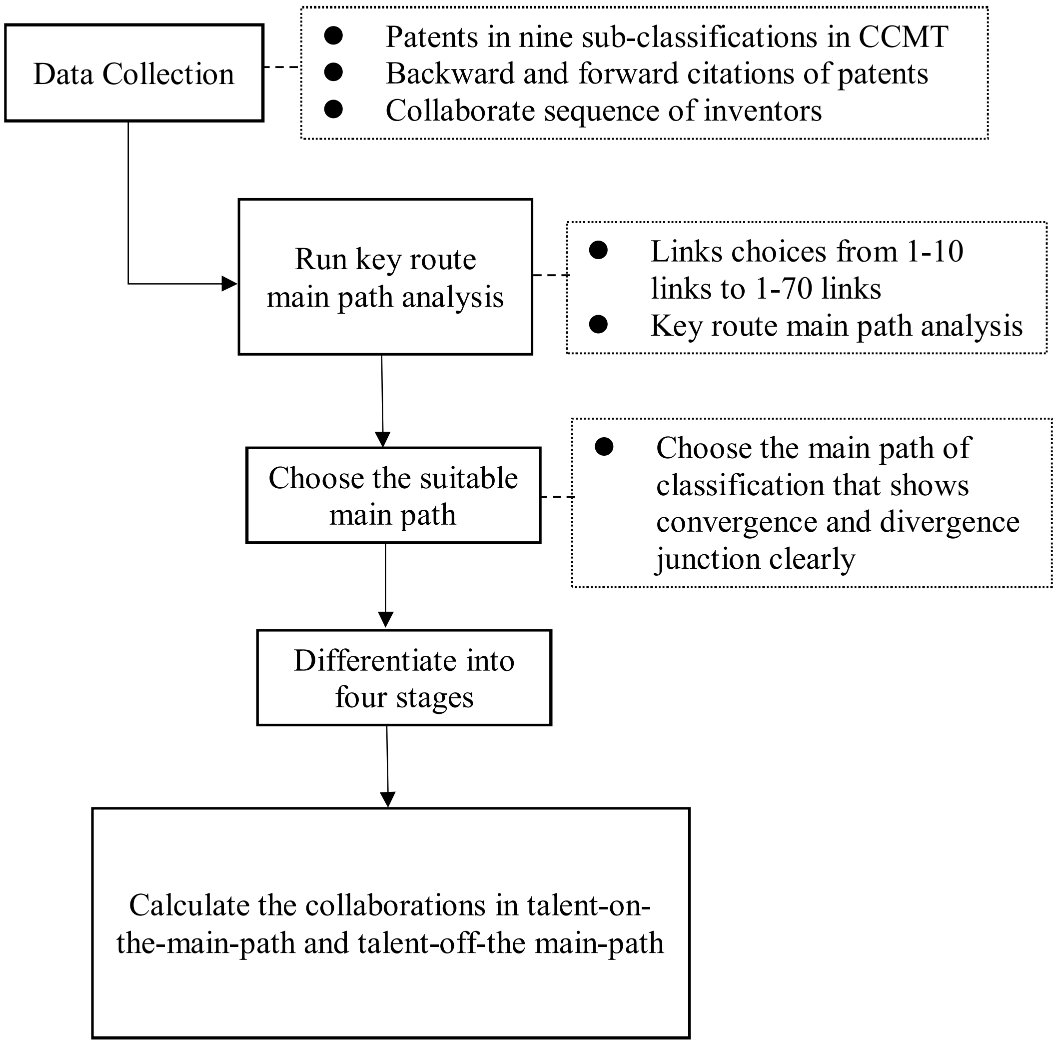

Figure 4. Research steps of the research

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3.2 Data Collection

In this section of the paper, we outline the approach used to collect and analyze data, as well as the tools employed in the analysis. It covers three main areas: data collection, Patentometricss, and key-route main path analysis in Pajek. The chapter explains how patent classification and the Y02 scheme were used to collect data, which was then analyzed using Patentometrics techniques to uncover trends and patterns in the citation network. Finally, the chapter details how the key-route main path analysis was conducted in Pajek, a network analysis software, to identify the most significant citation links and main research trajectories.

3.2.1 CCMT Patent Collection

There are several different types of patent classification systems, including the International Patent Classification (IPC), the United States Patent Classification (USPC), and the European Patent Classification (EPC). Each of these systems classifies patents into unique categories based on the subject matter of the patented invention. The IPC system is the most commonly used classification system and is used by patent examiners around the world. The USPC and EPC systems are primarily used in their respective regions.

The patent classification we are using is the Cooperative Patent Classification (CPC). The European Patent Office (EPO) and the United States Patent and Trademark Office (USPTO) launched the Cooperative Patent Classification (CPC) System. The CPC is the result of a collaboration between the EPO and the USPTO to develop a common, internationally compatible classification system for technical documents, specifically patent publications, that will be used by both offices in the patent granting process.

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In the Cooperative Patent Classification of USPTO, there are nine different classifications: A, B, C, D, E, F, G, H and Y, which stands for human necessities, performing operations; transporting, chemistry; metallurgy, textiles; paper, fixed constructions, mechanical engineering; lighting; heating; weapons; blasting, physics, electricity and general tagging of new technological developments. In 2012, a study on Patents and Clean Energy was conducted by the European Patent Office (EPO) in collaboration with the United Nations Environmental Program (UNEP) and the International Centre on Trade and Sustainable Development (ICTSD), and resulted in the creation of the Y02 patent classification to organize its findings (Veefkind et al., 2012). From the classification resources of USPTO (USPTO, 2023), we could get a Cooperative Patent Classification and its definition as below:

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Table 2. Cooperative Patent Classification

CPC (Cooperative Patent Classification)	Definition
Y	Cooperative Patent Classification: General Tagging of New Technological Developments; General Tagging of Cross-Sectional Technologies Spanning over Several Sections of the International Patent Classification; Technical Subjects Covered by Former United States Patent Classification Cross-Reference Art Collections and Digests.
Y02	Technologies or Applications for Mitigation or Adaptation Against Climate Change
Y02A	Technologies for Adaptation to Climate Change
Y02B	Technologies for Mitigation of Climate Change Related to Buildings, such as Housing, House Appliances, and Related End-User Applications
Y02C	Capture, Storage, Sequestration or Disposal of Greenhouse Gases
Y02D	Climate Change Mitigation Technologies in Information and Communication Technologies
Y02E	Reduction of Greenhouse Gas Emissions, Related to Energy Generation, Transmission or Distribution
Y02P	Climate Change Mitigation Technologies in the Production or Processing of Goods
Y02T	Climate Change Mitigation Technologies Related to Transportation
Y02W	Climate Change Mitigation Technologies Related to Wastewater Treatment or Waste Management

We retrieved our patent data from USPTO, as USPTO is a valuable resource provides access to a vast database of patents and patent applications. It offers various search tools and resources that enable users to conduct patent searches and retrieve

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relevant information. The USPTO provides powerful search functionalities that allow users to perform full-text searches across patent titles, abstracts, claims, and descriptions (USPTO,2023). The USPTO employs a classification system called the United States Patent Classification (USPC) and later the Cooperative Patent Classification (CPC) system, which organizes patents into specific technology areas. These classification systems help in narrowing down searches to specific technology domains (USPTO,2023).

For the patent search strategy, we first use Y02 series of patent as our classification text search. We follow the patent search strategy given by USPTO, which contain several steps (USPTO, 2023):

1. Step one: Having an accurate description of the inventions.
   In our case, as we mentioned above, we have eight CPCs in Y02, which are Y02A, Y02B, Y02C, Y02D, Y02E, Y02P, Y02T and Y02W.
2. Step two: Access and Review CPC schema.
   From classification resources in USPTO, we use the classification of CPC directly, since we want to search for the patents of CCMT.
3. Step three: Review classification definition.
   We get the result from the classification and review the patents in the certain CPC, to make sure it is belonging to the certain CPC.
4. Step four: Retrieve and review patents
   For each CPC, we retrieved different numbers of patents. For Y02A, we’ve got 26119 patents; for Y02B, we’ve got 34374 patents; for Y02C, we’ve got 4118 patents; for Y02D, we’ve got 41800 patents; for Y02E, we’ve got 105913 patents; for Y02P, we’ve got 55238 patents; for Y02T, we’ve got 72610 patents; for Y02W, we’ve got 8243 patents.

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3.2.2 Patent Citation Pair Output and the Authority Control Processing

A patent citation pair output typically consists of two pieces of information: the citing patent and the cited patent. The citing patent is the patent that is referencing or citing another patent. It is usually the more recent of the two patents, as it is citing an older patent as prior art. The citing patent is often referred to as the "forward citation". The cited patent is the patent that is being referenced or cited by another patent. It is usually the older of the two patents, as it is being cited as prior art by a more recent patent. The cited patent is often referred to as the "backward citation". Together, the citing patent and the cited patent form a citation pair, which is a key piece of information for patent analysis. By analyzing citation pairs, researchers can identify patterns in the way patents are cited and build networks of related patents.

To run the key-route main path, we need the patent citation relations to form the network and understand the knowledge flow. Patent citation pair is extracted from the patent database. A patent citation pair indicates that technological knowledge is diffusing from the cited patent to the citing patent (Qiao, Huang, Wu, Wu & Zhang, 2014). Each patent citation pair is sorted according to the patent classification under Y02, following by each CPC, containing Y02A, Y02B, Y02C, Y02D, Y02E, Y02P, Y02T and Y02W.

Nonetheless, authority control is the process of ensuring that the names and other identifying information associated with inventors and assignees in patent data are accurate, consistent, and standardized. The purpose of authority control is to help users of patent data to find and retrieve relevant patents more easily. The authority control process involves identifying all of the different names and variations of names associated with a particular inventor or assignee, and then choosing a standardized form of the name to use in the patent database. This may involve verifying the identity of the

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inventor or assignee, checking for name changes or aliases, and using external sources such as corporate registries or biographical databases to gather additional information.

Once a standardized form of the name has been chosen, it is added to a master authority file, which is used to ensure consistency across all of the patents in the database. This helps to prevent errors or inconsistencies that could make it difficult for users to find the patents they are looking for. Overall, authority control is an important part of managing patent data, as it helps to ensure that the data is accurate, consistent, and easy to use.

3.3 Key-Route Main Path Analysis

Traditional methods of searching for main paths, whether they involve local or global search, have a drawback in that the link with the highest traversal count may not necessarily be included in the main paths (Liu & Lu, 2012). To overcome this limitation, the key-route search approach is employed to map technological trajectories (Hung et al., 2022). This approach is a more sophisticated version of the main path method and has been widely studied and applied (Liu & Lu, 2012; Xu et al., 2020; Hung et al., 2022).

The key-route search approach begins by selecting a seed link, typically the highest-ranked link (Xu et al., 2020; Hung et al., 2022). From there, a forward search is conducted from the head node of the key-route, as well as a backward search from the tail node (Hung et al., 2022). To examine citation chains of secondary significance, one can choose multiple seed links, including several top links (Hung et al., 2022). After repeating the forward and backward search for all selected links, the key-route main paths are generated by combining the results of all searches (Liu & Lu,2012; Hung et al., 2022). For instance, the key-route main paths for the top 10 links are identified by

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conducting forward and backward searches from those links (Liu & Lu,2012; Hung et al., 2022). Because key-route main paths are an extension of the pre-selected top links, they are guaranteed to be included in the main paths (Xu et al., 2020; Hung et al., 2022).

The number of top links to be used in practice depends on the objectives of the analysis of the citation network (Hung et al., 2022). For the purpose of analyzing and mapping divergence-convergence knowledge flow in this study, neither a small number nor a very large number of top links is suitable. Using a small number of top links would lead to an oversimplified representation of the citation network, while using a very large number would obscure the main underlying structure (Chen, Zhang & Fu, 2019; Hung et al., 2022). As shown in Figure 4, it is a key-route main path of Y02C, with a rank number of key-route 1-20, mapping by using the software Pajek, but the divergent-convergent juncture is not that obvious. Therefore, we consider more key-routes to see if a divergence–convergence pattern emerges (Hung et al., 2022). In Figure 5, we could see that as we increase the rank number to 1-30, the pattern is still not obvious, but in Figure 7 with 1-50 key route rank number the juncture blurred out due to there are too many intersections. In conclusion, Figure 6 has the clearest juncture showing convergence and divergence.

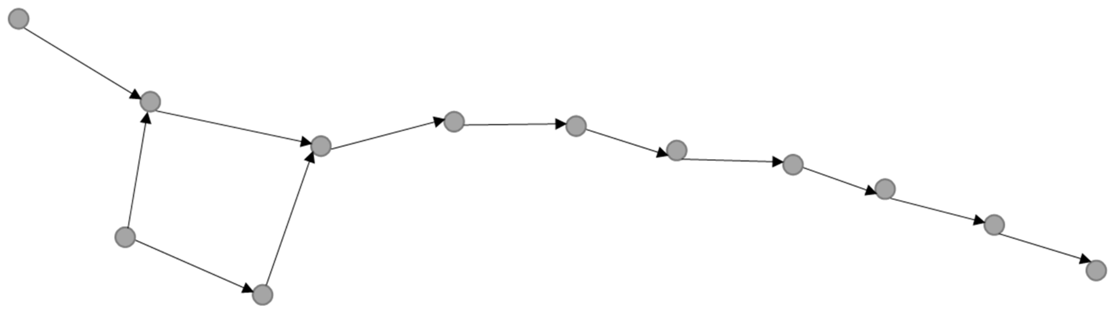

Figure 5. Key-route main path of Capture, Storage, Sequestration or Disposal of Greenhouse Gases (Y02C)_1

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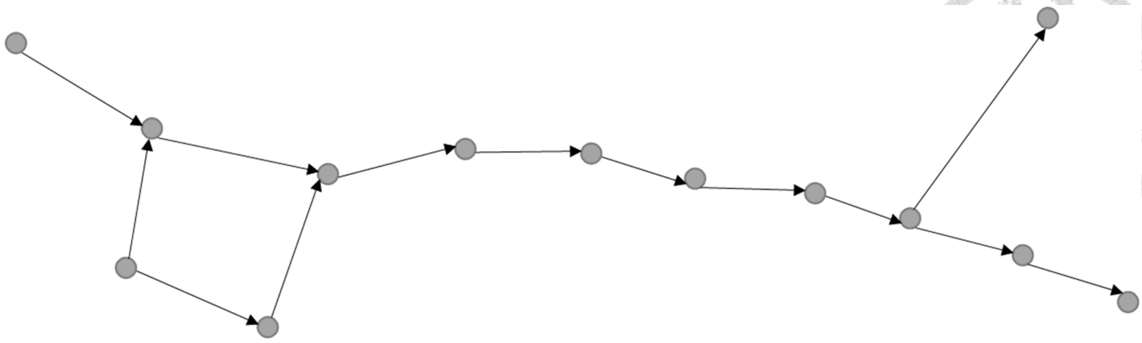

Figure 6. Key-route main path of Capture, Storage, Sequestration or Disposal of Greenhouse Gases (Y02C)_2

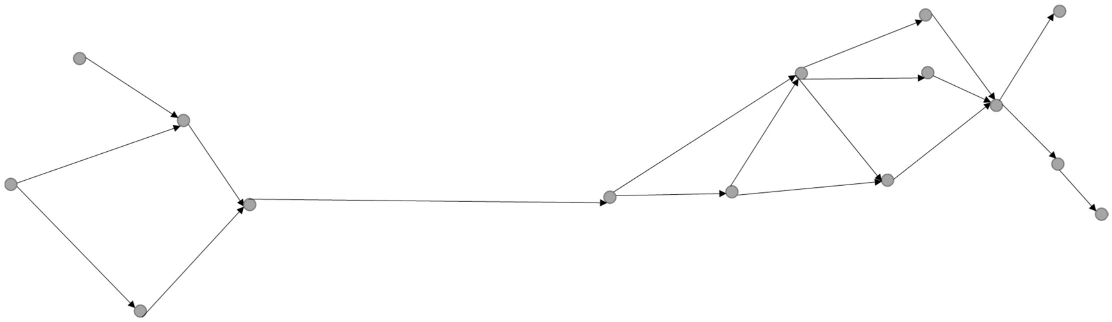

Figure 7. Key-route main path of Capture, Storage, Sequestration or Disposal of Greenhouse Gases (Y02C)_3

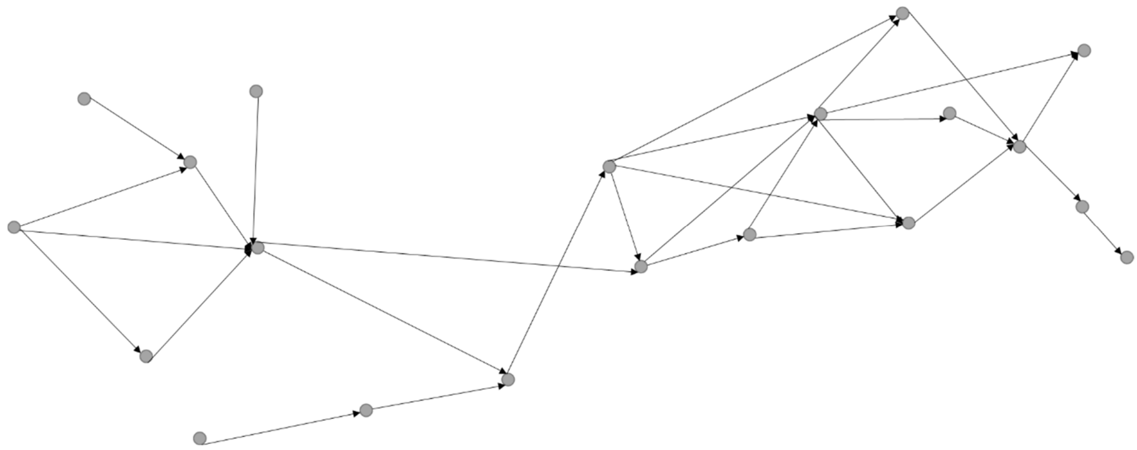

Figure 8. Key-route main path of Capture, Storage, Sequestration or Disposal of Greenhouse Gases (Y02C)_4

According to previous studies, when they tried different ranking of paths (Chen, Zhang & Fu, 2019; Hung et al., 2022), we first generated key-route paths from the top 10, 20, 30, 40, 50, 60 and 70 links based on their SPLC values. Take figure 4, 5, 6 and 7 as examples, we observe that the citation links ranked 40 exhibit clear patterns of

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divergence and convergence. As we increase the number of top links, less significant citation links gradually blur the pattern. Consequently, we decide to focus our analysis on the key-route main paths based on the top 1-40 links, which yields distinct research trajectories that comprise essential nodes and arrows. This applied to all of the key-route main path ranking choices in our studies.

While differentiating the phases in the main path, Figure 2 shows us most of the researchers differentiate it by the way the path intersects and departs, but there is no exact rule or way to differentiate it. In this paper we will differentiate it by their generality score and originality. Given that in table one, we have the generality and originality score level predicted, we will differentiate the four phases in the main path according to the score level relatively.

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3.4 Originality and Generality Indicators

After seeing the clear junctions of divergence-convergence, we are going to differentiate four phases in the main path, that mentioned by Roco (2016): creative phase, innovation/ fusion phase, innovation phase and spin-off phase. According to table 1 that arranged the relative generality and originality that we were supposed to find in each junction of the main path, we used the two measurements as indicators. Hall, Jaffe & Trajtenberg (2001) and Shin et al. (2010) listed out two equations to measure originality and generality as below:

(1) Originality

Originality= $1 - \sum_{j}^{n_i} S_{ij}^2$

$$S_{ij} = \frac{Number\ of\ cited\ patents\ belonging\ to\ Class\ j}{Number\ of\ backward\ citation}$$

n_i : Number of class

(2) Generality

Generality= $1 - \sum_{j}^{n_i} F_{ij}^2$

$$F_{ij} = \frac{Number\ of\ citing\ patents\ belonging\ to\ Class\ j}{Number\ of\ forward\ citation}$$

n_i : Number of class

Shih et al. (2010) propose that originality can be used as an indicator of the level of innovation of a patent; as a higher value of originality suggests a greater level of innovation of the patent. In contrast, generality is used as a measure of the extent of cross-disciplinary applications of a patent (Shih et al., 2010; Lee & Lee, 2021). A higher value of generality corresponds to a higher economic value of the patent, as it is

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cited in several different technological fields (Lee & Lee, 2021). Therefore, patents that are cited in a wider range of fields are considered to have higher generality.

Hung et al. (2014) illustrated the pattern that would appear in divergent-convergent junction, in divergence stage the knowledge flow will depart into multiple flows, while in convergence stage, multiple flow will intersect into one. By following this certain pattern and the relative value of originality and generality, we could separate each divergence-convergence pattern in the main path into four phases, to achieve our first purpose.

At the corporate level, one firm will have relative differences in originality and generality due to the different stage the firm is in. We investigate each firm that appears on the main path, their patents' originality and generality in that specific time frame. If the firms' originality and generality rate is as predicted in Table 1, in the first stage of convergence, the creative phase, multiple tools and methods are getting integrated and predicted to have a high originality but a low generality. In the next stage of convergence, the integration/ fusion phase, integrated knowledge has been incorporated into new designs or inventions, therefore, it has been predicted to have the highest originality since creativity is on peak, and the lowest generality. Thus, in the innovation phase of divergence, leading by the spiral of innovation, the firm will start to have a high generality and lower originality, followed by new product and business opportunities. Lastly, in the spin-off phase of divergence, immergence with other technologies happened, so that in this phase, the generality is the highest while the originality is the lowest.

To calculate the originality and generality, this study collects the backward citation and forward citation of each patent. This study used the third sequence of each backward citation and forward citation. By using the third sequence of the citation, we

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could filter out the count the originality, we used the backward citation of each patent, thus, for generality we used the forward citation.

3.5 Talent Collaboration Analysis

Given that researchers stated that by collaborating with a star/ key talent, one will have higher possibilities of becoming a star themselves. As the main path features the most significant innovation, the talents on the main path are key talents themselves. Therefore, we want to investigate in both phases in the convergence-divergence phase to see whether the talent that appears in the later phase, Phase B, has or has not appeared in the previous phase, phase A before.

In this study, inventor in a patent is the talent that we are going to observe. For the collaboration, we count in the co-inventors of the patent as the collaboration. Concurrently, we recognize the significance of collaboration in the patent development process, and to understand this aspect, we consider the involvement of co-inventors. By exploring the inventive capacity of individual inventors and analyzing collaborative dynamics, we aim to gain comprehensive insights into the interplay between talent and teamwork in the realm of patent innovation. By investigating the talent-on-the-main-path that was a non-main-path talent, we could find out whether it is true that a talent could help others to become a talent. First, we will find out the assignee on the main path during Phase B that was not on the main path during Phase A, and investigate whether it has been collaborating with talent on the main path before. For example, according to Liu et al. (2018) that a star will lead a non-star into a rising star by collaborating with them, supposedly in Phase A, Talent A was a non-main-path talent, that was not a key talent that appeared on the main path, but it had co-inventorship with

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a talent-on-the-main-path; and eventually, in Phase B, Talent A rise to be a talent-on-the-main-path.

We want to investigate in later phase when collaborations happened, as shown in the Table 3. talent becomes talent-on-the-main-path. We have three groups of talent type:

1. Talent-on-the-main-path collaborates with talent-on-the-main-path, and become talent-on-the-main-path in the next phase.
2. Talent-off-the-main-path collaborates with talent-on-the-main-path, and become talent-on-the-main-path in the next phase.
3. Talent-off-the-main-path collaborates with talent-off-the-main-path, and become talent-on-the-main-path in the next phase.
4. Talent-off-the-main-path collaborates with talent-on-the-main-path, and become talent-on-the-main-path in the next phase.
5. Not appeared in earlier stage but become a talent-on-the-main-path in the next phase

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Table 3. Talent-on-the-path and talent-off-the-path in each stage

Early Stage	Collaboration Type		Later Stage	Status of Talent B
	Talent A	Talent B		
Stage 1	Talent-on-the-main-path	Talent-on-the-main-path	**Stage 2**	Talent-on-the-main-path
Stage 1	Talent-on-the-main-path	Talent-off-the-main-path	**Stage 2**	Talent-on-the-main-path
Stage 1	Talent-off-the-main-path	Talent-off-the-main-path	**Stage 2**	Talent-on-the-main-path
Stage 1	Talent-off-the-main-path	Talent-on-the-main-path	**Stage 2**	Talent-on-the-main-path
Stage 1	Not appeared	Not appeared	**Stage 2**	Talent-on-the-main-path
Stage 2	Talent-on-the-main-path	Talent-on-the-main-path	**Stage 3**	Talent-on-the-main-path
Stage 2	Talent-on-the-main-path	Talent-off-the-main-path	**Stage 3**	Talent-on-the-main-path
Stage 2	Talent-off-the-main-path	Talent-off-the-main-path	**Stage 3**	Talent-on-the-main-path
Stage 2	Talent-off-the-main-path	Talent-on-the-main-path	**Stage 3**	Talent-on-the-main-path
Stage 2	Not appeared	Not appeared	**Stage 3**	Talent-on-the-main-path
Stage 3	Talent-on-the-main-path	Talent-on-the-main-path	**Stage 4**	Talent-on-the-main-path
Stage 3	Talent-on-the-main-path	Talent-off-the-main-path	**Stage 4**	Talent-on-the-main-path
Stage 3	Talent-off-the-main-path	Talent-off-the-main-path	**Stage 4**	Talent-on-the-main-path
Stage 3	Talent-off-the-main-path	Talent-on-the-main-path	**Stage 4**	Talent-on-the-main-path
Stage 3	Not appeared	Not appeared	**Stage 4**	Talent-on-the-main-path

Through the differentiation of the three groups: technologies for mitigation of climate change related to buildings, such as housing, house appliances, and related end-user applications (Y02B), the main path of capture, storage, sequestration or disposal of greenhouse gases (Y02C), and climate change mitigation technologies in information and communication technologies (Y02D), our aim is to investigate the proportions of each group within various pairs of talent collaborations. Specifically, we seek to examine the transition of non-main-path talents to talent-on-the-main-path status after

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collaborating with talents already situated on the main path. To accomplish this, we will determine the proportions of each group appearing in different stages and compare them.

By analyzing the collaboration data, this study will calculate the proportions of each group present at each stage of the main path. This analysis will shed light on the likelihood of non-main-path talents transitioning to the talent-on-the-main-path category following collaborative interactions. Comparing the proportions of the different groups will enable us to discern any significant differences in their prevalence within each stage.

Furthermore, this study aims to investigate the relationship between the different stages and each group of collaborations. To achieve this, we will employ the Chi-square test of Karl Pearson, a statistical test used to examine associations between categorical variables. By applying this test across the stages and the groups, we can assess whether there is a significant relationship between the stages of the main path and the composition of collaboration groups. The formula to compute the statistic is as below (Frankie, Ho & Christie, 2012):

$$x^2 = \sum_{i=1}^{n} \frac{(O_i - E_i)^2}{E_i}$$

n= Number of cells

O= Observed value

E= Expected value

By analyzing the data using the Chi-square test, we will determine whether the distribution of collaboration groups varies significantly across the different stages. This analysis will enable us to explore the potential dependencies or associations between the stages and the composition of the collaboration groups.

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The utilization of the Chi-square test of Karl Pearson provides a rigorous statistical framework to investigate the relationship between the stages of the main path and the groups of collaborations. By evaluating the significance of any observed associations, we can gain valuable insights into the interplay between talent trajectories and collaborative dynamics within each stage of the main path. These findings will contribute to a deeper understanding of the factors influencing talent movements.

To interpret the results of the chi-square test, we need to consider both the observed count and the expected count for each stage and collaboration group. The chi-square test assesses the discrepancy between the observed and expected frequencies, and the resulting test statistic indicates the degree of association or independence between the stages and collaboration groups.

By comparing the observed count with the expected count, we can assess the significance of the association between the stages and collaboration groups within Y02B. A significant chi-square test statistic suggests that there is a non-random relationship between the stages and the distribution of talents among different collaboration groups. Conversely, a non-significant result indicates no significant association or dependency.

Further analysis of the chi-square test results will allow us to gain insights into the nature of the relationship between the stages and collaboration groups within Y02B. These findings will contribute to our understanding of how talent trajectories and collaborative interactions intersect within this specific research context.

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Chapter 4: Result

4.1 Convergence and Divergence in Main Path

This chapter aims to address research question one, which pertains to the differentiation of stages within the main path based on the given year. Additionally, the objective is to establish an efficient methodology for segmenting the main path and gaining a comprehensive understanding of the various stages involved. By accomplishing this, valuable insights can be obtained regarding the progression and characteristics of the stages over time. The outcomes of this investigation will contribute to a deeper comprehension of the main path and its underlying dynamics.

4.1.1 Junctions in Main Path

To ensure the inclusion of main paths with clear indications of convergence and divergence, our research methodology involves selecting paths that exhibit distinct junctions. Paths lacking clear junctions indicating convergence and divergence are not considered for further analysis. Specifically, we focus on main paths that display evident junctions and prioritize those with the clearest indications of convergence and divergence. As previously discussed in the preceding chapter, the 1-40 links demonstrate the highest clarity and the largest number of junctions.

For the subsequent research phase, we investigate the main paths containing 1-40 links within the Y02A, Y02B, Y02C, Y02D, Y02E, Y02P, Y02T, and Y02W categories. Only main paths that exhibit at least five discernible junctions, without complicated intersections, will proceed to the subsequent research stage, where differentiation will be based on the year, originality, and generality. By implementing these selection criteria, we ensure that the main paths considered in the subsequent

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research possess clear junctions, allowing for a more accurate differentiation and analysis of the stages within the chosen main paths.

In Figure 9., we observe that the main path of technologies for adaptation to climate change (Y02A) contains only two junctions. Junction A in technologies for adaptation to climate change (Y02A) indicates convergence, while junction B in technologies for adaptation to climate change (Y02A) represents divergence. However, the presence of only two junctions within the main path does not meet the criteria for further research. Consequently, the main path of technologies for adaptation to climate change (Y02A) will not be included in the subsequent stage differentiation analysis.

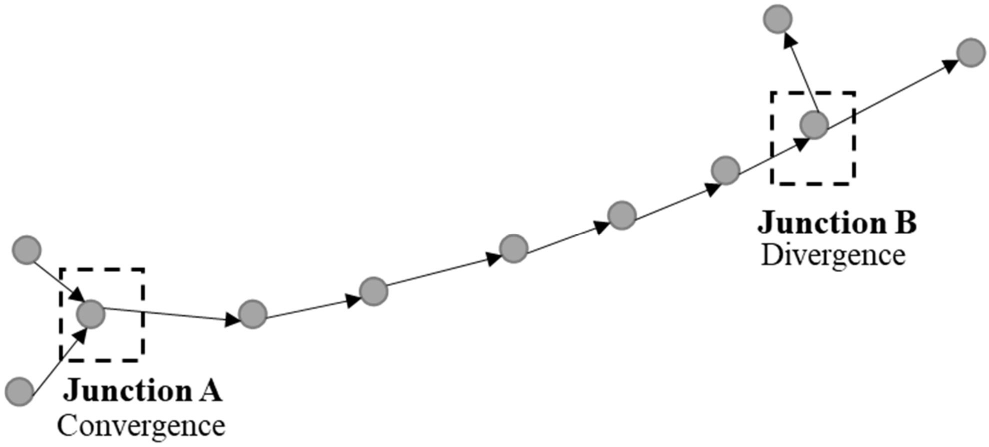

Figure 9. Math path of technologies for adaptation to climate change Y02A

In Figure 10., the main path of technologies for mitigation of climate change related to buildings, such as housing, house appliances, and related end-user applications (Y02B) has four junctions, which is Junction A, Junction C and Junction D which all show convergence, while Junction B shows convergence and divergence happened both in a junction. In the main path of technologies for mitigation of climate change related to buildings, such as housing, house appliances, and related end-user applications (Y02B), continuously, there are convergence and divergence happened,

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therefore, it will proceed to the next stage of the research to differentiate it using originality and generality, also by the year.

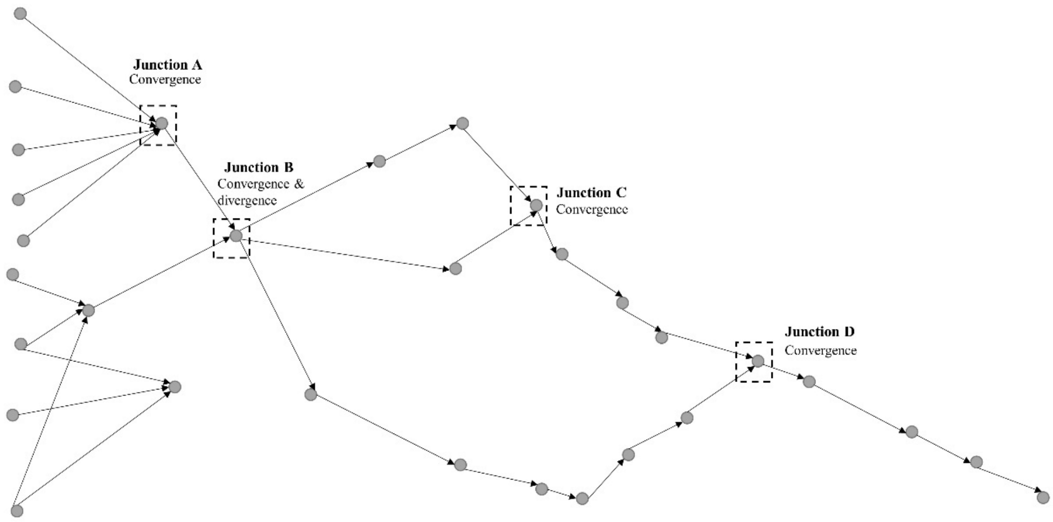

Figure 10. Math path of technologies for mitigation of climate change related to buildings, such as housing, house appliances, and related end-user applications (Y02B)

In Figure 11., the main path of capture, storage, sequestration or disposal of greenhouse gases (Y02C) has two junctions of convergence, two junctions of convergence and divergence, one junction of divergence. The junctions spread evenly among the main path. Therefore, it will proceed to the next stage of the research to differentiate it using originality and generality, also by the year.

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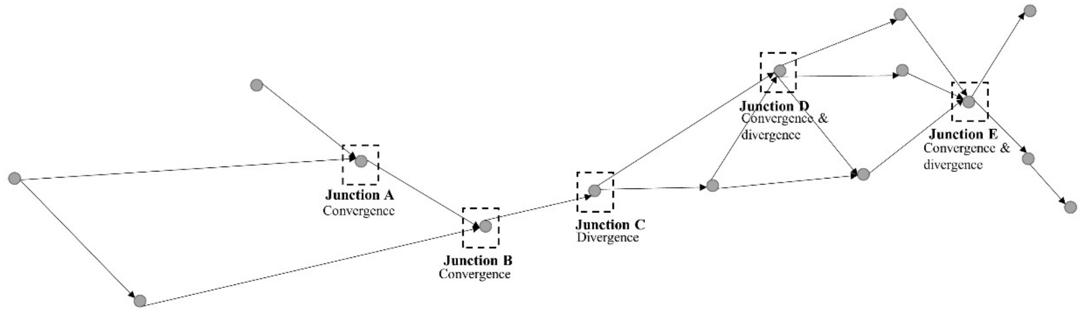

Figure 11. Math path of capture, storage, sequestration or disposal of greenhouse gases (Y02C)

Figure 12. shows the main path of climate change mitigation technologies in information and communication technologies (Y02D), with two junction of convergence and three junctions of convergence and divergence. The junctions spread evenly among the main path, and also contains at least five junctions, so that it could be used in our following research.

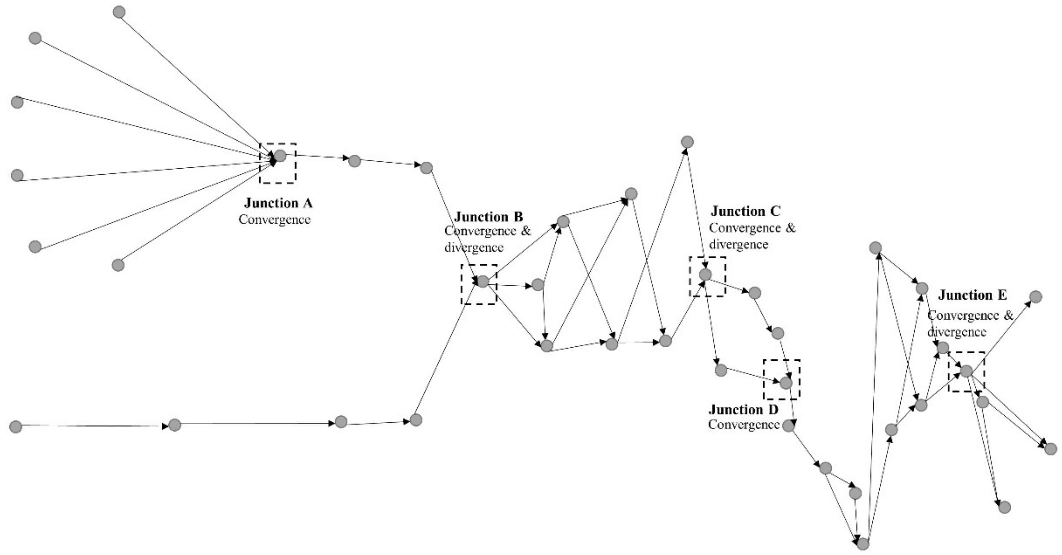

Figure 12. Math path of climate change mitigation technologies in information and communication technologies (Y02D)

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Figure 13. shows the main path of reduction of greenhouse gas emissions, related to energy generation, transmission or distribution (Y02E), with only one junction of convergence, and no clue of other junction in the following junction. Consequently, we will not use it in following research.

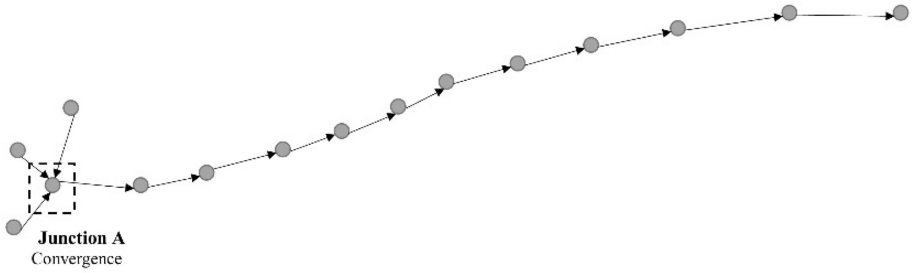

Figure 13. Math path of reduction of greenhouse gas emissions, related to energy generation, transmission or distribution (Y02E)

Figure 14. is the main path of climate change mitigation technologies in the production or processing of goods (Y02P), contains three chains of main path. Even though there is plenty of junctions in the main path, but part A in the main path has too many patents that blurred out the main path, and it has only three junctions. Thus, we will not use it in following research.

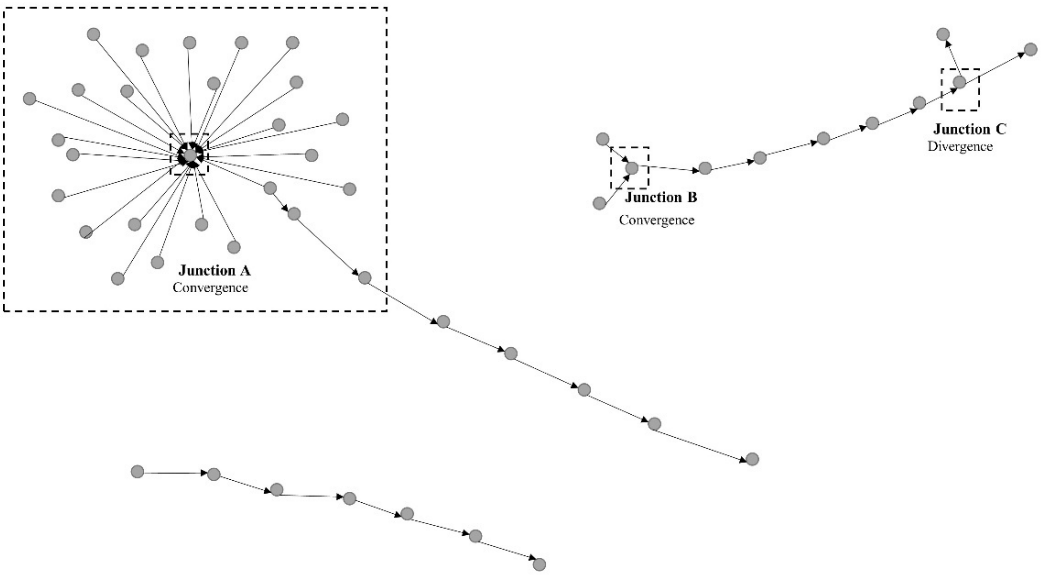

Figure 14. Math path of main path of climate change mitigation technologies in the production or processing of goods (Y02P)

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Figure 15. shows the main path of climate change mitigation technologies related to transportation (Y02T), which has a complicated intersecting junction in the beginning of the main path, the intersecting junctions blurred out the convergence and divergence of the main path. Although there are a few of convergence and divergence happening afterwards, but we will not take it to the next stage due to its complication. Figure 16. shows the main path of climate change mitigation technologies related to wastewater treatment or waste management (Y02W), which contains no junction, therefore, we will not take it to the next stage as well.

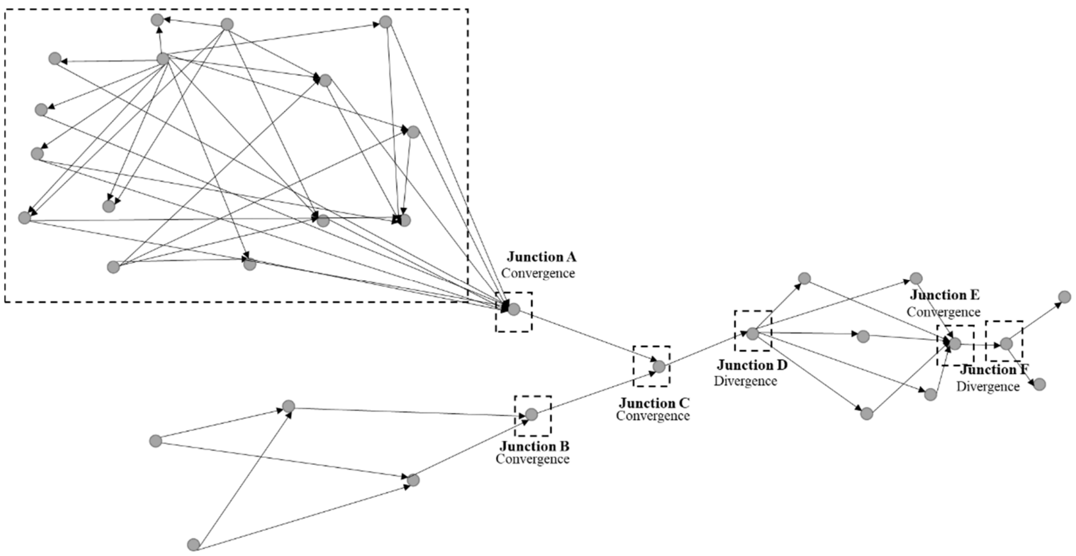

Figure 15. Math path of climate change mitigation technologies related to transportation (Y02T)

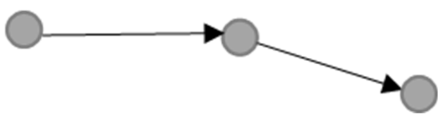

Figure 16. Math path of climate change mitigation technologies related to wastewater treatment or waste management (Y02W)

Overall, in all the main path of the Y02, technologies for mitigation of climate change related to buildings, such as housing, house appliances, and related end-user

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applications (Y02B), the main path of capture, storage, sequestration or disposal of greenhouse gases (Y02C), and climate change mitigation technologies in information and communication technologies (Y02D), have at least five junctions appeared and also have a clear main path to observe the divergence and convergence in the main path.

4.1.2 Stages in Main Path

In order to enhance the differentiation of stages within the main path, our approach involves measuring the generality and originality, which serve as indicators of innovation and cross-field measurement. This chapter focuses on assessing the generality and originality within the technologies for mitigation of climate change related to buildings, such as housing, house appliances, and related end-user applications (Y02B), capture, storage, sequestration or disposal of greenhouse gases (Y02C), and climate change mitigation technologies in information and communication technologies (Y02D) categories.

Table 4 presents the publication years, originality scores, and generality scores of technologies for mitigation of climate change related to buildings, such as housing, house appliances, and related end-user applications (Y02B), while Figure 17 displays the originality and generality trends along the main path. The main path spans a duration of 17 years, commencing with patents from 2003 and concluding with patents from 2019. Considering the originality and generality along the main path, the initial nodes are excluded from analysis due to the unavailability of preceding data. Within the main path, excluding the junctions formed by the initial nodes, three distinct junctions are observed. During these junctions, there is a rise and subsequent decline in generality, accompanied by an increase in originality. Notably, the patterns of originality and generality coincide at the occurrence of each junction. We could see that

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during the first junction 7155870, the patent before it: 6875914 and 6809251 both shown a decline of originality with an increase in originality. While the second junction 8122648, the junction before could see a rise of generality from 7155870 to 7762027, but there is a decrease of generality from 7905064 to the junction 8122648. For originality, we could observe a rise from 7762027 steadily to the junction 8122648. And the same happened to the other junctions, before the junction 8938932, we could see a rise in generality from 8272174 to 8448405, from 0.5708 to 0.8016, and after that the generality decrease from 8448405 to 8701354, from 0.8016 to 0.6981 and eventually become lower to 0.5623 when it meets the junction. For originality we could also see a rise from the patent before the junction.

In conclusion, in mitigation of climate change related to buildings (Y02B), we could see a similar pattern which is in generality, it rises and decline when meets the junction, and for originality, it rises steadily. This study could observe that when meeting a junction, the generality of mitigation of climate change related to buildings (Y02B) show an increase and then decrease when it reaches the junction of convergence or divergence, while the originality of mitigation of climate change related to buildings (Y02B) will continually rise until reaching the junction of convergence or divergence. Therefore, four stages are being differentiate by each pattern happens, after the junction that show a series of pattern to ensure the differentiation of the stage.

Regarding the initial nodes, the technologies for mitigation of climate change related to buildings (Y02B) had the first convergence and divergence node at 2007, with the patent 7155870. The patent 7155870 was applied by applicant Powerlight Corp. with the inventor Charles Almy, and the patent is about a shingle system. The second convergence junction happened in 2012, which is the patent 8122648 that being converged. This patent was being applied and invented by Jun Liu, and it is a system for

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mounting equipment such as solar panels. The last junction of convergence is 8938932, which was applied by Quality Product LLC, and invented by Stuart Wentworth and Claudia Wentworth. The invention is also a mounting equipment for roof. The three junctions that could differentiate the stages are formed by patent that is shingle system and the other two is both mounting equipment. Therefore, we could understand that the mounting equipment is the key technology out of the technologies for mitigation of climate change related to buildings (Y02B).

The consistent occurrence of this regular pattern during junctions enables the distinction of stages within the main path. Consequently, we identify four stages characterized by the time periods: 2003-2007, 2008-2012, 2013-2015, and 2016-2019. This systematic approach allows for a more nuanced understanding of the progression along the main path, facilitating a comprehensive analysis of the differentiated stages.

In relation to the main path of capture, storage, sequestration or disposal of greenhouse gases (Y02C), Table 5. provides an overview of the publication years, originality scores, and generality scores of the corresponding patents, while Figure 18. depicts the trends in originality and generality along the main path. However, upon closer examination, it became evident that the originality and generality scores of the main path in Y02C did not exhibit a discernible or consistent pattern. Given the absence of a specific pattern in the originality and generality scores, an alternative approach was employed to differentiate the main path based on the presence of junctions. Consequently, the main path in Y02C was divided into distinct time periods: 2005-2010, 2011-2012, 2014-2016, and 2018.

In the main path of capture, storage, sequestration or disposal of greenhouse gases (Y02C), the first junction that appeared is 7699909 from 2010, was applied by The Trustees of Columbia University in the City of New York, and invented by Klaus S.

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Lackner and Frank S. Zeman. The patent is the systems and methods for extraction of carbon dioxide from air. In the next stage, 2011-2012, there are two junctions that have convergence and divergence relatively. In 2011, the patent 7993432 is air collector with functionalized ion exchange membrane for capturing ambient CO2, with Kilimanjaro Energy, Inc. as the applicant, and Allen B. Wright and Eddy J. Peters as the inventors. In 2012, the patent 8221527 is air collector with functionalized ion exchange membrane for capturing ambient CO2, with Kilimanjaro Energy, Inc. as the applicant, and Allen B. Wright and Eddy J. Peters as the inventors. Out of these three junctions that differentiate the stages, two of them are the same technology which is the air collector and applied and invented by the same group f people. Therefore, we could observe that the air collector is the key technology while Kilimanjaro Energy, Inc. is the key applicant of capture, storage, sequestration or disposal of greenhouse gases (Y02C) during 2005 to 2018, while Allen B. Wright and Eddy J. Peters could be seen as the key inventor of this technology.

For the capture, storage, sequestration or disposal of greenhouse gases (Y02C), even though the generality and originality do not have a similar pattern like mitigation of climate change related to buildings (Y02B) did, but by looking at the convergence and divergence junction, we could roughly see a pattern. But given that in Y02B, before every junction there’s a similar pattern in generality and originality, therefore, even though we have two patents appear to have the convergence junctions: 769909 and 7993432, but the stage was differentiated after the patent 769909 because of seeing the generality decrease and the originality increase similar to the technologies for mitigation of climate change related to buildings (Y02B).

Next, Table 6. presents the publication years, originality scores, and generality scores of climate change mitigation technologies in information and communication

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technologies (Y02D) patents, while Figure 19. displays the originality and generality trends along the main path. The originality and generality score did not show similar pattern in this main path. Thus, the main path is distinguished by the junction into four time periods: 2003-2007, 2008-2012, 2013-2015 and 2016 to 2018.

The first junction is 7260731 on 2007, which is saving power when in or transitioning to a static mode of a processor, applied by Transmeta Corporation and invented by Chun Cao. The second junction 8255708 on 2012, which is the patent for apparatuses and methods for power saving in USB devices, which applied by Marvell International Ltd. And invented by Zhenyu Zhang. And the third junction is 9116550 on 2015, a device kickstand, applied by Microsoft Corporation, invented by Kabir Siddiqui, Ralf Groene, Karsten Aagaard, Anthony Christian Reed, Stephan Alexander Cummings, Darryl I. Jensen, and Joseph B Gault.

To sum up, even though the generality and originality of climate change mitigation technologies in information and communication technologies (Y02D) do not have a similar pattern like mitigation of climate change related to buildings (Y02B) did, but by looking at the convergence and divergence junction, we could roughly see a pattern. Therefore, this study differentiates each of the stages after the junctions of divergence or convergence as a complete stage.

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Table 4. Technologies for mitigation of climate change related to buildings (Y02B) patent number's publication year, originality and generality

Publication/Patent Number	Publication Year	Generality	Originality
6521821	2003	0.8156	0.6111
6525262	2003	0.4664	0.8178
6534702	2003	0.8099	0.7500
6534703	2003	0.9680	0.5926
6546535	2003	0.7336	0
6553729	2003	0.6261	0.6848
6570084	2003	0.7038	0.6111
6630622	2003	0.9053	0.7959
6729081	2004	0.6832	0.6403
6809251	2004	0.6970	0.5882
6875914	2005	0.7151	0.602
6883290	2005	0.6509	0.6875
7155870	2007	0.6221	0.6801
7435897	2008	0.8443	0.7653
7762027	2010	0.9694	0.6208
7895808	2011	0.7167	0.6208
7905064	2011	0.7695	0.6400
7987641	2011	0.7187	0.8452
8122648	2012	0.6790	0.7734
8256169	2012	0.7372	0.8741
8272174	2012	0.5708	0.7153
8448405	2013	0.8016	0.8422
8464496	2013	0.5689	0.8949
8572909	2013	0.6981	0.6844
8701354	2014	0.6981	0.7238
8740163	2014	0.6389	0.5331
8938932	2015	0.5643	0.8014
9431953	2016	0.5623	0.7658
9647433	2017	0.7677	0.4856
9954479	2018	0.8000	0.6122
10236821	2019	0.7778	0.7500

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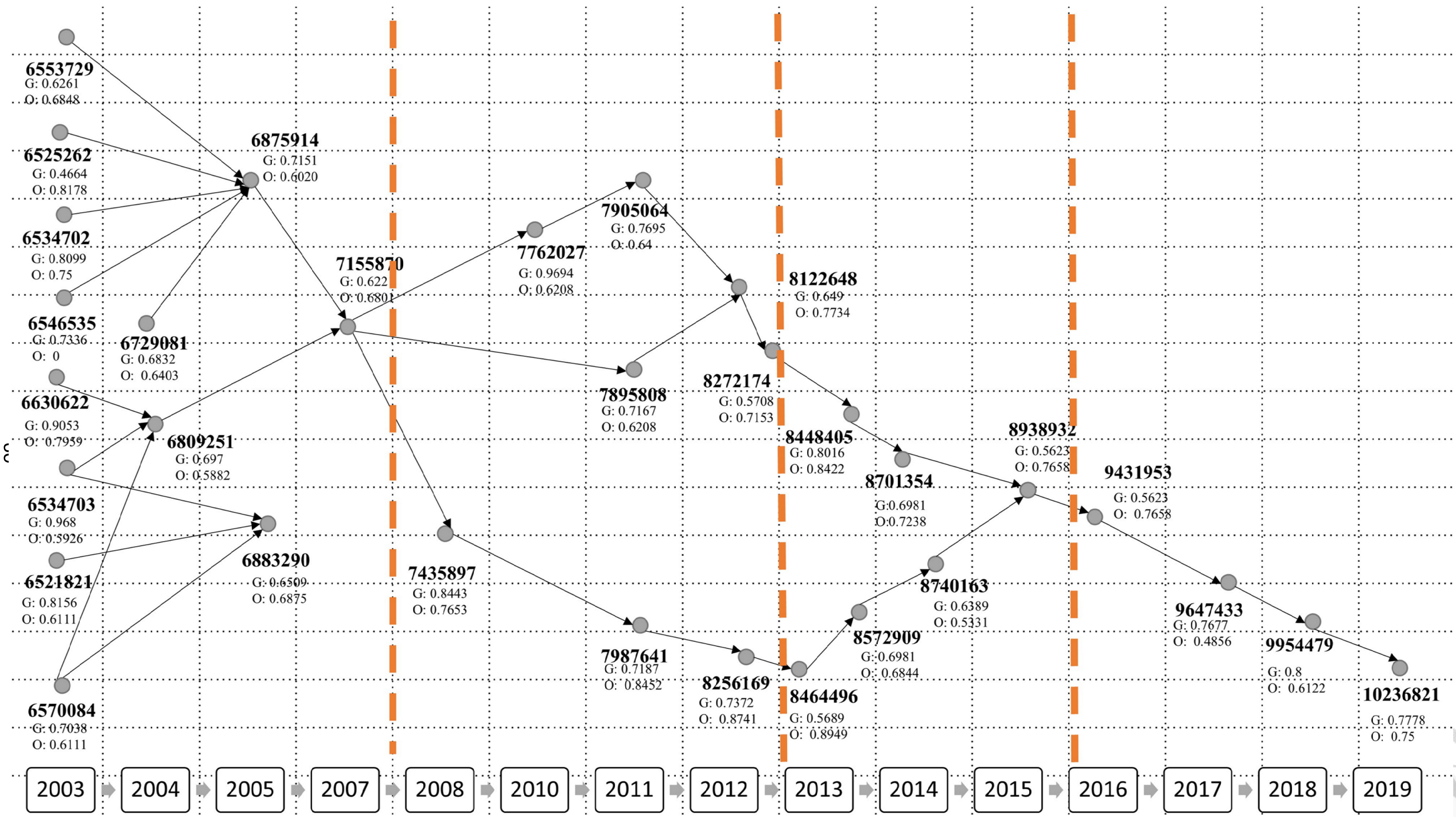

Figure 17. Generality and originality on main path of technologies for mitigation of climate change related to buildings, such as housing, house appliances, and related end-user applications (Y02B)

doi:10.6342/NTU202303415

Table 5. Capture, storage, sequestration or disposal of greenhouse gases (Y02C) patent number's publication year, originality and generality

Publication/Patent Number	Publication Year	Generality	Originality
6890497	2005	0.721	0.503
7132090	2006	0.7536	0.8333
7604787	2009	0.3045	0.7347
7699909	2010	0.5598	0.7813
7993432	2011	0.4344	0.7734
8221527	2012	0.568	0.8052
8715393	2014	0.6975	0.8299
8999279	2015	0.7361	0.8201
9205372	2015	0.7654	0.817
9266051	2016	0.7456	0.8126
9266052	2016	0.8	0.8134
9527747	2016	0.5714	0.8115
9861933	2018	0.4444	0.8041
10010829	2018	0	0.8033
10150112	2018	0	0.8115

In summary, the differentiation of the main paths within the technologies for mitigation of climate change related to buildings (Y02B) category was achieved by considering both the presence of junctions and the patterns observed in the originality and generality scores. For capture, storage, sequestration or disposal of greenhouse gases (Y02C) and climate change mitigation technologies in information and communication technologies (Y02D), by analyzing the junctions four stages within these main paths was obtained.

The differentiation process allowed for the identification of specific time periods and transitions within each main path. This approach enhances our understanding of the underlying factors and mechanisms influencing the progression of innovation and collaboration within the respective fields. This study observed that the pattern of the generality and originality not necessarily could be used in all technologies, but by

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analyzing the junctions we could still find the pattern of divergence and convergence. The generality and originality score of the technologies for mitigation of climate change related to buildings (Y02B) not as predicted in Table 1 but given a similar pattern to study.

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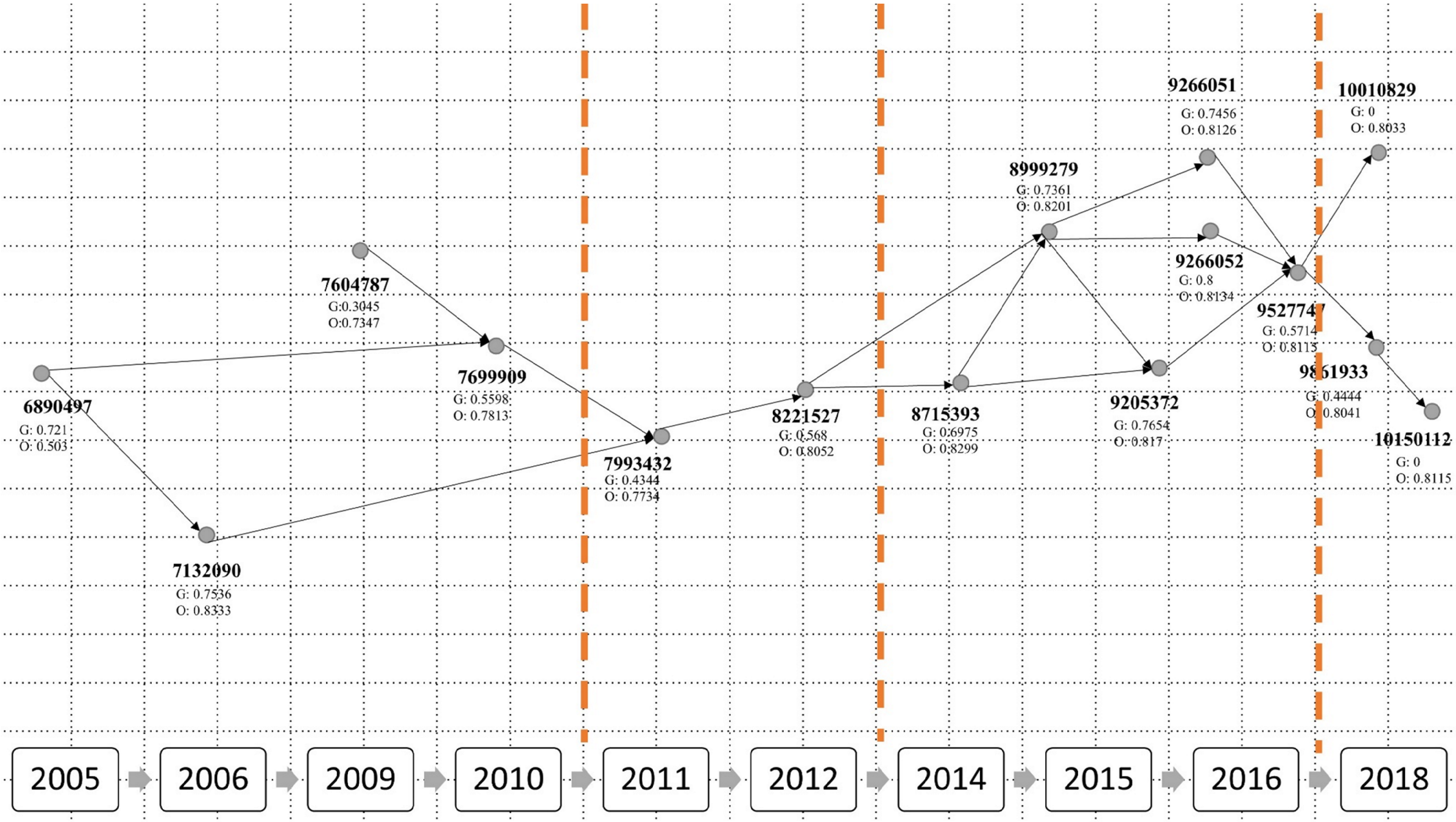

Figure 18. Generality and originality on main path of capture, storage, sequestration or disposal of greenhouse gases (Y02C)

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Table 6. Climate change mitigation technologies in information and communication technologies (Y02D) patent number's publication year, originality and generality

Publication/Patent Number	Publication Year	Generality	Originality
6510525	2003	0.5509	0
6513124	2003	0.5017	0
6519706	2003	0.6736	0
6574739	2003	0.54	0
6622251	2003	0.5449	0
6675304	2004	0.1172	0.716
6704880	2004	0.2917	0.6667
7130668	2006	0.4149	0.5313
7260731	2007	0.349	0.3541
7430421	2008	0.3311	0.716
7454634	2008	0.6538	0.6837
7684835	2010	0.6074	0.5
7752473	2010	0.5864	0.6281
8255708	2012	0.3158	0.3781
8646999	2014	0.2936	0.727
8699215	2014	0.4064	0.7144
8724302	2014	0.3664	0.7503
8780541	2014	0.3932	0.7988
8791382	2014	0.2373	0.7988
8830668	2014	0.3871	0.8011
8854799	2014	0.3388	0.8387
8896993	2014	0.2986	0.7021
8947864	2015	0.377	0.8361
8949477	2015	0.2107	0.7011
9047207	2015	0.1023	0.7404
9116550	2015	0.0588	0.7229
9176900	2015	0.3296	0.8327
9275809	2016	0.322	0.7509
9348605	2016	0	0.7013
9411751	2016	0	0.6991
9465412	2016	0.0832	0.8184
9460029	2016	0	0.7832
9618977	2017	0.142	0.8115
9619071	2017	0.142	0.8188
9710093	2017	0	0.7901
9766663	2017	0.2917	0.8056

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Publication/Patent Number	Publication Year	Generality	Originality
9852855	2017	0	0.7931
9904327	2018	0.62	0.8196
9946307	2018	0	0.6916
9959241	2018	0	0.6835

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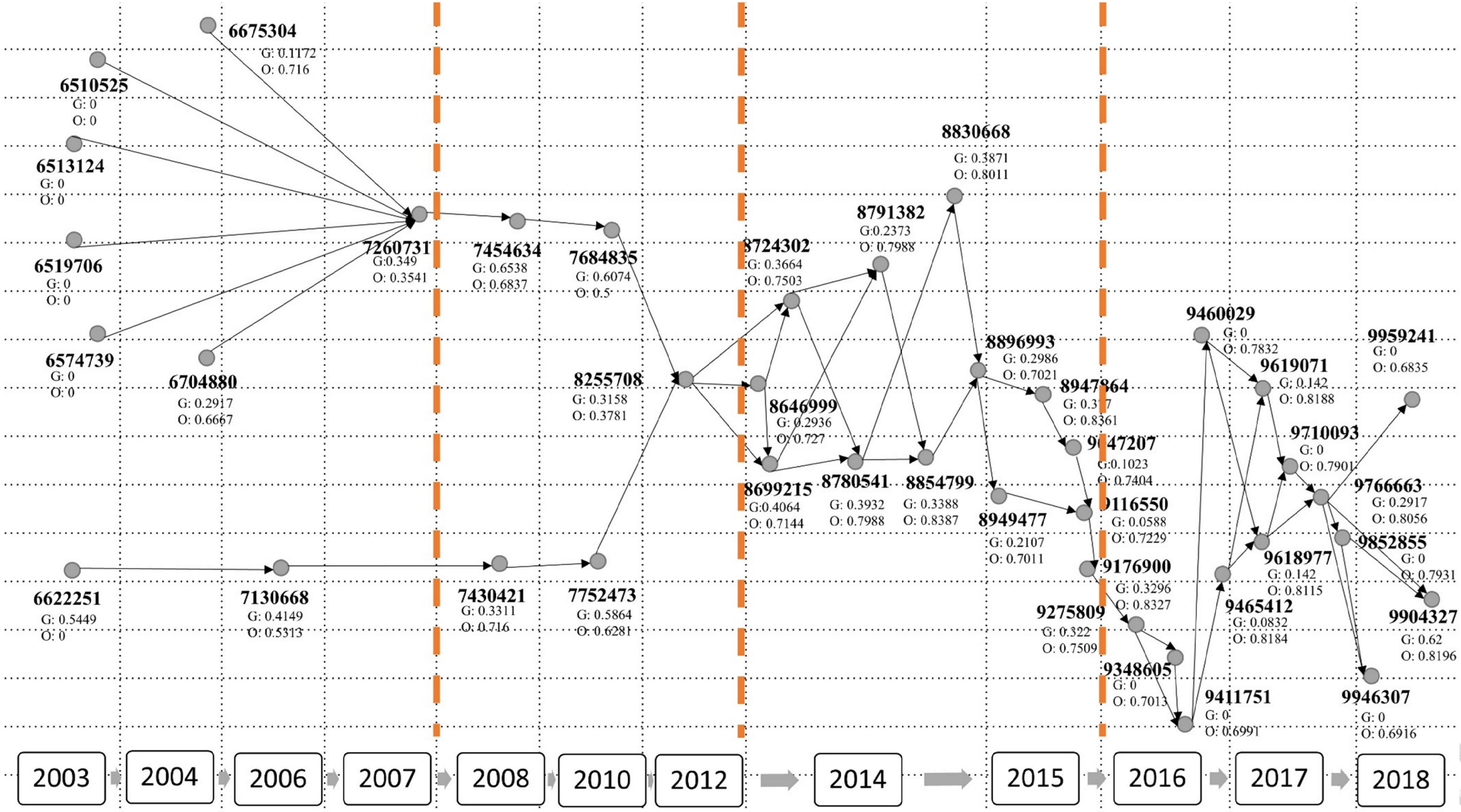

Figure 19. Generality and originality on main path of climate change mitigation technologies in information and communication technologies (Y02D)

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4.2 Talent-on-the-main-path and talent-off-the-main-path

This chapter serves the purpose of investigating the second research objective, which aims to determine whether talent transitioned from the off-the-main-path trajectory to the on-the-main-path trajectory following collaboration with talent already situated on the main path. Furthermore, it seeks to examine the collaborative interactions within each stage to uncover the relationship between convergence-divergence dynamics and talent collaborations. By addressing these objectives, this study will contribute to a comprehensive understanding of talent movements and the influence of collaborations on career trajectories. The findings will shed light on the complex interplay between talent pathways and collaborative practices, enriching the existing knowledge in this domain.

4.2.1 Talents within each group

As shown in Table 7., in technologies for mitigation of climate change related to buildings (Y02B), during 2003-2007 there is 3999 patents in total, with 13 main path patent count; during 2008-2012 there is 6482 patents in total, with 8 main path patent count; during 2013-2015 there is 8110 patents in total, with 6 main path patent count; during 2016-2019 there is 15783 patents in total, with 4 main path patent count.

Secondly, as shown in Table 8., in capture, storage, sequestration or disposal of greenhouse gases (Y02C), during 2005-2010 there is 965 patents in total, with 4 main path patent count; during 2011-2012 there is 453 patents in total, with 2 main path patent count; during 2013-2016 there is 1515 patents in total, with 6 main path patent count; during 2017-2018 there is 1185 patents in total, with 3 main path patent count.

Third, as shown in Table 9., in climate change mitigation technologies in information and communication technologies (Y02D), during 2003-2007 there is 3603

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patents in total, with 9 main path patent count; during 2008-2012 there is 7871 patents in total, with 5 main path patent count; during 2013-2015 there is 9762 patents in total, with 13 main path patent count; during 2016-2018 there is 17335 patents in total, with 13 main path patent count.

Table 7. Year period, total patent count and main path patent count in four stages of technologies for mitigation of climate change related to buildings (Y02B)

	Year Period	Total Patent Count	Main Path Patent Count
stage 1	2003-2007	3999	13
stage 2	2008-2012	6482	8
stage 3	2013-2015	8110	6
stage 4	2016-2019	15783	4

Table 8. Year period, total patent count and main path patent count in four stages of capture, storage, sequestration or disposal of greenhouse gases (Y02C)

	Year Period	Total Patent Count	Main Path Patent Count
stage 1	2005-2010	965	4
stage 2	2011-2012	453	2
stage 3	2013-2016	1515	6
stage 4	2017-2018	1185	3

Table 9. Year period, total patent count and main path patent count in four stages of climate change mitigation technologies in information and communication technologies (Y02D)

	Year Period	Total Patent Count	Main Path Patent Count
stage 1	2003-2007	3603	9
stage 2	2008-2012	7871	5
stage 3	2013-2015	9762	13
stage 4	2016-2018	17335	13

Table 10. presents the proportions of talents within technologies for mitigation of climate change related to buildings (Y02B), in stage 2 of both talents are talent-on-the-path, there are talents comprising a count of 7 out of the total 10 cases, which is shown

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in Table 14. Therefore, the proportion of talents in technologies for mitigation of climate change related to buildings (Y02B) in stage 2 of talent-on-the-main-path & talent-on-the-main-path is calculated as 0.7. Analysis of the proportions reveals that, during the transition from the convergence to the divergence stage, the collaboration group consisting of talent-on-the-main-path and talent-on-the-main-path individuals is the most prevalent combination.

The observed proportion provides valuable insights into the distribution of talents within Y02B across different stages. The prominence of the talent-on-the-main-path and talent-on-the-main-path collaboration group during the convergence to divergence stage highlights their significant representation and influence within this category. This finding suggests that, during this critical stage, talent-on-the-main-path individuals engage in collaborations predominantly with their counterparts, fostering a cohesive network within the main path. In technologies for mitigation of climate change related to buildings (Y02B), the most that appeared is during stage 2, happening between the collaboration of talent-on-the-main-path. Other than that, in stage 3, three kinds of collaboration all have a proportion of 0.1.

In the earlier stage that did not appear, but emerge to a talent-on-the-main-path, in stage 1 there are 11 talents that appear to be on the main path in the later stage. In stage 2 and stage 3, there are 3 and 8 talents that appear to be on the main path in the later stage. In conclusion, we could see that there are a huge number of talents pops out in the later stage to become a talent-on-the-path in the technologies for mitigation of climate change related to buildings (Y02B).

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Table 10. Proportion of talents in technologies for mitigation of climate change related to buildings (Y02B)

	Talent-***on***-the-main-path & talent-***on***-the-main-path	Talent-***on***-the-main-path & talent-***off***-the-main-path	Talent-***off***-the-main-path & talent-***off***-the-main-path	Talent-***off***-the-main-path & talent-***on***-the-main-path
stage 1 to stage 2	0	0	0	0
stage 2 to stage 3	0.7000	0	0	0
stage 3 to stage 4	0.1000	0.1000	0.1000	0

Table 11. displays the proportions of talents within capture, storage, sequestration or disposal of greenhouse gases (Y02C) across different stages. The analysis reveals distinct patterns in the prevalence of collaboration groups within each stage. In Stage 1, the group consisting of "talent-on-the-main-path & talent-off-the-main-path" exhibits the highest proportion. Similarly, in Stage 2, the same group retains the highest proportion, while the group of "talent-off-the-main-path & talent-off-the-main-path" follows as the second highest. Conversely, the group of "talent-on-the-main-path & talent-on-the-main-path" demonstrates the lowest proportion in Stage 2. Finally, in Stage 3, the group of "talent-on-the-main-path & talent-on-the-main-path" emerges as the most prevalent, while the group of "talent-on-the-main-path & talent-off-the-main-path" retains the second highest proportion.

The observation that the "talent-on-the-main-path & talent-off-the-main-path" group consistently holds a significant proportion in Stages 1 and 2 suggests a strong collaborative interaction between talents from convergence to divergence stage. However, in Stage 3, the proportion of the "talent-on-the-main-path & talent-on-the-main-path" group becomes more prominent, indicating a shift towards collaboration

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among talents already established on the main path, which is going to the divergence part.

In the technologies of capture, storage, sequestration or disposal of greenhouse gases (Y02C), in stage 3 the "talent-on-the-main-path & talent-on-the-main-path" has the most proportion, "talent-on-the-main-path & talent-off-the-main-path" has the second most proportion, while "talent-on-the-main-path & talent-off-the-main-path" in the third most proportion. Other than that, in this technology, the talents that appeared in the later stage and on the main path, but did not appeared in the earlier stage is 0 in all three stages. Therefore, we could conclude that in this technology, the talents that appeared on the main path in the later stage all appear in the stage before.

Table 11. Proportion of talents in capture, storage, sequestration or disposal of greenhouse gases (Y02C)

	Talent-***on***-the-main-path & talent-***on***-the-main-path	Talent-***on***-the-main-path & talent-***off***-the-main-path	Talent-***off***-the-main-path & talent-***off***-the-main-path	Talent-***off***-the-main-path & talent-***on***-the-main-path
stage 1 to stage 2	0	0.0316	0	0
stage 2 to stage 3	0.0127	0.1582	0.0823	0
stage 3 to stage 4	0.4304	0.2850	0	0

Table 12. presents the proportions of talents within the climate change mitigation technologies in information and communication technologies (Y02D) category. Consistent with the observations in Y02B and Y02C, Stage 3 exhibits the highest proportion among the different groups. This finding suggests that during the divergence stage, the collaboration groups consisting of "talent-on-the-main-path & talent-on-the-main-path" and "talent-on-the-main-path & talent-off-the-main-path" are the most prevalent.

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The prominence of these collaboration groups during the divergence stage implies the significant role played by talent-on-the-main-path individuals in facilitating talent transitions and advancements within Y02D. Their collaborations contribute to the elevation of talents from different paths, propelling them towards talent-on-the-main-path status.

These findings underscore the importance of talent interactions and the influence of the divergence stage in shaping talent trajectories within Y02D. The collaborative efforts between talent-on-the-main-path and other talent categories are crucial for talent development and progression within the main path. As such, the divergence stage serves as a key opportunity for talent-on-the-main-path individuals to contribute to the growth and integration of talents from various paths.

In the climate change mitigation technologies in information and communication technologies (Y02D), the talent that appeared on the main path of the later stage but not appeared in the earlier stage, is 11, 10 and 8 in each three stages. Which means there are 11, 10 and 8 talents that pop up in the later stage, but did not appear in the earlier stage. It means that the talents that turned out to be the talent-on-the-main-path in this technology are not necessarily being affected by the collaboration of talent with the talent-on-the-main-path.

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Table 12. Proportion of talents in climate change mitigation technologies in information and communication technologies (Y02D)

	Talent-***on***-the-main-path & talent-***on***-the-main-path	Talent-***on***-the-main-path & talent-***off***-the-main-path	Talent-***off***-the-main-path & talent-***off***-the-main-path	Talent-***off***-the-main-path & talent-***on***-the-main-path
stage 1 to stage 2	0.0025	0	0.0049	0
stage 2 to stage 3	0	0	0.0049	0
stage 3 to stage 4	0.5441	0.4436	0	0

4.2.2 Talents within different stages

In technologies for mitigation of climate change related to buildings (Y02B), we obtained a dataset comprising 10 valid cases that are suitable for the chi-square test as shown in Table 13. The crosstabulation table, presented as Table 14., provides the observed count or frequency for each stage and collaboration group. Notably, it is observed that in stage 1, no talent from the group is present, indicating an absence of talent in the earlier stage. However, as the stages progress, these talents subsequently become part of the talent-on-the-path category.

Table 13. Case Processing Summary technologies for mitigation of climate change related to buildings (Y02B)

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Stage*Path	10	100.0%	0	0.0%	10	100.0%

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Table 14. Climate change related to buildings, such as housing, house appliances, and related end-user applications (Y02B) talent count under crosstabulation

Collaboration Type / Stages	Talents A (Early stage)				Total in Later Stage
	Talent-***on***-the-main-path	Talent-***on***-the-main-path	Talent-***off***-the-main-path	Talent-***off***-the-main-path	
	Talents B (Early stage)				
	Talent-***on***-the-main-path	Talent-***off***-the-main-path	Talent-***off***-the-main-path	Talent-***on***-the-main-path	
stage 1 to stage 2	0	0	0	0	0
stage 2 to stage 3	7	0	0	0	7
stage 3 to stage 4	1	1	1	0	3
Total	8	1	1	0	10

In the case of technologies for mitigation of climate change related to buildings (Y02B), Table 15. presents the chi-square value of 5.833. The associated p-value (0.054) is reported under the "Asymptotic Significance (2-sided)" column. To evaluate the statistical significance, we compare the p-value to the predetermined alpha level, typically set at 0.05. If the p-value is equal to or less than the alpha level, the result is considered significant. Conversely, if the p-value is greater than the alpha level, the result is not considered statistically significant.

In this particular analysis, the calculated p-value (0.054) exceeds the standard alpha level. As a result, we accept the null hypothesis, indicating that there is no significant association between the variables of stage and path. In simpler terms, the data suggests that the stages and the talent paths are not statistically associated with each other.

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However, it is important to note that the observed number of cases in technologies for mitigation of climate change related to buildings (Y02B) is relatively small. This limited sample size may have influenced the statistical power and the ability to detect a significant relationship between the variables. Consequently, caution is warranted when interpreting these findings, as the observed data may not provide a comprehensive representation of the true relationship between stage and path within technologies for mitigation of climate change related to buildings (Y02B).

Considering the limitations imposed by the small sample size, further research with a larger dataset or an expanded scope may be necessary to obtain more conclusive insights into the association between the stages and talent paths within technologies for mitigation of climate change related to buildings (Y02B). The data of technologies for mitigation of climate change related to buildings (Y02B) is not significant to allow the study to observe.

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Table 15. Technologies for mitigation of climate change related to buildings (Y02B) talent under Pearson's chi-square test

	Value	df	Asymtotic Significance (2-sided)
Pearson's chi-square	5.833^{a}	2	.054
Likelihood Ratio	6.189	2	.045
N of Valid Cases	10		

For Y02C, our dataset consisted of 158 valid cases suitable for the chi-square test, as shown in Table 16. Table 17. presents the crosstabulation table, displaying the observed count or frequency for each stage and collaboration group. In this analysis, as shown in Table 18. the associated p-value is reported as 0.000 in the "Asymptotic Significance (2-sided)" column.

To assess the statistical significance, we compare the obtained p-value to the predetermined alpha level, typically set at 0.05. In this case, the p-value of 0.000 is considerably smaller than the specified alpha level. Thus, we reject the null hypothesis and conclude that there is a significant association between the variables of stage and path within Y02C.

The statistically significant result indicates that the stages and talent paths are not independent but rather exhibit a relationship. This finding suggests that the progression through stages within the main path is influenced by the specific talent paths in Y02C. Consequently, the variables of stage and path demonstrate a notable degree of association, highlighting the interconnectedness of talent trajectories and collaborative patterns within this specific category.

The results indicate a significant association between the stage and path variables within capture, storage, sequestration or disposal of greenhouse gases (Y02C). Notably, Stage 3 emerges as the stage with the highest count for the collaboration group

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comprising talent-on-the-main-path and talent-off-the-main-path, as well as the collaboration group consisting solely of talent-on-the-main-path. Stage 3 represents a transition stage leading to Stage 4, which is characterized by divergence. These findings suggest that during the divergence stage, talent-on-the-main-path plays a prominent role in collaborating with both talent-on-the-main-path and talent-off-the-main-path individuals, facilitating their transition to talent-on-the-main-path status in subsequent stages.

Additionally, in Stage 2, there is a higher propensity for talent-on-the-main-path to collaborate with talent-off-the-main-path individuals. This collaboration pattern aligns with the predictions put forth by Liu et al. (2018) and contributes to the transition of talent-off-the-main-path individuals to talent-on-the-main-path status in later stages.

Overall, the results indicate that talent-on-the-main-path individuals play a significant role in fostering collaboration and facilitating the progression of talent trajectories within capture, storage, sequestration or disposal of greenhouse gases (Y02C). These findings are consistent with previous research and lend support to the notion that collaboration between talent-on-the-main-path and talent-off-the-main-path individuals is instrumental in enabling the latter group to transition to talent-on-the-main-path status in subsequent stages.

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Table 16. Case Processing Summary of capture, storage, sequestration or disposal of greenhouse gases (Y02C)

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Stage*Path	158	100.0%	0	0.0%	158	100.0%

Table 17. Capture, storage, sequestration or disposal of greenhouse gases (Y02C) talent count under crosstabulation

Collaboration Type / Stages	Talents A (Early stage)				Total in Later Stage
	Talent-***on***-the-main-path	Talent-***on***-the-main-path	Talent-***off***-the-main-path	Talent-***off***-the-main-path	
	Talents B (Early stage)				
	Talent-***on***-the-main-path	Talent-***off***-the-main-path	Talent-***off***-the-main-path	Talent-***on***-the-main-path	
stage 1 to stage 2	0	5	0	0	5
stage 2 to stage 3	2	25	13	0	40
stage 3 to stage 4	68	45	0	0	114
Total	70	75	13	0	158

Table 18. Capture, storage, sequestration or disposal of greenhouse gases (Y02C) talent under Pearson's chi-square test

	Value	df	Asymtotic Significance (2-sided)
Pearson’s chi-square	67.141^{a}	4	.000
Likelihood Ratio	74.037	4	.000
N of Valid Cases	158		

For climate change mitigation technologies in information and communication technologies (Y02D), our dataset consisted of 1224 valid cases suitable for the chi-square test, as shown in Table 19. Table 20. presents the crosstabulation table,

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displaying the observed count or frequency for each stage and collaboration group. In this analysis, as shown in Table 21., the associated p-value is reported as 0.000 in the "Asymptotic Significance (2-sided)" column, with the chi-square value of 1018.806.

The findings indicate that the divergence stage within climate change mitigation technologies in information and communication technologies (Y02D) plays a crucial role in shaping talent trajectories. Talent-on-the-main-path individuals are actively involved in collaborations during this stage, which likely contributes to their sustained presence on the main path in subsequent stages.

These results align with expectations and provide empirical evidence of the impact of collaboration on talent paths within climate change mitigation technologies in information and communication technologies (Y02D). The significant association observed underscores the importance of the divergence stage and the collaborative interactions that occur within it. It suggests that talent-on-the-main-path individuals are more likely to continue on the main path due to their engagement in collaborations during this critical stage.

Table 19. Case Processing Summary of climate change mitigation technologies in information and communication technologies (Y02D)

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Stage*Path	1224	100.0%	0	0.0%	1224	100.0%

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Table 20. Climate change mitigation technologies in information and communication technologies (Y02D) talent count under crosstabulation

Collaboration Type / Stages	Talents A (Early stage)				Total in Later Stage
	Talent-***on***-the-main-path	Talent-***on***-the-main-path	Talent-***off***-the-main-path	Talent-***off***-the-main-path	
	Talents B (Early stage)				
	Talent-***on***-the-main-path	Talent-***off***-the-main-path	Talent-***off***-the-main-path	Talent-***on***-the-main-path	
stage 1 to stage 2	3	0	6	0	9
stage 2 to stage 3	0	0	6	0	6
stage 3 to stage 4	666	543	0	0	1209
Total	669	543	12	0	1224

Table 21. Climate change mitigation technologies in information and communication technologies (Y02D) talent under Pearson's chi-square test

	Value	df	Asymtotic Significance (2-sided)
Pearson’s chi-square	1018.806^{a}	4	.000
Likelihood Ratio	126.996	4	.000
N of Valid Cases	1224		

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Chapter 5: Conclusion and Suggestion

5.1 Conclusion

In conclusion, the technologies for mitigation of climate change related to buildings (Y02B) could be differentiate into stages using generality and originality while capture, storage, sequestration or disposal of greenhouse gases (Y02C), and climate change mitigation technologies in information and communication technologies (Y02D) categories could be differentiated by junctions.

Thus, the analysis of talent proportions within the technologies for mitigation of climate change related to buildings (Y02B), capture, storage, sequestration or disposal of greenhouse gases (Y02C), and climate change mitigation technologies in information and communication technologies (Y02D) categories reveal distinct patterns and dynamics in talent collaborations across different stages.

5.1.1 The Technologies for Mitigation of Climate Change related to Buildings (Y02B) could be Differentiate Using Generality and Originality

This study used the indicators of generality and originality to differentiate the stages, but only technologies for mitigation of climate change related to buildings (Y02B) shows a significant pattern and result. Also, this study observed that, using generality and originality as indicators to differentiate the junctions could be only applied on the technologies for mitigation of climate change related to buildings (Y02B).

But contrarily, capture, storage, sequestration or disposal of greenhouse gases (Y02C), and climate change mitigation technologies in information and communication technologies (Y02D) did not show a significant pattern in the generality and originality. But we can still see the convergence and divergence junctions in it. Therefore, this

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study shows that generality and originality not necessarily could be used as an indicator, but still, we could differentiate the main path by the junctions.

The pattern of generality and originality predicted in Table 1 could not be seen in this study but in the technologies for mitigation of climate change related to buildings (Y02B), it could be seen as a different kind of pattern. Other than that if we use the convergence and divergence junction to differentiate the stage, it could be used in every technology in climate change mitigation.

5.1.2 Talent-off-the-main-path is being Led to the Main Path from the Stage 3 to Stage 4

For the second purpose of the study, we tend to find out the highest proportion of collaboration type is on stage 3 of climate change related to buildings (Y02B), capture, storage, sequestration or disposal of greenhouse gases (Y02C) and climate change mitigation technologies in information and communication technologies (Y02D). We understand that the talent-on-the-main-path will be formed in the later stage: stage 4, if it collaborates with talent-on-the-main-path. The same case happened if the talent-off-the-main-path collaborates with talent-on-the-main-path in stage 3 to stage 4. The study enabled us to understand that to become talent-on-the-path in stage 4, talents need to collaborate with talent-on-the-main-path, as we want to understand in the purpose 2 of our study.

For talents that turned into talent-on-the-main-path in stage 3, most of them are the collaboration of talent-off-the-main-path and talent-off-the-main-path. It means that even though the talent-off-the-main-path did not appear on the main path because of the talent-on-the-main-path, it follows the changing of the stage from convergence (stage 2) to divergence (stage 3). As in stage 2 the talent started to incorporated into new system

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designs and inventions, preparing to immerge; while entering into stage 3 the talent will immergence with other technologies (Roco, 2016). Eventually, the changes between integrated within oneself in stage 2 faced the changes of emerging and corporate with other kind of technologies, these changes will push the talent that originally off the main path to the main path.

5.2 Suggestion

For future work, if the corporate could differentiate four stages, primarily controlled by whom. As mentioned by the researchers, to find the corporate which disciplines bottom-up and top down, to control of matter at the nanoscale, that have new products, application (Roco, 2016), this study suggests the corporate could differentiate the stages. After differentiate the stages, the corporate could get the further insights of the industry.

Thus, in the progress of finding talents, in stage 2 to stage 3 the talents will be in the collaboration type of “talent-off-the-main-path”, while in stage 3 to stage 4, the talents will be in the collaboration type of “talent-on-the-main-path”. Corporate or researchers could find the talents that could lead other into the main path in these specific stages.

For the academic, even though the researchers pointed out that there are evolutionary traits among the four stages, but we could see that in climate change related to buildings (Y02B) has its pattern in the generality and originality. Therefore, it still worth a try to use it as indicators in other technology.

5.3 Limitation

During the process of addressing the first research objective, which involves the differentiation of stages within the main path, a challenge has emerged regarding the

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ability to distinguish every class within Y02. This difficulty arises from the unique structure of the main path itself, wherein intersecting segments or the absence of clear junctions complicate the differentiation process. While alternative approaches might exist for differentiating the main path, the current research context limits our ability to effectively process and analyze these intersecting or non-junction instances. Acknowledging this constraint is essential in order to provide accurate and transparent findings in the subsequent analysis of the main path stages.

Contrary to the initial expectations, the differentiation of stages within the main path did not align with the predicted outcomes. The envisioned slicing of the main path into four distinct paths, each characterized by varying levels of originality and generality scores, did not manifest as anticipated. While originality and generality scores were initially considered promising indicators, their ability to exhibit substantial differences across the main path was limited within the scope of our research.

It is evident that the scores of originality and generality, while potentially valuable measures, did not adequately capture the nuances or distinctions within the main path. Despite their initial potential as indicators, the observed variations in these scores across the main path were not sufficiently discernible. Consequently, alternative approaches and additional factors need to be explored to gain a more comprehensive understanding of the differentiated stages within the main path. Acknowledging these findings is crucial for ensuring the validity and reliability of the subsequent analyses conducted within this research. By recognizing the limitations and exploring alternative avenues for differentiation, we can refine our approach and uncover more meaningful insights into the main path's stages.

During the pursuit of our second research objective, we encountered a limitation regarding the count of talent collaborations, which was insufficient to conduct a reliable

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Chi-squared test. Consequently, we were unable to obtain meaningful results for the specific class under investigation. The lack of an adequate number of talent collaborations within the dataset restricted our ability to perform a comprehensive analysis and draw conclusive findings. This limitation highlights the importance of having a sufficient sample size for statistical tests, such as the Chi-squared test, to yield reliable and meaningful results.

It is important to acknowledge this constraint and its impact on our research outcomes. Future studies with a larger dataset or alternative approaches to gathering talent collaboration data may be necessary to overcome this limitation and enable a more in-depth examination of the specific class within the research context.

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