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The Impact of Financial Development on Innovation: A Comparative Study of Central and Eastern European Countries and Western European Countries

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Abstract

This thesis applies a panel dataset of 40 European nations from 1995 to 2021 to investigate the impact of financial development on innovation. Considering the heterogeneity of these European countries, they are divided into two subgroups (Central and Eastern European countries and Western European countries) to carry out a comparative study and determine whether financial development influences innovation differently in the two groups of countries. This paper measures the development of the financial system from four dimensions, consisting of depth, access, efficiency, and stability, and selects two indicators to capture innovation, including innovation input and innovation output. The empirical outcomes deliver that in CEE countries, improvements in financial depth, access and efficiency can significantly contribute to innovation input and innovation output. In WE countries, the positive effect of financial development on innovation is mainly achieved by enhancing financial efficiency and access. Whether with respect to innovation output or innovation input, depth, access, and efficiency of financial systems exert a greater influence on promoting innovation in CEE countries than in WE countries.

Keywords

financial development, innovation, financial systems, patent, research and development, Central and Eastern European countries, Western European countries

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Declaration of Authorship

1. The author hereby declares that he compiled this thesis independently, using only the listed resources and literature.

2. The author hereby declares that all the sources and literature used have been properly cited.

3. The author hereby declares that the thesis has not been used to obtain a different or the same degree.

Prague 20.07.2023

Yuhan LIU Yuhan Liu

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Contents

1. Introduction

1.1 Background and Research Objectives

As of 2023, the global financial development and national innovation have witnessed remarkable progress and transformation. Economies around the world have rebounded from the challenges posed by the COVID-19 pandemic, leading to a period of robust growth and improved fiscal stability. Governments and private sectors alike have intensified their focus on fostering innovation and technological advancements, with investments pouring into research and development across various industries. Artificial Intelligence (AI), blockchain, renewable energy, and biotechnology are among the key areas experiencing significant breakthroughs, driving forward the next era of economic expansion and sustainable development. This unprecedented synergy between financial growth and technological innovation has paved the way for a promising future, where nations strive to be at the forefront of innovation and harness their economic potential for the benefit of their citizens and the global community.

The significant effect of innovation in promoting long-term economic growth has been extensively discussed by previous research (e.g., Schumpeter and Backhaus, 1934; Solow, 1957; Aghion, 2004). Taking into account the pivotal contribution of innovation to economic development, investigating the determinants of innovation becomes particularly essential. The process of innovation tends to be long, requiring substantial resources and continuous capital investment, and the outcomes are unpredictable, potentially facing the risk of failure (Holmstrom, 1989). Schumpeter (1911) proposed that financial development is essential to promote innovative activities in a country. Numerous theoretical studies have discussed the mechanisms through which financial development influences innovation. Some scholars believe that the functionality of the financial system is crucial in enhancing innovation, because it alleviates information asymmetry, provides external financing access for innovative enterprises, reduces financing costs, diversifies risks, and strengthens

supervision (Hall and Lerner, 2010; Aghion et al., 2004; Tee et al., 2014; Hall and Lerner, 2010; Meierrieks, 2014; Tadesse, 2005). In contrast, some studies propose the development of the financial system may encourage market monopolization and inefficient resource allocation, hindering innovation (Brown et al., 2009; Boustanifar et al., 2017; Trinugroho et al., 2021). Even though most theoretical studies confirm that financial development exerts a favourable influence on innovation, empirical investigations on the impact of financial development on innovation are limited, of which the conclusions are inconsistent. Therefore, this dissertation aims to re-examine the role of financial development in influencing innovation by utilizing cross-country panel data.

1.2 Research Methods

The objective of this empirical analysis is to investigate how financial development influences innovation in European countries. Utilizing a panel dataset comprising 40 European nations over the period 1995-2021, a rigorous quantitative analysis is employed to achieve the research objectives. The analytical methods encompass comparative analysis, correlation analysis, Hausman test, multiple linear regression analysis, which includes fixed-effect models and system-GMM models. To account for the heterogeneity among European countries concerning their financial development and innovation levels, the study conducts a comparative analysis, categorizing them into two subgroups: Central and Eastern European countries and Western European countries. The classification facilitates the assessment of whether the influence of financial development on innovation differs between the two groups. The study uses correlation analysis, Hausman test, and fixed-effect models to examine the impact of financial development on innovation while employing the system-GMM models to validate the robustness of the empirical findings. Through these rigorous methodologies, the study provides meaningful revelations into the complex interplay between financial development and innovation in the European context.

1.3 Contributions and Novelty

The novelty of this paper is mainly manifested in three aspects. Firstly, the paper concentrates on European countries, which, due to the existence of heterogeneity, have been divided into two groups (Western countries group and Central and Eastern European countries group) to conduct a comparative study and examine the differences in the relationship between financial development and innovation in these two groups. Secondly, this paper will examine how financial development affect innovation not only by using an aggregate indicator, but also by categorizing the level of financial development into four dimensions (depth, access, efficiency, and stability) to test the impact of each dimension on the level of innovation. The purpose of categorizing the impact of financial development into four dimensions is to examine the contribution of each dimension to the level of innovation in depth and to understand which dimension dominates in the interplay of financial development and innovation in these two groups, providing more effective policy recommendations on how to raise the level of innovation by enhancing the functioning of financial system. Thirdly, the combination of two techniques is employed to carry out the empirical study, including fixed-effect models and system-GMM models.

1.4 Research Structure

The dissertation follows a well-structured roadmap to investigate the connection between financial development and innovation. In Chapter 1, the introduction sets the stage by presenting the research themes and objectives, clarifying the significance of the discussion, and outlining the methodology. Chapter 2 conducts a comprehensive literature review, elucidating key terms, definitions, and prior theoretical and empirical works associated with financial development and innovation. Subsequently, Chapter 3 formulates hypotheses based on the literature review. Moving forward, Chapter 4 elaborates on the methodology, encompassing data sources, variable selection, statistical analysis, and econometric techniques and models adopted in this

research. The empirical outcomes, crucial to achieving the research objectives, will be presented and analysed in Chapter 5. To ensure the robustness of findings, Chapter 6 encompasses rigorous robustness checks. In Chapter 7, the paper discusses the principal findings and offers valuable policy recommendations for policymakers. Finally, Chapter 8 concludes the research by summarizing the key insights, outlining contributions, and discussing the study's limitations, thereby providing a foundation for future study.

2. Literature Review

This chapter consists of three sections, namely ‘innovation’, ‘financial development’ and ‘the relationship between financial development and innovation’, presenting the concepts and relevant research of financial development and innovation, and the previous theoretical and empirical literature on their relationship.

2.1 Innovation

In this section, some contents on innovation will be introduced. First, it explains the definition and types of innovation. Then the interplay of innovation and economic development will be discussed, followed by the determinants of innovation.

2.1.1 Definition and Types of Innovation

The concept of innovation was initially introduced by Schumpeter in 1911, who suggested that innovation is the process of recombining a production factor and a production condition, introducing it into the production system and establishing a new production function, in which a new product, method of production, or market can be regarded as an innovation. Moreover, he highlighted the dominant effect of the entrepreneur in the innovation process. After Schumpeter, later scholars have been extending and developing the understanding of innovation. For example, Solow (1957) reinterpreted and reviewed Schumpeter's theory by proposing two conditions for the establishment of innovation, consisting of the source of new ideas and the realization and development of later stages.

Regarding the types of innovations, Schilling (2008) proposes three ways to categorize them, including process or product innovations; incremental or radical innovations; and original or architectural innovations, based on the characteristics of the innovation, the extent of the innovation, and the relationship between the new technology and the existing technology, respectively. The distinction between process

and product innovation lies in the nature of the innovation. Product innovation is related to products or services, while process innovation refers to upgrades in the way an organization manages its business, often with the goal of increasing productivity and capacity. The key disparity between radical and incremental innovation lies in the extent to which they deviate from pre-existing technology. Radical innovation is groundbreaking and brings about 'creative destruction,' signifying a significant departure from existing technology. On the other hand, incremental innovation entails gradual improvements to existing technologies. Furthermore, innovations can be further classified as either component or architectural innovations, based on whether they impact only specific product components or bring about changes to the overall structure. This classification system allows a nuanced understanding of various types of innovations, their characteristics, and their potential impact on the technological landscape.

2.1.2 Innovation and Economic Development

The theoretical foundation for the interplay of innovation and economic growth was proposed by the seminal research of Schumpeter and Backhaus (1934). They illustrate that 'creative destruction' due to innovation can promote economic growth. Numerous subsequent studies have supported his view that progress of technology is a decisive factor of economic growth (e.g., Solow, 1957; Denison, 1962; Romer 1990; Aghion et al. 2005; Grossman and Helpman, 1994). There is a broad consensus that innovation acts as a driving force for growth across firms, sectors, and countries (Ganter and Hecker, 2013; Aghion and Howitt, 1992; Lacasa et al., 2019). The advantageous influence of innovation on economic growth have been tested and confirmed both theoretically (e.g., Aghion and Howitt, 1992; Romer, 1990; Temple, 1999; Dhrifi, 2015; Wang and Tan, 2021) and empirically (e.g., F are et al., 1994; Freeman, 1994; Fagerberg et al., 2007; Meierrieks, 2014; Zhu et al., 2020). In terms of theoretical research, Aghion and Howitt (1992) argue that innovation created by a competitive research sector can contribute to economic growth by increasing productivity through

'creative destruction'. The diffusion of innovation in economic activity brings technological transformation and knowledge flows, which facilitates the accumulation of physical, human and technological capital, facilitates the improvement of labour and total factor productivity (Belze and Gauthier 2000; Crépon et al. 1998). Empirical evidence also demonstrates the positive impact of innovation, for example, according to Ulku's (2004) investigation of 10 non-OECD and 20 OECD countries, the favourable influence on economic development in both developed and emerging economies was confirmed. Moreover, some studies have also evidenced that economic growth promotes innovation (Sinha, 2008; Howells, 2005; Pradhan et al., 2016; Cetin, 2013). That means, there exists a bidirectional relationship between innovation activities and economic growth, where they can reciprocally impact each other (Cetin, 2013; Pradhan et al., 2016). Overall, innovation has been shown to be significant for economic development, both theoretically and empirically.

2.1.3 Determinants of Innovation

Innovation is a crucial factor in driving economic development, making it imperative to understand the determinants that enhance innovation performance. The academic literature encompasses a diverse array of potential factors influencing innovation, broadly classified into two categories: internal and external determinants. The first category encompasses firm-specific attributes, for instance human capital, size, R&D expenditures, organizational culture, and behavioural and strategic patterns. Concurrently, the second category pertains to external environmental conditions, for instance trade openness, property rights protection, and financial development. Citing studies by Furman et al. (2002), Varsakelis (2006), and Gogokhia and Berulava (2020), the significance of these determinants is highlighted. Notably, Mazzucato (2000) advocates that smaller firms possess greater managerial control, flexibility, and incentives to foresee technological advancements, fostering a conducive environment for innovative activities. Moreover, empirical research conducted by Storey (1983), Kleinknecht (1987), and Acs and Audretsch (1988) has consistently supported the

notion that smaller firms significantly contribute to national innovation. Acemoglu et al. (2016) emphasize the pivotal effect of R&D expenditure and human capital on promoting innovation. By comprehending and leveraging these determinants, businesses and policymakers can effectively bolster innovation and propel economic growth to new heights.

Apart from these, the significant effect of external factors on innovation is emphasized by some studies (Hu and Png 2013; Furman et al., 2002; Varsakelis, 2006; Mtar and Belazreg, 2020). For example, Varsakeli (2001) evidenced that a higher degree of patent protection safeguards contract enforcement and the interests of innovators and provides incentives for firms to innovate. Well-enforced legislation and IPRs attract more FDI into technology-intensive sectors by providing adequate legal remedies against infringements Fu (2008). In addition, benefited from openness, more trade flows mean more exports and imports of goods and services, which contributes to more technology diffusion, knowledge spillovers, and innovative activities (Meierrieks, 2014). Moreover, investment in education and training affects the total amount of knowledge in a country, which is a necessary condition to facilitate innovative activity (Tee et al., 2014).

2.2 Financial Development

This section delivers some information about financial development, consisting of the concept and related studies of financial development, structure and components of financial system, and the dimensions of financial development.

2.2.1 The Concept and Related Studies of Financial Development

The emergence of the concept of financial development is attached to the alleviation of market imperfections in the financial system. High costs and uncertainties exist both in the transaction of goods and services and in the interpretation and enforcement of contracts. In addition, it is also difficult and costly to obtain and process

information about potential investment. These market imperfections impede the efficient allocation of resources and restrain economic development. Financial instruments and institutions are created to reduce the transaction cost and address market imperfections. The concept of financial development emerged with the creation and development of financial instruments, markets and intermediaries that reduce transaction costs and addressed limited contract enforcement. As the financial system develops, the functions it provides to the economy are reflected in more ways. Therefore, Merton (1992), Merton and Bodie (2004), and Levine (1997, 2005) suggest that advancements in the performance of five main financial functions can reflect increased levels of financial development. The key functions consist of: (1) the ability to produce and process information on potential investments and allocate capital according to the valuations; (2) the ability to monitor firms and individuals and implement corporate governance after the allocation of capital; (3) the ability to facilitate transactions, risk management and diversification; (4) the ability to mobilize and pool savings; (5) the ability to facilitate the exchange of financial instruments. These detailed and specific explanations of the financial functions reflect the development of the financial system, and the significance of financial development.

Research related to financial development mainly concentrates on the contribution of financial development on economic growth and poverty reduction. Financial development can directly or indirectly influence economic development. In terms of indirect mechanics, for example, Zhu et al. (2020) argues that financial development can increase productivity and bring economic growth by stimulating innovation activities. The beneficial influence of financial development on economic growth has been confirmed by substantial empirical papers (e.g., De Gregorio and Guidotti, 1995; Levine, 2005; Demirgüç-Kunt and Levine, 2009). In addition, some studies evidence that financial development can reduce poverty either directly, or indirectly by stimulating economic development (Jeanneney and Kpodar, 2008; Boukhatem, 2016; Rashid and Intartaglia, 2017).

2.2.2 Structure and Components of Financial System

The financial system comprises four fundamental components, namely financial markets, financial institutions, financial services, and financial instruments, each playing a crucial role in facilitating economic activities (Allen and Gale, 2009). Financial markets act as platforms where buyers and sellers engage in trading various assets, such as bonds, stocks, commodities, and more (Pagano, 1993). This encompasses money markets, stock markets, bond markets, and derivative markets, fostering the efficient allocation of capital (Greenwood and Smith, 1997). Financial institutions, acting as intermediaries, bridge the gap between investors and borrowers, offering essential financial services to their clients (Berger and Humphrey, 1997; Allen, 2001). Key players in this realm are banking sectors and insurance companies (Saunders and Cornett, 2008; Lee and Shin, 2018). Banks, for instance, gather deposits from the public, enabling them to provide loans to borrowers, thereby generating revenue (Jokipii and Monnin, 2013; Jayawardhena and Foley, 2000). Insurance companies, on the other hand, offer risk management solutions, with the insured paying premiums in exchange for compensation in times of loss (Santomero and Babbel, 1997; Cummins and Doherty, 2006). As such, insurance plays a vital role in mitigating risk. Financial instruments encompass a wide range of financial assets traded in markets, including money, securities, and contracts, serving as crucial tools for investment and risk management (Hull, 2003; Ryan, 2007). Finally, financial services are provided by various entities within the financial industry, for instance insurance companies, investment funds, and accountancy firms (Claessens, 2006; Rose and Hudgins, 2008). These services aid in identifying suitable investment opportunities, securing necessary funds, and ensuring optimal returns for investors. Altogether, the harmonious functioning of these components underpins the stability and enhancement of the financial system, contributing significantly to the economy.

2.2.3 Dimensions of Financial Development

To build a link between the actual functioning of the financial system and quantitative measure, some scholars categorize financial development into different dimensions

(e.g., Beck et al., 2010; Čihák et al., 2013). For example, Beck et al. (2010) illustrates that financial system can be measured from the respective of activity, efficiency, size, and stability. Similarly, Čihák et al. (2013) illustrates that the functioning of financial systems is multi-dimensional and can be characterized into four dimensions, consisting of depth, access, efficiency, and stability. This paper will follow the way of Čihák et al. (2013) and explain these four dimensions of financial development. Financial depth reflects the size of financial systems. Financial access captures the extent to which the public and businesses can get access to and utilize financial services. Financial efficiency measures whether financial intermediaries are efficient in allocating resources and facilitating transactions. Financial stability involves the capability of the financial system to remain stable when experiencing severe shocks. As financial systems can be divided into two sectors, financial institutions and financial markets (Boukhatem, 2016), Čihák et al. (2013) proposes a 4*2 matrix for four dimensions in both sectors to capture the characteristics and functioning of financial system comprehensively. The relevant indicators to measure these four dimensions in both financial markets and financial institutions are listed and explained in their study (Čihák et al., 2013).

2.3 The Relationship Between Financial Development and Innovation

This section reviews previous theoretical and empirical findings on the interplay of financial development and innovation. The discussion of theoretical findings is divided into three parts, illustrating the different mechanisms by which financial development can positively or negatively affect innovation, and comparing the different roles of banking institutions and financial markets.

2.3.1 Theoretical Findings

2.3.1.1 Four mechanisms by which FD positively affects innovation

(1) The development of financial systems mitigates information asymmetries, provides reliable information about the value of innovative projects, and addresses adverse selection and moral hazard.

Business investment can suffer from information asymmetry due to differences in the way managers and investors obtain information, and the problem of asymmetric information is more serious in innovation projects than in other projects for three reasons. Firstly, the long time period from conception to commercialization of an innovation project and the high level of uncertainty about the benefits make it difficult to evaluate (Allen and Gale, 1999). Second, although information disclosure is an effective approach to alleviate information asymmetry, innovators tend to be unwilling to provide information. This is because disclosing specific information about an innovation to public investors allows the competitors to be informed at the same time, which will reduce the comparative advantage of the innovation project and turns the innovator into a passive position in market competition (Anton and Yao, 1998). Third, to mitigate information asymmetry, banks usually require borrowers to provide physical capital with collateralized value, which innovative firms often do not have (Hall and Lerner, 2010; Xiao and Zhao, 2012). This information asymmetry resulted that investors cannot reasonably assess the investment value of an innovative activity (Chowdhury & Maung, 2012). And investors are mostly risk averse, whose willingness to fund innovation projects is dampened, contributing to less financial support for innovation.

The development of the financial system mitigates information asymmetry, offers reliable information regarding the worth of innovative projects, and promotes investment in innovation (Chowdhurya and Maung, 2012; Wang and Tan, 2021). Financial intermediaries lower the average expenses of obtaining information through

specialisation and economies of scale, which not only screen high-quality projects and reduce investment risk for the public, but also disclosure and disseminate information related to innovation, helping investors to make decisions based on their own risk preferences (Diamond, 1984; Holmstrom and Tirole, 1993). Furthermore, the trading price of shares in financial markets serves as an invaluable barometer reflecting the value of innovative projects. Stock markets, with their timely equilibrium security prices, effectively gauge the quality of innovative activities through share prices and other disclosures about innovation. With the advantages derived from financial development, investors gain a comprehensive understanding of the risks and returns associated with innovation projects, facilitating a rational approach to investment in innovation (Grossman and Stiglitz, 1980; Holmstrom and Tirole, 1993).

Financial development can also address adverse selection and moral hazards attributed to information asymmetry. According to Brown et al. (2012) and Aristizabal-Ramirez et al. (2017), information asymmetry contributes to adverse selection before investment and moral hazard after investment. Before investment, information asymmetry between innovators and investors will cause adverse selection problems, which will prevent innovators with good projects from obtaining adequate financing. Due to information asymmetry, investors are unable to identify the quality of innovation projects and are thus willing to invest only in the average quality of the pool of innovation, which can drive innovation with high quality out of the market or face financing constraints. In this case, adverse selection occurs, which significantly limits innovative activity (Akerlof, 1970). In addition, information asymmetry can lead to moral hazard problems (De la Fuente and Marin, 1996; Law et al., 2018). After investment, entrepreneurs may use their information advantage to pursue policies that favor themselves to the detriment of the project, or to hide successful outcomes of innovation and avoid repaying loans (Aghion and Howitt, 2005). The development of the financial system deals with both problems. First, financial development increases the availability, examination, and disclosure of information about innovative projects, reducing information asymmetry and thus addressing

adverse selection. Second, the contract between the financial intermediary and the entrepreneur is structured in such a way as to provide incentives and supervision to the innovator to address moral hazard and induce best effort (Law et al., 2018).

(2) The development of the financial system facilitates the realisation of innovation by providing innovative firms with access to external financing, lowering the cost of financing and increasing the efficiency of financing.

Innovation activities require high start-up and operating costs. The time period of technological innovation projects tends to be long, and the cost cannot be recovered in a short period of time. According to (Aghion et al., 2004; Hall and Lerner, 2010), innovative firms have a hierarchy of financing, as they first use internal funds to maintain control over the innovations, and then more funds come from external financing, including bank credit and stock markets (Maskus et al., 2011). Considering that the internal funding sources of innovative enterprises are usually insufficient, innovation is vulnerable to external financing constraints (Brown et al., 2012; Aristizabal-Ramirez et al., 2017). Therefore, external financing is crucial for innovative firms (Hsu et al., 2014). Limited access to finance can prevent innovative firms from achieving the optimal scale, thus limiting innovative activities (Levine, 1997; Cabral and Mata, 2003). Tee et al. (2014) believe that the incidence of innovation failure will increase due to financing constraints. Howitt and Mayer-Foulkes (2005) consider that increasing the funding of research and development will improve the likelihood of successful innovation (Wang and Tan, 2021). This implies that innovation requires the pooling of savings from the public to offer adequate external financing. However, mobilizing and channelling savings to innovators incurs transaction costs. The development of the financial system reduces the associated transaction costs and broadens the access of firms to finance by providing a variety of funding options, thus promoting innovative activities (Maskus et al., 2012; Wang and Tan, 2021). For example, financial intermediaries (e.g., banks) can help to save on the cost of savings mobilization, through which innovative firms can collect funds

(Meierrieks, 2014). The important feature of financial institutions such as banks is that they collect idle funds from the public to form a certain scale and utilize them for the most suitable investments, which can address the financing constraints of innovative enterprises (Agion et al., 2005). In addition to this, specific financial instruments (e.g., equities) provide ways to finance directly, further optimize the concentration of savings, as well as release foreign sources of finance (Levine, 1997; Meierrieks, 2014). The high liquidity of the stock market can also reduce the cost of finance for enterprises, which can then access more funds to support the research and development and ensure the smooth progress of innovation projects (Maskus et al., 2011; Trinugroho et al., 2021). Through these mechanisms, well-developed banking sectors and capital markets can mobilize savings and channel the large amounts of finance needed for innovative activities centrally to entrepreneurs (Blackburn and Hung, 1998; King and Levine, 1993; Meierrieks, 2014). Tadesse (2005) also suggests that it is the development of the financial system that provides long-term large-scale financial support for innovation activities, making it feasible for new technologies to be created, adopted, and fully implemented. In general, the development of the financial system satisfies the large amount of capital demanded by enterprises in the process of innovation, provides a variety of external financing channels, ensures financial support, and stimulates innovative activities.

(3) The development of the financial system can manage and diversify liquidity risk and idiosyncratic risk for market participants, encouraging investors to shift towards innovative projects.

Investing innovative projects is subject to two types of risk, including liquidity risk and idiosyncratic risk. Liquidity risk arises when a financial assets cannot be rapidly traded within a certain period without influencing the market price. Idiosyncratic refers to the risk resulting from events that are specific to specific investment. Innovative projects often require long-term investment commitments, which restricts investors from trading funds due to liquidity needs, resulting in liquidity risks. In

addition, investing in innovative activities involves idiosyncratic risks. High-tech corporations develop new products or create new technologies through the systematic application of technical knowledge and science. Compared to other enterprises, they are exposed to uncertainty and idiosyncratic risk (Holmstrom, 1989; Hsu et al., 2014). The development of the financial system provides a set of risk management tools to help investors diversify these two risks, encouraging investors to shift their portfolios towards innovative projects (Rajan and Zingales, 1996; Levine, 2005; Bravo-Biosca, 2007; Trinugroho et al., 2021). Firstly, the financial system offers a wide range of financial instruments (e.g., bonds, equities, derivatives) that can be traded at low cost on specific financial markets (e.g., stock exchanges), enabling investors to trade assets at a reasonable price and desired time and reduce liquidity risk (Hwang et al., 2010). Bencivenga and Smith (1991) and Levine (1997) argue that greater liquidity provided by financial markets increases the investment in innovative projects that take longer to brew and have higher returns. Tadesse (2005) also concludes that liquidity risk is monitored and managed by developed financial systems, which contributes to more investment and fundings for riskier, long-term, but productive projects, such as innovation activities. Second, the financial system provides a set of risk management tools, and diversified portfolios, which reduces the idiosyncratic risks of innovative projects. There is a large number of financial securities available to the investors in developed financial system, which are correlated, so that investors can take less risk and obtain same expected return when diversifying the securities in their portfolio (Tadesse, 2005). According to Meierrieks (2014), diversifying investment in the portfolio reduces the exposure of investors to the idiosyncratic risk associated with specific project. Through diversified portfolios, the financial system allocates resources to different types of innovation projects, promotes investment in higher-quality projects, and reduces idiosyncratic risks, contributing to the development of the technological innovation industry. Therefore, developed countries with more developed capital markets can provide greater diversification of idiosyncratic risk for innovation projects and create more specialized and advanced products and technology (Meierrieks, 2014). Moreover, with the support of tools or investment

portfolios provided by the financial system, the stock of innovation projects can be priced higher because investors do not have to refrain from choosing innovation enterprises because of excessive worries about losses and risks, which also blocks potential high returns (Levine, 2005; Hsu et al., 2014). Investing in innovative activities implies potential high risks and expected returns. Individuals can invest according to risk appetite, some of which will choose high-tech corporations, such as Google, because of their preference for positive skewness in stock returns (Kapadia, 2006; Pástor and Veroesi, 2009). Higher stock prices benefited from financial markets stimulates innovation activities (Levine, 2005; Bravo-Biosca, 2007). Overall, financial markets can diversify and reduce liquidity and idiosyncratic risks, make long-term innovation projects more attractive to investors, and increase capital flows to high-tech enterprises, improving the level of innovation (Saint-Paul, 1992; King and Levine, 1993; Meierrieks, 2014).

(4) The development of financial system reduces the cost of screening and monitoring investment projects, and governing innovation enterprises.

As mentioned above, there is an information asymmetry between investors and borrowers, which is more pronounced in investments regarding innovation projects (Meierrieks, 2014). According to La porta et al. (1997) and Meierrieks (2014), insiders of the borrowing company (e.g. Managers) have motivations to misrepresent results about investment returns or research findings to outside investors. Aghion and Howitt (2005) also consider that borrowing innovation enterprises possibly tend to deceive creditors and hide successful outcomes of their projects to avoid repaying loans if there is no adequate supervision. In the analysis of possible defaults by entrepreneurs, Aghion and Howitt (2009) conclude, considering that innovation projects may face losses or be unfeasible, it is necessary for investors to spend time and costs on screening out the worthwhile loan projects. According to Ang (2011), investors also need to supervise the progress of the financing project to ascertain the entrepreneur's adherence to the loan agreement. Such costs arising from screening and

monitoring make innovation projects less attractive to investors (La porta et al., 1997; Meierrieks, 2014). The development of the financial system reduces the cost of screening and monitoring investment projects and governing innovation enterprises, addresses agency problems, thus stimulating firms to engage in innovation-related activities (De La Fuente and Marin, 1996; Morales, 2003; Mtar and Belazreg, 2020). Levine (1997) argues that financial intermediaries can help monitor investment projects and be entrusted to exercise corporate control by investors (Levine, 1997). Banks or other financial institutions screen loan applications and offer funds to innovation projects with higher quality to avoid risks and losses to the institutions themselves or to investors in the first place. When innovation projects raise funds in the financial market, financial institutions will specify the provisions on loan-related information and liability for breach of contract in the contract. After lending to innovation enterprises, financial institutions will also follow up and monitor the use of funds, financial statements, and the progress of innovation projects. To ensure that the funds lent can eventually be profitable, financial institutions track the activities of enterprises, review the performance of entities related to innovation projects, and evaluate the project reasonably, which to some extent guarantees the smooth process of projects (Barbosa and Faria, 2011). The supervision of financial institutions on innovation project can be considered as a significant determinant of ensuring the process of innovation (Barbosa and Faria, 2011; Tee et al., 2014). In the case of underdeveloped financial institutions, it is difficult to protect the interests and rights of creditors and the borrowing innovative enterprises cannot be supervised, which will promote fraudulent behaviour of borrowers. This in turn investors cannot trust and provide fundings to innovation projects, hindering innovation (Aghion et al., 2005; Tee et al., 2014). In the analysis of the relationship between finance and innovation-based growth, models developed by Aghion and Howitt (2009) predict that imperfect financial markets increase the cost of supervision, encouraging the hiding of successful outcomes so that enterprises can avoid repayments on loans. In contrast, a well-developed financial system substantially protects the rights of creditors, better monitoring and governing of borrowing companies, and reduces the risk of fraud.

Benefited from this, creditors are more likely to trust and offer credit to corporations that have greater prospects for successful innovation (Aghion et al., 2005; Aghion and Howitt, 2009; Tee et al., 2014). Moreover, because of specialization, financial intermediaries can effectively structure financial arrangements to alleviate conflicts between outsiders and insiders and establish contractual incentives to avoid misrepresentation of insider (Morales, 2003; Meierrieks, 2014). Overall, the selection, continuous attention, and supervision of the invested projects by the financial system reduces costs for investors and ensures the smooth process of innovation projects, which contributes to the improvement of innovation and technical sector (Tee et al., 2014; Ang, 2011).

2.3.1.2 Three mechanisms by which FD negatively affects innovation

(1) The high liquidity of the stock market resulting from a well-developed financial system provides convenience for large shareholders to freely exit the market and brings large fluctuations in stock prices.

As mentioned above, the financial system provides a wide range of financial instruments that can be traded at a low cost in specific financial markets, enabling investors to trade assets at reasonable prices and at the desired time, improving liquidity. However, considering that major shareholders with large shareholdings are more likely to obtain private information, higher liquidity provides convenience for major shareholders to sell the stocks and withdraw capital (Bharath et al., 2011). Based on the empirical results, Bharath et al. (2011) concludes that high liquidity can result in greater fluctuations in stock price, which indirectly increases the likelihood that companies are acquired. Financial markets may magnify the consequences of undesirable events, causing innovative companies that are in crisis or stagnant in the short term to be divested and plunged into financial distress (Bharath et al., 2011). Innovation companies may pay more attention to short-term benefits and give up

implementing policies that are beneficial to innovation in the long run, in which way they can keep stock prices stable.

(2) The development of the financial system stimulates market monopoly, hindering innovation activities.

According to Brown et al. (2009) and Trinugroho et al. (2021), further development of the financial system can negatively affect innovative activities as it promotes the occurrence of market monopolies. It is believed by some scholars that the development of the financial system will hinder innovative activities, because credit markets are more inclined to invest in mature or representative enterprises instead of innovative or young corporations, considering the lower risk of capital loss (Stiglitz, 1985; Rajan, 1992; Morck and Nakamura, 1999; Weinstein and Yafeh, 1998). Trinugroho et al. (2021) also argues that the improved access to information resulted from the development of credit markets dissuades financial intermediaries from providing funding to young innovative enterprises. This investment behaviour that favours mature enterprises and alienates young innovative firms is amplified by the developed financial system due to the availability of information, which hinders competition and promotes the formation of monopoly (Law et al., 2018). Financial intermediaries may filter out potential competitors to protect the interests of their existing clients, increasing monopolies and hampering healthy competition and innovative activity in the marketplace (Rajan, 1992; Trinugroho et al., 2021). Through an empirical study, Zhu et al. (2020) and Trinugroho et al. (2021) also concluded that the expansion of the financial sector may harm innovative activities.

(3) Overdevelopment of the financial system may result in the emphasis on the financial sectors, rather than innovative or productive sectors with high productivity and growth potential, contributing to a misallocation of resources and capital.

Tobin (1984) consider that human capital and material resources can be wrongly allocated to the financial sectors instead of the productive sectors due to the overdevelopment of the financial system. It is also illustrated by Borio et al. (2016) and Cecchetti and Kharroubi (2015) that, less productive but collateralizable projects are easily funded with the development of financial sector. Axelson and Bond (2015), Célérier and Vallée (2019), and Boustanifar et al. (2017) consider that due to high financing compensation, employees, even the competent employees in science, technology, engineering, and mathematics (STEM) are attracted to the sectors with low productivity and R&D potential when credit inflates. According to Zhu et al. (2020), reduced resources and investment in productive sectors may prolong the lag period for implementation and restructuring, diminishing the contribution of innovation to productivity and economic growth. Some empirical studies also illustrate the negative impact of financial development. For example, by including the financial sector in the endogenous growth model, Morales (2003) concludes that, although the favourable influence of the development of financial sector can spill over into other sectors leading to increased productivity, such spillovers can also undermine the innovation process. In addition, by examining firm-level data, Weinstein and Yafeh (1998) illustrate that while facilitating the access to credit, banks may also prevent lenders from investing in high-return and risky projects, for instance research and development projects, so that less productive but collateralizable projects are easily funded, rather than innovation firms with high growth potential.

2.3.1.3 Comparison of banking institutions and financial markets

According to Xiao and Zhao (2012), financial development is mainly manifested in two parts, including the development of stock market and banking sector, which have different effects on innovation activities. By examining the relationship between industrial innovation and financial structure, Dosi (1990) and Tee et al. (2014) also concluded that bank-based and market-based financial systems affect innovative activities to different degrees in different ways, and the design of financial system structures in different countries can promote the occurrence of innovative activities.

Allen and Gale (1999) believe that the difference in the impact of the two systems on innovation activities stems from their different functions in allocating resources. Different scholars have generated different opinions on which of the two financial systems, the banking sector, or the stock market, has a more significant positive impact on innovative activities.

Some studies argue (e.g., Allen and Gale, 1999) that market-based financial structures are more effective in promoting innovation than bank-based financial structures for the following three reasons. Firstly, the operating mechanism of equities is more suitable for innovation firms than debt contracts. Kortum and Lerner (2000) believe that stock markets provide higher stock prices for innovative projects and an exit mechanism for venture capital, which can catalyze innovative activity. Pastor and Veroesi (2009) and Trinugroho et al. (2021) suggest that stock markets can provide higher prices for innovative projects with potential high risks and expected returns. On the contrary, banks cannot offer higher prices or exit mechanisms for innovative projects with growth potential (Xiao and Zhao, 2012). Stiglitz (1985) and Law et al. (2018) indicate that the structure of debt contracts is relatively fixed, which is not suitable for innovative projects with large fluctuations in returns and risks. This explains why venture capital, which is essential for innovative activities, is more active in the stock market (Black and Gilson, 1998; Xiao and Zhao, 2012). Secondly, banks have a more conservative investment style, which tend to avoid risk and uncertainty and underinvest in innovative projects (Hsu et al., 2014). According to Rajan and Zingales (2001) and Hsu et al. (2014), due to lack of price signals from the market, banks are exposed to the risk of continuing to finance the projects with poor performance. Therefore, the credit market is more conservative in choosing investment projects, avoiding the projects with high uncertainty and risk (Morck and Nakamura,1999). Due to risk aversion, banks are unwilling to participate in innovative activities, which inhibits the flow of external funds to innovation enterprises (Weinstein and Yafeh, 1998; Beck and Levine, 2002; Hsu et al., 2014). Thirdly, due to leverage, debt financing may increase the financial distress of young

innovative companies. According to Cornell and Shapiro (1988) and Law et al. (2018), the market value of young innovation projects often depends on their future options, therefore, when they encounter financial distress, the cost of the distress will be magnified by leverage.

However, as argued by Trinugroho et al. (2021), much of the literature focuses more on the stock market and undermines the positive impact of the banking sector on innovation activities. The significant contribution of the banking sector to innovative activities is mainly reflected in the following two aspects. Firstly, according to Tee et al. (2014), banking institutions are the first choice of financing for innovative firms when they need external funding to support their innovation projects. Trinugroho et al. (2021) indicate that most enterprises follow the Pecking order theory when seeking external finance. This means that firms adhere to a hierarchy to raise finance, which will issue debt first and then issue equity when their internal funds are not sufficient. Second, the banking sector provides significant assistance to innovative projects in monitoring the innovation process and enforcing corporate governance, which cannot be provided by the stock market (Ramakrisnan and Thakor, 1984; Tee et al., 2014). Moreover, according to Trinugroho et al. (2021), considering that financial markets in developing countries are less developed, this supervisory and enforcement governance role of the banking sector is particularly important for firms in these countries.

In general, financial institutions and financial markets complement rather than substitute for each other in terms of their role in promoting innovative activities. As Merton and Bodie (1995) and Levine (1997) argue, it is financial markets and banks that work together to create sound financial services. Moreover, the actual impact of the two sectors on innovative activity varies across countries, making it pointless to argue which of the two plays a more significant role. Considering the different functions of the two in stimulating innovative activities, the question of how the two sectors can work together to create a well-functioning financial system is important

(Tee et al., 2014). A well-functioning financial system promotes the flourishing of innovation.

2.3.2 Empirical Findings

Some of the empirical research on analysing the relationship between financial development and innovation are shown in the Table 1.

Table 1. Review of Empirical Studies (organized by the author)

Authors	Methodology	Sample	Measurement of Financial Development	Measurement of Innovation	Results
Hwang et al., 2010	Two-step least square (2SLS) model	50 countries (1996-2000)	Market capitalization/GDP, Bank credit/GDP, Domestic private credit/GDP, Liquid liability/GDP, Stock traded value/MC, Lending minus deposit rate	6 indicators (3 indicators for creative input, 3 indicators for knowledge output)	Structure of financial system (+); Size of financial system (no effect); Market liquidity (+); Banking sectors (no effect)
Maskus et al., 2012	OLS regressions following Rajan and Zingales (1998) 's model	22 manufacturing industries in 18 OECD countries (1990-2003)	4 indicators for domestic FD (liquid liabilities, private credit by deposit money banks, stock-market capitalization, private bond-market capitalization), 4 indicators for international FD	R&D intensity (industry-level R&D expenditures/ industry output)	Domestic financial markets development (+); The results of international financial markets are divergent in different indicators
Xiao and Zhao, 2012	Ordered Logit model	28,000 firms from 46 countries (2002-2005)	stock market capitalization/GDP, domestic credit provided by banking sector/GDP	4 aggregate indicators from a questionnaire to examine firms' innovation activities	Stock market (+); Banking sector (+) in countries with lower government ownership of banks; Banking sector (- / no effect) in countries with higher government ownership of banks
Bhatti et al., 2013	Fixed-effect model, difference GMM model, system GMM model	36 countries (26 OECD and 10 non-OECD) (1980-2006)	Finance Activity (the product of Private Credit and Trading Value), Finance Size (the sum of Private Credit and Market Capitalization)	business enterprise expenditures on R&D financed by industry/GDP	The effect of FD on economic growth depends on the level of innovation.
Hsu et	Fixed-effect	32 developed	equity market development	Patent, Citation,	equity markets (+) in the industries that

al., 2014	model	and emerging countries (1976-2006)	(Stock Market Capitalization/GDP), credit market development (Bank Credit/GDP)	Originality, Generality, R& D	are more high-tech intensive or more dependent on external finance; credit markets (-) in the industries that are more high-tech intensive or more dependent on external finance
Meierrie ks, 2014	OLS regressions	51 developed and emerging countries (1993-2008)	liquid liabilities/GDP private credit by deposit money banks/GDP	patent applications by residents of a country per thousand residents	FD (+)
Tee et al., 2014	random effects models	7 East Asian countries (1998-2009)	11 indicators (3 indicators for FD size, activity and structure, 4 indicators for banking sector, 4 indicators for stock market)	the number of innovation patent applications, the number of researchers and technicians	Size of financial system (+); Activity of financial system (+); Structure of financial system (no effect); Banking sector (+); Stock market (no effect);
Aristizab al-Ramir ez et al., 2017	binary response models (probit models)	11,029 representative firms from 18 developing countries (2006-2013)	private credit from banks and other financial institutions/GDP, private credit of banks/GDP, stock market capitalization/GDP	Innovation Dummy, Innovation Index, Product Innovation, Process Innovations, Patents, Use of licensed Technology	FD (-) for firms' innovation in developing countries
Law et al., 2018	Generalized Method of Moments (GMM) estimators	75 developed and developing countries (1996-2010)	Private sector credit/GDP, Domestic credit/GDP	patent application divided by labor force, patent grant divided by labor force	inverted U-shaped between FD and innovation; the (+) effect of FD decreases with increased FD level
Zhu et al., 2020	linear system GMM	50 countries (1990-2016)	private credit by banks and other financial institutions/GDP, credit issued to private sector by money deposite banks/GDP, demostic credit to private sector/GDP, liquidity liability/GDP	patent applications per 100 billion USD, the number of utility models	FD (+) in full sample; the (+) effect of FD decreases with increased FD level.
Trinugro ho et al., 2021	dynamic GMM estimation	68 developed and developing countries (1995-2018)	2 indicators for credit market development (domestic credit to the private sector/GDP, domestic credit provided by financial sectors/GDP); 2 indicators for equity market development (the total value of stock traded/GDP, the market capitalization of the listed domestic companies/GDP)	patent application per labor, patent grants per labor	inverted U-shaped relationship between FD and innovation; inverted U-shaped relationship exists both in equity and credit market; the effect of equity market (+) on innovation is greater than credit market (+);

The content of these studies can be summarized in the following five points. Firstly, regarding the research sample, most scholars collect country-level data to examine how financial development affects innovation in a set of countries from a macro perspective, some of which also examine the impact of financial development on specific industries, (e.g., Maskus et al., 2012; Hsu et al., 2014). In contrast, a few scholars utilize firm-level data to test whether financial development increases firms' level of innovation (Xiao and Zhao, 2012; Aristizabal-Ramirez et al., 2017). Second, most of the country-level studies analyze a number of countries as the overall sample, including developed and developing countries, only two of them divide the whole sample into different groups to conduct comparative studies (Zhu et al., 2020, Trinugroho et al., 2021). For example, Zhu et al. (2020) divide the sample countries into two groups according to the level of financial development, examine whether the effect of financial development on innovation is different in the two groups of countries, and concludes that in contrast to countries with low financial development, the positive effect of financial development on innovation is relatively less in countries with high financial development. Third, some studies divide financial development into two parts to study its impact on innovation (Hwang et al., 2010; Tee et al., 2014; Hsu et al., 2014; Maskus et al., 2012; Xiao and Zhao, 2012; Trinugroho et al., 2021). Among them, Maskus et al. (2012) study the role of domestic financial market and international financial market and conclude that the domestic financial market exerts a favourable effect on innovation, while the role of the international financial market is difficult to draw a conclusion. Differently, Hwang et al. (2010), Xiao and Zhao (2012), and Tee et al. (2014) separate financial development into the banking sector and the stock market, to examine the effect of financial development, but the results of the three are divergent. Among them, both Hwang et al. (2010) and Xiao and Zhao (2012) confirm the positive influence of the stock market on innovation. In the realm of the banking sector's impact on innovation, researchers Hwang et al. (2010) suggest a relatively insignificant role, whereas Xiao and Zhao (2012) contend that the significance of this influence is contingent upon the extent of

government ownership in banks. Specifically, their findings reveal that in countries with low government ownership of banks, the banking sector assumes a vital and constructive role in fostering innovation. Conversely, in nations with high government ownership of banks, the sector's impact on innovation appears to be neutral or even detrimental, hindering the level of innovative progress. These contrasting perspectives shed light on the complex interplay between banking structures and their contribution to fostering innovation across different national contexts. Different from the results of Hwang et al. (2010) and Xiao and Zhao (2012), Tee et al. (2014) conclude that the effect of the banking sector is positive and significant, while the stock market has no effect on innovation. Both Hsu et al. (2014) and Trinugroho et al. (2021) examine the impact of stock market and credit market in the financial system. Hsu et al. (2014) believe that the stock market promotes the innovation in the industries that are more reliant on external finance or high-tech intensive, while the effect of credit market on innovation in these industries is negative. Trinugroho et al. (2021) find that the relationship between the stock market and credit market and innovation is inverted U-shaped, which means that the positive effect of financial development on innovation will decrease as the level of financial development increases. They also conclude that stock market has a stronger positive effect than credit market on promoting innovation. Fourth, numerous different indicators are applied to measure the level of financial development from one or several dimensions, which reflects the complexity of financial development. Instead of quantifying the overall level of financial development by employing several proxies, some articles analyze the effect of financial development from several dimensions (Hwang et al., 2010; Tee et al., 2014). For example, Tee et al. (2014) examine how financial development affects innovation from three dimensions, consisting of the size, activity, and structure of the financial system, and conclude that the size and activity of financial system have a significant and positive impact on innovation, while structure has no effect. Fifth, in terms of methodology, scholars applied various econometric techniques to conduct panel data analysis, including OLS

regressions, random effects model, fixed-effect model, and Generalized Method of Moments (GMM) estimators, etc.

3. Research objectives and questions

3.1 Gaps of Previous Research and Objectives of This Paper

For the following three considerations, this paper will design research to fill in the gaps of previous studies. First, this thesis decides to analyse the relationship between financial development and innovation at the macro level by choosing European countries as sample, which will be divided into two groups (Western countries and Central and Eastern European countries) for comparative study to examine whether there are differences in the role of financial development on innovation levels in these two groups. As mentioned above, most of previous papers analyse numerous countries as a pooled sample, including developing and developed countries, and only a few separate them into different groups (Zhu et al., 2020, Trinugroho et al., 2021). The existence of heterogeneity among these countries may lead to bias in the results, which cannot be applicable to all selected countries. In addition, both Law et al. (2018) and Trinugroho et al. (2021) conclude that the relationship between financial development and innovation is inverted U-shaped, which suggests that there are differences in the effect of financial development on innovation in countries with different levels of financial development. Therefore, it is necessary for the paper to conduct a comparative study.

Second, this thesis will constraint the analysis to the role of financial institutions in the financial system without considering the financial market and quantify the level of financial development from the four dimensions of financial institutions, including depth, access, efficiency, and stability, which will be explained in detail in Chapter 4. Most of the literature on the stock market, an important component of the financial market, shows its positive impact on innovation. However, the results of research on the effect of the banking sector in financial institutions are not divergent. More importantly, the countries selected in this paper include some developing countries, and according to Boukhatem (2016), the banking sectors play a dominant role in the

financial systems of these countries. Boukhatem (2016) delivers that proxies of financial institutions are applied by many studies to quantify the level of financial development. Trinugroho et al. (2021) also suggest that in developed countries, the impact of financial institutions in the financial system is more significant. The financial markets in these countries cannot perform well, while banking sectors can provide more supervision and enforcement governance. For these two reasons, this paper will focus on measuring the development of financial institutions in the financial system. Most articles choose different indicators to represent the level of financial development, which may contribute to divergent results, and is not convenient to provide more detailed policy recommendations. A few scholars consider financial development from different dimensions and select indicators for each dimension to examine the effect of financial development on innovation (Hwang et al., 2010; Tee et al., 2014). Čihák et al. (2013) also illustrate that the functioning of financial systems is multi-dimensional. Inspired by them, this paper follows the approach proposed by Čihák et al. (2013) and measures the development of financial institutions from four dimensions, consisting of depth, access, efficiency, and stability.

Third, the combination of two techniques is employed to carry out the empirical analysis on the relationship between financial development and innovation, including fixed-effect models and system-GMM models. The fixed effects model will be used as the main model to examine the impact of financial development on innovation. The system GMM model is used to check the robustness of the empirical results, which will be illustrated in detail in the methodology part.

3.2 Research Questions

To fill in the gaps of previous studies and achieve the objectives mentioned above, the following research questions is proposed and will be analysed:

Question 1: How does financial development affect the level of innovation?

Question 2: How does the contribution of financial development to innovation differ in these two groups of countries (Central and Eastern European countries and Western European countries)?

Question 3: How do the four dimensions (depth, access, efficiency, and stability) of financial development affect the level of innovation in these two groups of countries (Central and Eastern European countries and Western European countries)?

4. Data and Methodology

4.1 Variables and Sources of Data

This section introduces the definition, measures, and source of dependent variables, independent variables, and control variables to examine the effect of financial development on innovation. Table 2 presents the summary of these variables. The selection of variables and detailed explanations is discussed in the following part.

Table 2. Variables in empirical analysis

	Indicators	**Variables**	**Description**	**Source**
Dependent Variables	The number of total patent applications	Patent	Total patent applications (direct and PCT national phase entries)	World Intellectual Property Organization (WIPO)
	Research and Development Expenditure	R&D	R&D expenditure as a percentage of GDP, comprising both capital and current spending in private non-profit sectors, higher education government, and business enterprise.	World Development Indicators (World Bank)
Independent Variables	Financial Institutions Development	FD	An aggregate of three dimesons, Depth, Access, and Efficiency of Financial Institutions through PCA	Financial Development Index Database (IMF)
	FD dimension: Depth	Depth	An aggregate of sub-index: private-sector credit to GDP, insurance premiums, life and non-life to GDP, mutual fund assets to GDP, pension fund assets to GDP.	Financial Development Index Database (IMF)
	FD dimension: Access	Access	An aggregate of sub-index: branches per 100, 000 adults, ATMs per 100, 000 adults	Financial Development Index Database (IMF)
	FD dimension: Efficiency	Efficiency	A re-scale aggregate of sub-index: net interest margin, lending-deposits spread, return on assets, return on equity, overhead costs to total assets, non-interest income to total income.	Financial Development Index Database (IMF)
	FD dimension: Stability	Stability	Bank credit to bank deposits (bank credit offered to the private sector by domestic money banks as a share of total deposits)	Global Financial Development Database (World Bank)
Control Variables	GDP per capita, PPP (current international $)	GDP per capita	Gross domestic product (GDP) per capita in current international dollars with the conversion factor of purchasing power parity (PPP)	World Development Indicators (World Bank)
	School enrolment, tertiary (% gross)	Education	Ratio of total tertiary school enrolment, regardless of age, to the population of the age group that officially corresponds to the level of tertiary education.	World Development Indicators (World Bank)
	General government final consumption expenditure (% of GDP)	GOV_EXP	All government current expenditures for purchases of goods and services	World Development Indicators (World Bank)
	Trade (% of GDP)	Trade	Trade is the sum of exports and imports of goods and services measured as a share of gross domestic product.	World Development Indicators (World Bank)
	Political Stability and Absence of Violence/Terrorism	Political Stability	The perceptions of the likelihood of political instability and/or politically motivated violence, including terrorism.	World Development Indicators (World Bank)

4.1.1 Panel Data Description

This study applies a panel dataset to analyse how financial development affects the level of innovation by using 40 European countries over the period 1995-2021. The 27-year period starting in 1995 is chosen for two reasons. First, the 1989 revolutions reshaped the political and economic landscape of Central and Eastern European countries. Some of the affected countries, such as the Czech and Slovak Republics, which separated from the Czechoslovak Republic in 1993, needed time to establish policy and financial systems. Second, with globalization, market opening and legal and regulatory reforms since 1995, and the creation of the euro area in 1999, the reforms and transformation of financial development in European countries began to accelerate. Therefore, choosing 1995 as the starting point for a 27-year study helps to capture the impact of these events on financial liberalization, market development and innovation capacity, providing a sufficiently meaningful window of time to examine how financial development affects innovation. The sample of countries includes Albania, Austria, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Georgia, Hungary, Iceland, Ireland, Italy, Kosovo, Latvia, Liechtenstein, Lithuania, Luxembourg, Moldova, Montenegro, Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, Russia, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, United Kingdom. Due to the heterogeneity of these European countries in terms of their level of financial development and innovation level, they are divided into two subgroups (Western European countries and Central and Eastern European countries) to carry out a comparative study to determine whether the impact of financial development on innovation is different in the two groups of countries.

4.1.2 Measures of Financial Development

In terms of independent variables, five indicators are adopted to measure the level of financial development, consisting of 'FD', 'depth', 'access', ' efficiency', and 'stability', where FD as an overall indicator represents the level of financial development, while

the other four indicators represent the four dimensions of financial development, depth, access, efficiency, and stability, respectively. Four of the five indicators, including FD', 'depth', 'access', and 'efficiency', are from the Financial Development Index Database in the International Monetary Fund (IMF), and the other one indicator, 'stability', is from the Global Financial Development Database in the World Bank. According to Boukhatem (2016), financial systems can be divided into two sectors, financial markets and financial institutions. Financial institutions include institutions that provide financial services, for instance insurance companies and banks, while financial markets mainly encompass bond markets, stock markets, and derivative markets (Boukhatem, 2016). This study focuses on European countries, which includes both Western European countries group with a relative high level of financial development and Central and Eastern European countries group with a relative low level of financial development. In the latter group, the data on the financial market sector in these countries is superficial and insufficient to support the empirical research. Furthermore, Boukhatem (2016) illustrates that the banking sector in those countries provides more reliable financial services and stands dominant in their financial systems, therefore, indicators of financial institution are applied by many scholars to quantify the functioning of financial system. Following the approach adopted by them, this research also uses the indicators of financial institutions to measure the level of financial development.

FD, measured by the indicators of financial institutions, is generated through Principal Component Analysis (PCA), which, as Svirydzenka (2016) states, comprehensively captures the aggregated effect of financial institutions. As mentioned above, considering the dominant role of financial institutions in the financial systems of the chosen countries, it can be regarded as a reasonable proxy to quantify the level of financial development. Čihák et al. (2013) illustrates that the functioning of financial systems is multi-dimensional and can be characterized into four dimensions, consisting of depth, access, efficiency, and stability. Financial depth reflects the size of financial systems. Financial access captures the extent to which individuals and

businesses can get access to and utilise financial services. Financial efficiency measures whether financial intermediaries are efficient in allocating resources and facilitating transactions. Financial stability refers to the ability of the financial system to remain stable when experiencing severe shocks. Therefore, this study aims to examine the impact of each dimension on the level of innovation comprehensively and thoroughly. Three of these four dimensions are measured by composite indicators of multiple sub-indices to summarize the characteristics, provide more comprehensive information, and avoids bias, including ‘Depth’, ‘Access’ and “Efficiency. The measure of depth aggregates five indexes, consisting of private-sector credit to GDP, insurance premiums, life and non-life to GDP, mutual fund assets to GDP, and pension fund assets to GDP. The indicator of access summarizes the information on branches per 100, 000 adults, and ATMs per 100, 000 adults. Net interest margin, lending-deposits spread, return on assets, return on equity, overhead costs to total assets, and non-interest income to total income are consolidated into the proxy for financial efficiency, some of which, for example, the net interest margin, representing inefficiency instead of efficiency are rescaled so that the composite indicator reflects financial efficiency (Svirydzenka, 2016). In contrast, financial stability lacks a composite indicator, hence, the 'bank credit to bank deposits ratio' is chosen to gauge the level of this dimension. The use of this measure spans a longer time period than other proxies, aligning better with the empirical analyses in this thesis. It is essential to note that a higher value for 'bank credit to bank deposits ratio' signifies greater financial system instability. By examining these dimensions in detail, this study aims to contribute to a comprehensive understanding of the relationship between financial development and innovation in the selected countries.

4.1.3 Measures of Innovation

According to the literature, there are mainly three ways to measure the level of innovation, consisting of productivity growth, innovative inputs, and innovative outputs (Hsu et al., 2014; Meierrieks, 2014; Mtar and Belazreg, 2020). First,

productivity growth can be considered as an indicator of innovation (Hall 2011; Mtar and Belazreg, 2020). Generated by innovation, the excess of high output growth over capital and labour inputs can contribute to multifactor productivity growth (Jorgenson, 2011). This measure as a reasonable proxy of innovation have been employed by some scholars in their empirical studies (Jones, 2002; Hall, 2011; Iwaisako and Futagami, 2013; Mtar and Belazreg, 2020). The remaining two approaches focus on the process of innovation, quantifying the level of innovation in terms of inputs and outputs respectively. The indicators related to the input method mainly includes Research and Development expenditure, the number of R&D personnel, etc. The output approach considers the results of innovation, measuring how many patents are applicated, granted or cited.

In this paper, two indicators are selected, including Research and Development expenditure and the number of patent applications, to measure the level of innovation from the perspectives of inputs and outputs, respectively. The first selected innovation measure, Research and Development expenditure, captures the costs incurred by a given entity in carrying out research and development activities. The measure is obtained from World Development Indicators database in World Bank, some scholars have been applied it to quantify the level of innovation (Hsu et al., 2014; Meierrieks, 2014). The second indicator selected to measure the level of innovation is the number of patent applications. Acs et al. (2002) has empirically evidenced that patent data can be considered as reliable proxies for innovation, which reflects the flow of new knowledge and information. The use of patent data to quantify innovation has been adopted in numerous previous research (e.g., Griffith et al, 2006; Varsakelis, 2006; Acharya and Subramanian, 2009; Hsu et al., 2014; Pradhan et al., 2018; Meierrieks, 2014). Among them, there are three main patent indicators adopted to measure the level of innovation as innovative output, including the number of patents applications, the number of patents granted, and the number of patent citations (Trinugroho et al., 2021). Among these three indicators, patent citations, which measures the number of

times a patent is cited, reflects the quality, impact and value of innovation and has been used in some literature as a measure of innovation (Hsu et al., 2014).

However, due to the scarcity of databases pertaining to the number of patent citations and the absence of data beyond 2006, some studies have limited their research scope to this year (Hsu et al., 2014). Although Guellec et al. (2000) highlighted the significant implications of patent citations, this indicator had to be omitted from our study due to data unavailability. Our research focuses on investigating the impact of financial development on innovation over the past 27 years, necessitating a broader time dimension. As an alternative, we selected the number of patent applications, rather than granted patents, as our innovation indicator. This choice was motivated by the fact that there is typically a two-to-three-year lag between the application and grant years, and using patent applications can address this truncation issue (Squicciarini et al., 2013; Zhu et al., 2020). Moreover, since innovation's effects on the real economy begin right from its creation, we deemed the application year to be a more suitable representation of its actual effective time, in line with previous studies by Griliches et al. (1987), Hsu et al. (2014), and Zhu et al. (2020). Consequently, the number of total patent applications, obtained from the World Intellectual Property Organization (WIPO), was chosen as the second indicator to measure the level of innovation. This proxy has been widely adopted by several scholars, including Wang (2013), Ang and Madsen (2012), Ang (2010, 2014), Pradhan et al. (2017), Kortum (1993), Agenor and Neanidis (2015), Varsakelis (2006), Tee et al. (2014), and Trinugroho et al. (2021).

4.1.4 Control Variables

In line with the existing studies, some variables regarded as determinants of innovation are introduced in empirical model as control variables. The first control variable is GDP per capita, PPP (current international $) to control the level of

economic development of a country. A higher level of economic development leads to more open markets for investment and innovation activities (Lall, 1992; Meierrieks, 2014; Mtar and Belazreg, 2020). GDP per capita tends to imply the ability of a country's wealth to increase its innovative activities (Tee et al., 2014). The second control variable is the level of education, which is measured by the ratio of total tertiary school enrollment, regardless of age, to the population of the age group that officially corresponds to the level of tertiary education. Education can promote innovation by increasing the dissemination of knowledge, raising the cognitive level and technological competence of the citizens, and creating a more skilled workforce (Varsakelis, 2006). In addition, general government final consumption expenditure is included to characterize the increased innovation activity from more public spending. As emphasized by Lall (1992) and Furman et al. (2002), considering the effect of trade openness on promoting innovative activity, Trade (% of GDP) should be also introduced, which is measured by the sum of exports and imports of goods and services as a share of GDP. More trade flows mean more imports and exports of goods and services, which contributes to more knowledge spillover, technological diffusion, and innovative activities (Meierrieks, 2014). Lall (1992) also states that increased domestic and international competition resulted from trade openness can foster more innovative activities by market participants. Finally, to consider the impact of political stability on innovation, the indicator, ‘political stability and absence of violence/terrorism’ is also added, which measures the extent to which a country can ensure political stability. Political instability weakens the protection of property rights, reduces Foreign direct investment, and fails to provide a conducive entrepreneurial environment, which constrains innovative activity (Svennson, 1998; Varsakelis, 2006; Meierrieks, 2014). The measures of these control variables are all sourced from World Development Indicators database in World Bank.

4.2 Statistical Analysis

4.2.1 Descriptive Information

The descriptive information of all variables in this thesis is summarized in Table. 3, including observations, mean value, median value, maximum value, minimum value, and standard deviation.

Table 3. Descriptive Information

Variables	Obs	Mean	SD	Min	Median	Max
Patent	902	6.75	2.091	2.56	6.69	11.20
R&D	756	1.43	0.927	0.08	1.24	3.60
FD	858	0.59	0.230	0.12	0.60	0.98
Depth	858	0.45	0.298	0.02	0.39	1.00
Access	858	0.57	0.281	0.04	0.58	1.00
Efficiency	858	0.55	0.124	0.15	0.58	0.79
Stability	767	4.65	0.598	2.59	4.71	6.43
Education	830	0.58	0.192	0.10	0.59	0.93
GDP per capita	913	10.00	0.774	7.98	10.15	11.52
GOV_EXP	908	0.19	0.038	0.10	0.19	0.26
PS	798	0.61	0.670	-1.64	0.71	1.64
Trade	913	1.00	0.466	0.44	0.88	3.12

To ensure homogeneity and avoid heteroscedasticity, the thesis employs logarithmic transformations for the variables 'Patent', 'Stability', and 'GDP per capita'. This approach helps maintain consistency with the other dimensions derived from different databases. Specifically, the logarithmic form of 'Stability' is applied to ensure its magnitude remains comparable to the other three variables. Notably, the table reveals interesting insights. After applying natural logarithms to the number of patent applications, the average value is 6.75, with a minimum value of 2.56, a maximum

value of 11.20, and a standard deviation of 2.091. Similarly, the R&D expenditure indicator has a mean value of 1.43, a minimum value of 0.08, a maximum value of 3.60, and a standard deviation of 0.927. Comparing these innovation indicators with the variables of financial development, it becomes apparent that there is a relatively large degree of dispersion in innovation levels among the selected European countries. Furthermore, among the control variables, both 'GDP per capita' and 'PS' also exhibit relatively large standard deviations, indicating variations in economic development and political stability across these countries. Overall, this comprehensive analysis highlights the significant differences in innovation, economic development, and political stability among the selected European countries.

4.2.2 Correlation

Appendix 1. shows the correlation matrix for all the variables that will be adopted in the following empirical studies. The correlation coefficient between ‘Patent’ and ‘R&D’ is 0.601 and $p<0.001$, which indicates that the number of total patent applications (innovation output) is positively correlated with R&D expenditure (innovation input). This implies that countries with more innovation inputs may also have higher levels of innovation output. In terms of explanatory variables, there is a positive and significant correlation between ‘FD’ and both ‘Patent’ and ‘R&D’, and the correlation coefficients are 0.474 and 0.613, respectively, indicating that an increase in the level of financial development is expected to increase R&D expenditure and the number of patent applications. Among the four dimensions of financial development, ‘Depth’, ‘Access’ and ‘Efficiency’ are significantly and positively correlated with both ‘Patent’ and ‘R&D’, of which the correlation coefficients between ‘Depth’ and both ‘Patent’ and ‘R&D’ are relatively large (0.604 and 0.831, respectively), which implies that the depth of financial development may have a greater impact on innovation input and output.

However, the other dimension, ‘Stability’, only has a significant and positive correlation with R&D expenditure and has no significant correlation with the number of patent applications. In addition, the overall indicator of financial development ‘FD’ is significantly and positively correlated with all four dimensions and has a high correlation coefficient with the other three dimensions except stability. This is because the proxy for ‘FD’ aggregates the indicators of the three dimensions of depth, access, and efficiency, while the index of stability is sourced from another database. As for the control variables, the four variables except for ‘Trade’, consisting of ‘Education’, ‘GDP per capital’, ‘GOV_EXP’, and ‘PS’, all have a significant and positive correlation with both ‘Patent’ and ‘R&D’. It indicates that the improvements in the level of education, economic development, government expenditure, and political stability are expected to increase R&D expenditure and the total number of patent applications. Among these control variables, ‘GDP per capita’ has relatively large correlation coefficients with both ‘Patent’ and ‘R&D’, which means that the level of economic development can largely affect innovation input (R&D expenditure) and innovation output (the number of total patent applications). Compared with the number of patent applications, these four control variables have a larger correlation coefficient with R&D expenditure. This suggests that the increase in the level of education, economic development, government expenditure, and political stability have a greater impact on R&D expenditure than the number of total patent applications. On the other hand, it is noteworthy that trade volume shows no significant correlation with R&D expenditure, indicating that changes in trade activity do not seem to have a direct impact on R&D expenditure. However, a striking finding emerges as trade volume exhibits a significant and negative correlation with the number of total patent applications. This unexpected result suggests that increased trade might hinder innovation output, contrary to what was initially anticipated. The possible underlying reasons for this negative correlation could be linked to how resources are allocated and the degree of reliance on existing technology. Certain countries may prioritize the production and export of goods and services, allocating fewer resources to innovation endeavors. Additionally, nations heavily dependent on

imported technology might be less inclined to invest in independent research and development. While the majority of correlation outcomes align with our initial expectations, it is crucial to conduct empirical analysis to thoroughly examine the intricate relationship between financial development and innovation.

4.3 Methodology

4.3.1 Comparative Analysis

As Law et al. (2018) and Zhu et al. (2020), have summarized in their studies, the impact of financial development on the level of innovation varies depending on the level of financial development or economic development. Considering the significant differences between Western European countries and Central and Eastern European countries, this thesis will conduct a comparative study to examine the distinct effects of financial development on innovation in these two groups of countries. The sample of this paper consists of 40 European countries, including 22 CEE countries and 18 WE countries, and the list of two groups of countries provided in the Appendix 2. The grouping of WE and CEE countries is based on a comprehensive consideration of geographical location, historical background, economic development, and political systems. Therefore, among the selected Western European countries, even some countries, such as Sweden, which are geographically located in Northern Europe, are still considered as ‘Western European countries’. This is because the term ‘Western European countries’ refers to European countries that are geographically located to the west compared to Central and Eastern European countries and also denotes countries that significantly differ from Eastern European countries in terms of their social and economic characteristics. These economically developed countries with similar institutional frameworks located in the western Europe are collectively referred to as Western European countries in this thesis, distinguishing them from CEE countries. The 22 selected CEE countries share common characteristics in terms of economic development and historical background. It is important to note that the

level of economic development in CEE countries is relatively lower compared to their counterparts in WE. The economic disparities can be attributed to the influence of the Eastern European transition, with most CEE countries having been part of the Eastern Bloc or former members of the Yugoslav Federation, which led to significant political and economic transformations. In contrast, the 18 chosen Western European countries have not experienced the communist period or major upheavals. As a result, they boast stable social systems, higher levels of economic development, and open institutional environments that have contributed to their progress and prosperity.

Before conducting the empirical analysis, it is essential to gain a preliminary understanding of the status of financial development and the level of innovation in the CEE and WE countries. Figure 1-14 presents the level of innovation and financial development in each country of the two groups. For example, in Figure 1-4, the horizontal axis delivers the countries' names in CEE group and WE group, the vertical axis presents the value of 'Patent' and 'R&D' index, and the height of each bar represents the average value of 'Patent' and 'R&D' over the period of 1995-2021. The bars for countries in the CEE group and WE group are colored blue and yellow respectively for better distinction and contrast. In addition, the orange line stands for the average value in the CEE group, or WE group, to compare the values of the two groups of countries more intuitively. Specifically, Figure 1-4 show the number of patent applications (in natural logarithmic form) and the level of R&D expenditure for each country in the two groups. The results indicate that both in terms of the number of patent applications and R&D expenditure, the innovation levels in Western European countries are significantly higher than those in Central and Eastern European countries. As for the number of patent applications, the average value in the CEE countries is 1637 (in the form of natural logarithm), and the value in the WE countries is 9485 (in the form of natural logarithm). Moreover, the number of patent applications in most WE countries exceeds the average value in CEE countries. As for R&D expenditure, the average value in CEE countries is 0.737, and that in WE countries is 2.06, which means that the R&D expenditure in WE countries is almost

three times as that in CEE countries. In addition, WE countries also have higher level of financial development than CEE countries. To be more specific, as shown in Figure 5 and 6, the average value of the overall financial development index in CEE countries is 0.41, while the average value in WE countries is 0.76, indicating that the functioning of financial systems in WE countries better. In terms of the four dimensions of the financial system, financial depth and access in WE countries are performed significantly better, compared to CEE countries. The financial depth and access of WE countries are nearly four times and almost twice as much as those of CEE countries, respectively. This indicates that in comparison to CEE countries, the financial systems of WE countries are larger in size, and individuals get access to financial products and services easier. The difference between WE countries and CEE countries with respect to financial efficiency and stability is not significant, especially the levels of financial stability in the two groups of countries are quite similar.

In addition, Figures 15-21 are framed over time, displaying the average values of countries in the CEE and WE group for each year. The values of each group are plotted as a line over the years, illustrating the changes in the level of financial development and innovation from 1995 to 2020. The blue line represents CEE countries, and the yellow line stands for WE countries, allowing for an intuitive comparison of the trends between the two groups. Figures 15 and 16 deliver the changes in 'Patent' and 'R&D' from 1995 to 2020. While there is a significant difference in the number of patent applications and R&D expenditure between the two groups, the overall trends of CEE group and WE group are similar. Both groups experienced several major fluctuations in the number of patent applications over the years, followed by a downward trend in the most recent six years. The change of R&D expenditure in CEE and WE group from 1995 to 2020 present a slow upward trend. Regarding financial development, as shown in table 18, both CEE and WE groups exhibit an initial increase followed by a decrease over the years, and the significant difference between the two groups remains relatively unchanged from 1995 to 2020. As for the four dimensions of financial development, as displayed in

figures 18-21, the trends of CEE group and WE group are generally consistent. Both groups deliver a gradual increase in financial depth and efficiency, an initial rise and subsequent decline in financial access, and stable financial stability. The disparity between CEE and WE countries in the four dimensions of financial development is substantial, the functioning of financial systems in WE countries are significant superior over CEE countries. This discrepancy remains unchanged in access, efficiency, and stability of financial systems, and has increased in financial depth over the years. This indicates that CEE countries are unable to keep up with WE countries in enhancing financial depth.

Overall, the results of the preliminary study show significant differences in financial development and innovation between CEE countries and WE countries, therefore, comparative analysis should be conducted to examine whether the influence of financial development on innovation differs between the two groups of countries.

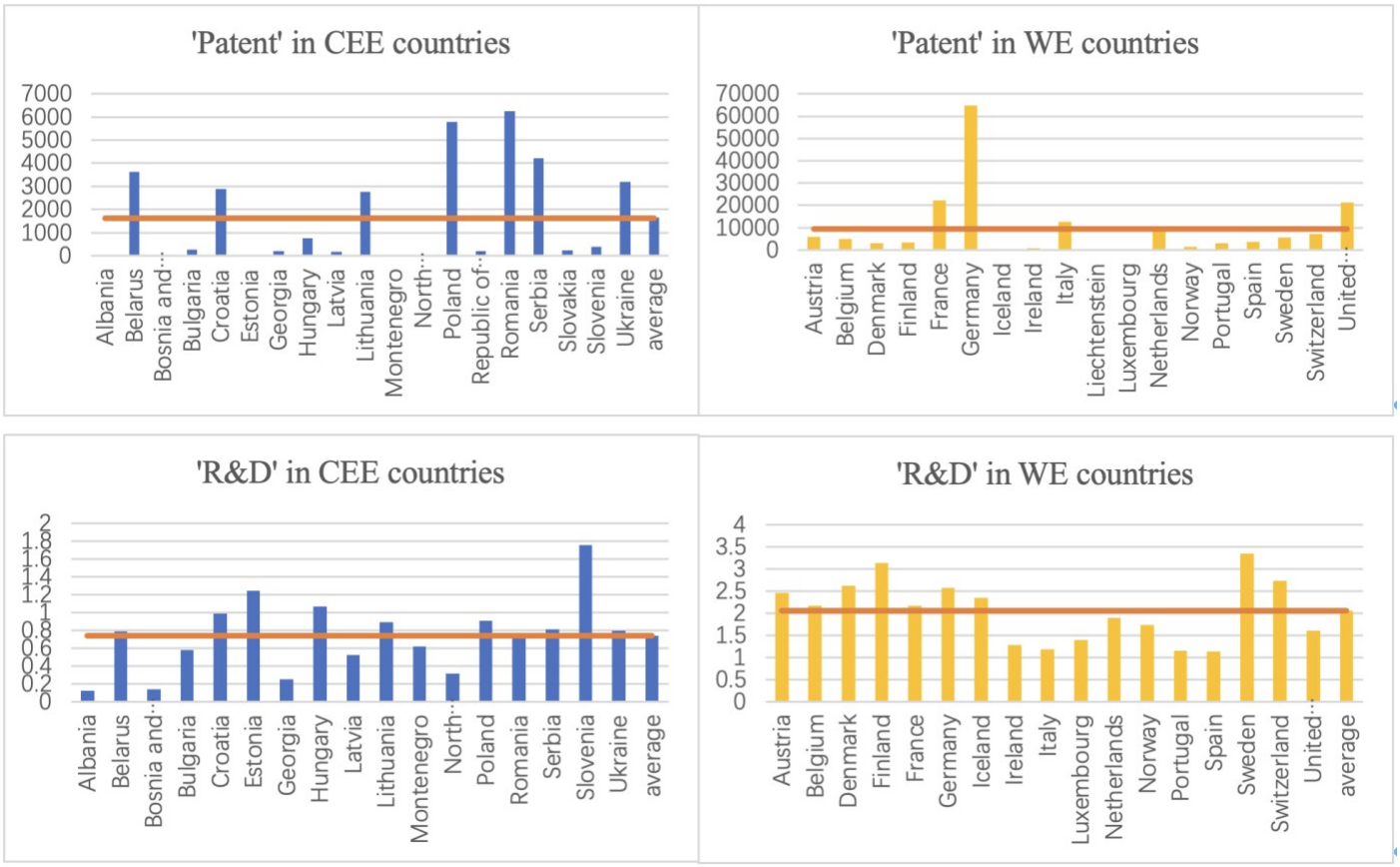

Figure 1-4. ‘Patent’ and ‘R&D’ in CEE group and WE group.

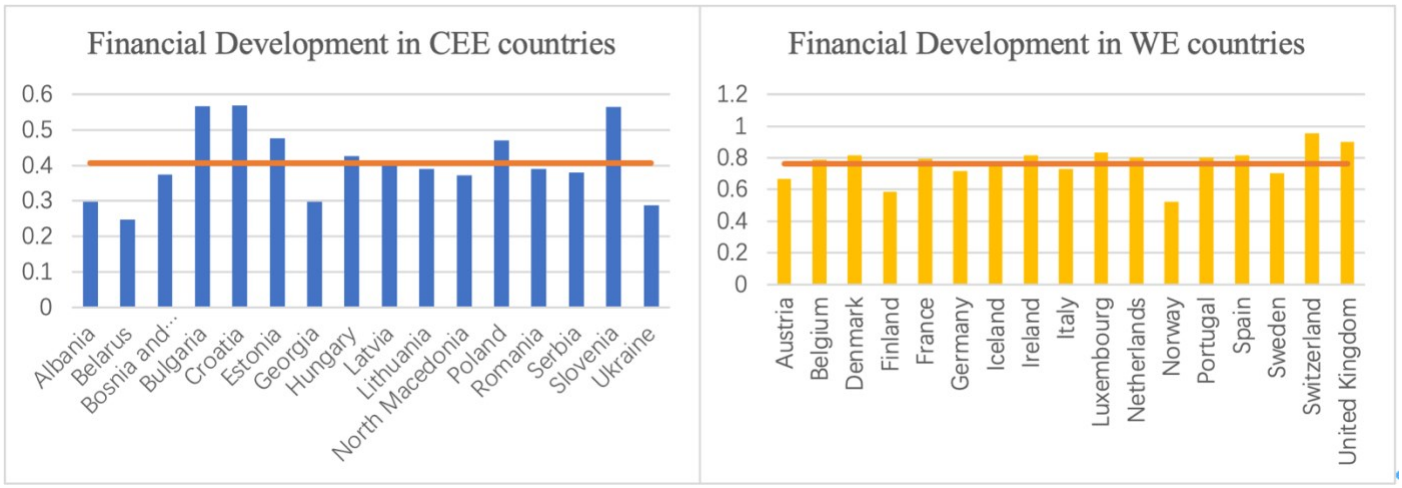

Figure 5-6. Financial Development in CEE group and WE group.

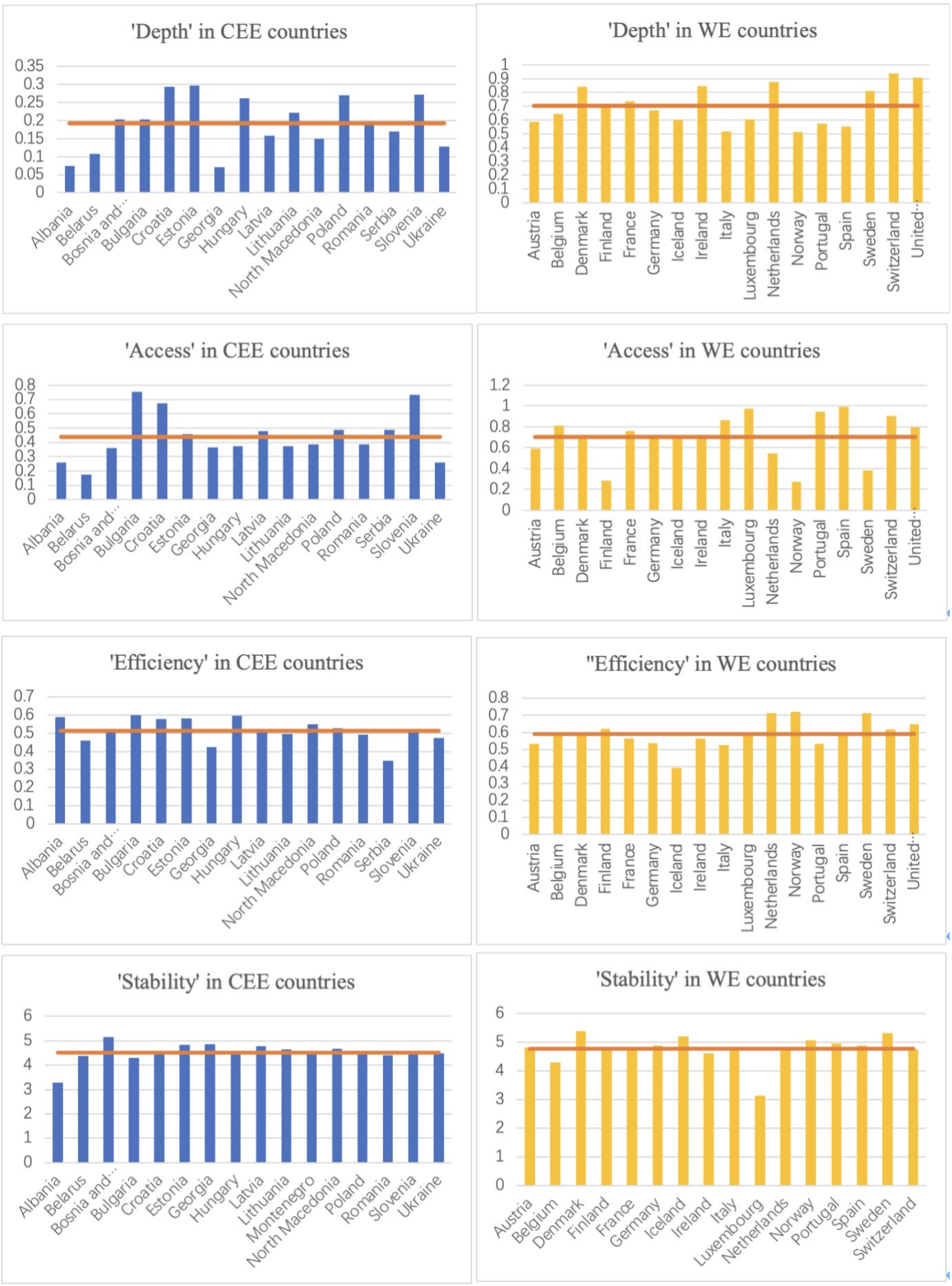

Figure 7-14. Four dimensions of financial development in CEE group and WE group.

Figure 15-16. the change of innovation ('Patent' and 'R&D') from 1995-2020 in CEE group and WE group.

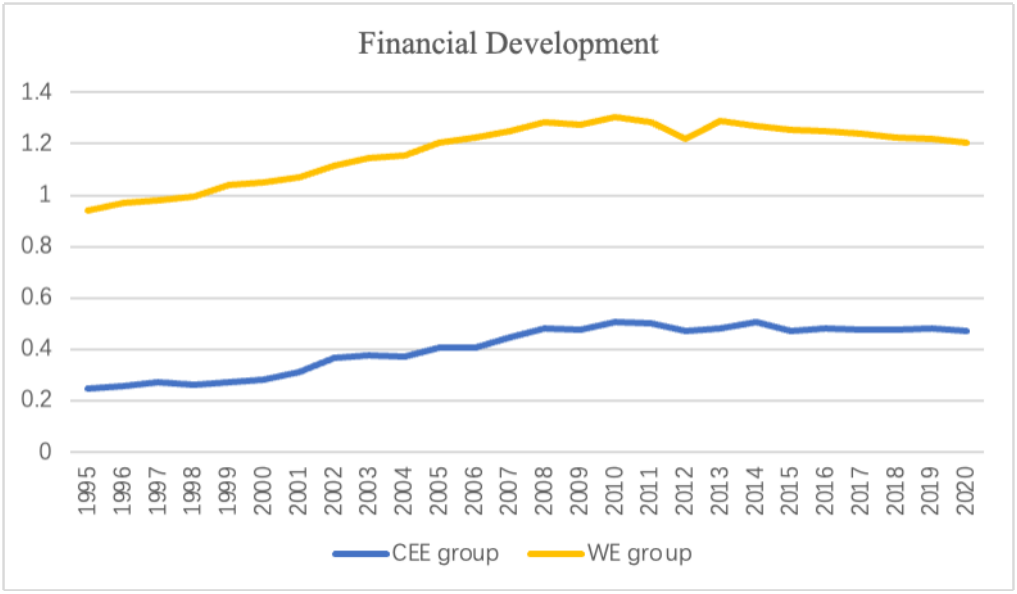

Figure 17. the change of financial development from 1995-2020

in CEE group and WE group.

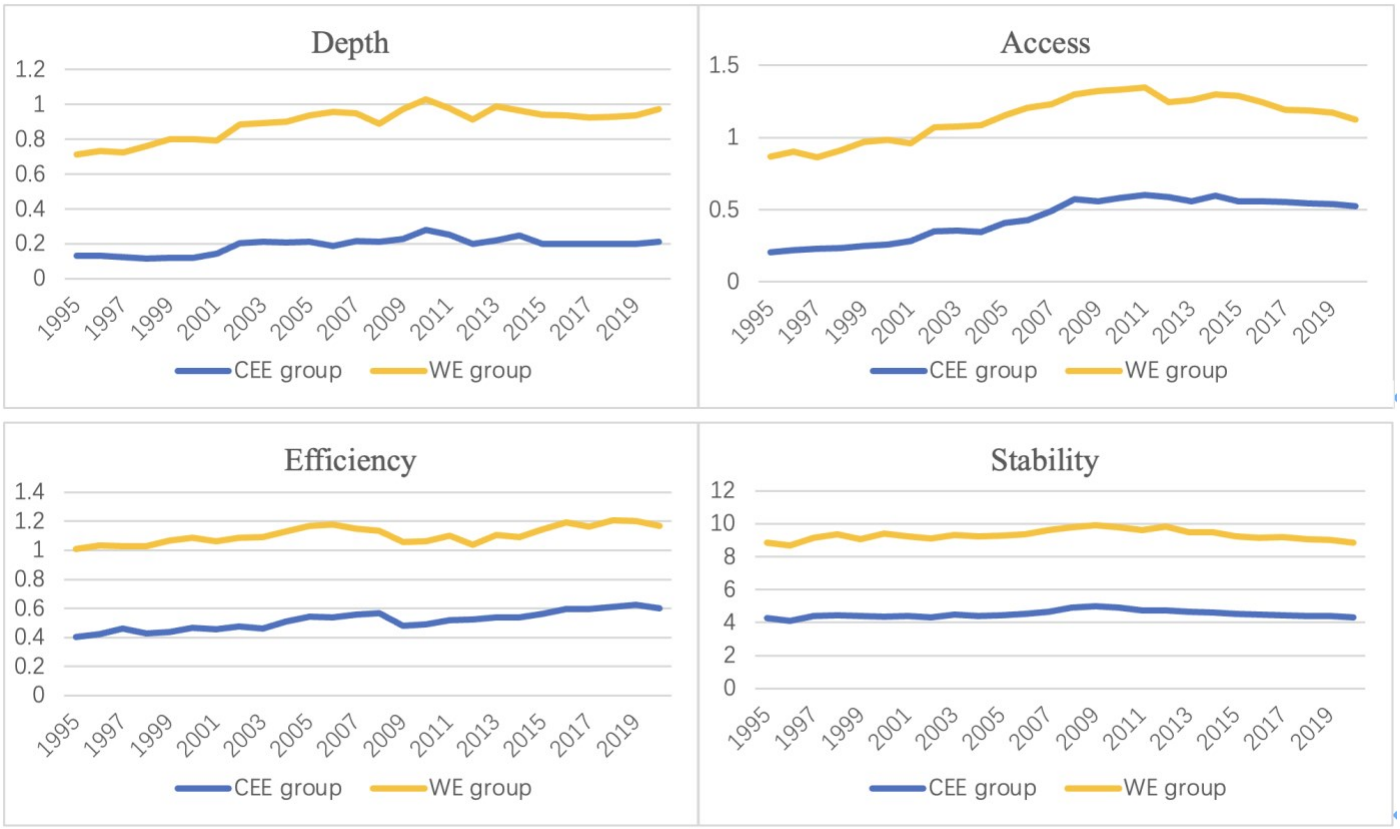

Figure 18-21. the change of four dimensions of FD from 1995-2020 in two groups.

4.3.2 Models and Methodology

The regression models employed in the empirical part of this paper is shown in Table 4. The first two studies (study 1 and study 2) use the fixed-effect models to run the specification (1) to test the impact of overall financial development indicator on the level of innovation, including total patent applications and R&D expenditures. Among them, the research objective of study 1 is the full sample, and study 2 analyses the situations in the two groups of countries (WE and CEE), of which the regression results will be presented in Table 6 and Table 7 respectively.

Study 3 and study 4 conduct studies on the full sample and apply the fixed effect model to run the specification (2) to test how the four dimensions of financial development affect the level of innovation. Study 3 examines the impact of the four dimensions on the number of total patent applications (innovation output), and study 4 tests the effect of the four dimensions on R&D expenditure (innovation input). Studies 5, 6, 7, and 8 detect how the four dimensions of financial development contribute to innovation output and input in WE group and CEE group respectively.

Specifically, Study 5, 6 examines whether the impact of the four dimensions of financial development on the number of total patent applications is different in the WE group and the CEE group, and Study 7, 8 compares the effects of the four dimensions of financial development on R&D expenditures in the WE group and the CEE group. All four studies will be implemented by applying fixed-effect models and specification (2). Finally, in the full sample, system GMM technique and specification (3) will be used to test whether the results of the contribution of financial development on innovation levels (including total patent applications and R&D expenditures) are robust.

This thesis will apply three following specifications to conduct empirical analysis:

$$Innovation_{i,t} = \beta_0 + \beta_1 FD_{i,t} + \beta_2 Controls_{i,t} + \varepsilon_{i,t} \quad (1)$$

$$Innovation_{i,t} = \beta_0 + \beta_1 Dimension_{i,t} + \beta_2 Controls_{i,t} + \varepsilon_{i,t} \quad (2)$$

$$Innovation_{i,t} = \beta_0 + \alpha innovation_{i,t-1} + \beta_1 FD_{i,t} + \beta_2 Controls_{i,t} + \varepsilon_{i,t} \quad (3)$$

where the dependent variable ‘Innovation’ in the three specifications indicates the innovation level of country i at time t, which is measured by the number of total patent applications (innovation output) and R&D expenditure (innovation input). In terms of independent variables, ‘FD’ in the first and third specifications refers to the overall level of financial development for country i at time t, and ‘Dimension’ in the second specification represents the four dimensions of financial development, consisting of depth, access, efficiency, and stability. In other words, specification (2) will be applied to study how each dimension affects the level of innovation. Based on the specification (1), the lagged one period of innovation variables is added in the specification (3), which is employed to run the regression of the system GMM model and test the robustness of the empirical results. Control variables include indicators of education, economic development, government expenditure, political stability, and trade volume. ε represents the error term. As mentioned above, among all these variables, logarithmic forms are adopted for the variables ‘Patent’, ‘Stability’, and ‘GDP per capital’ to avoid heteroscedasticity. Considering that the proxy for ‘Stability’ is different from three other dimensions that sources from other database, therefore, logarithmic form of ‘Stability’ is applied to keep its magnitude similar to the other three ones. Except for ‘stability’, the coefficients of all other independent and control variables are expected to be positive for both total patent applications and R&D expenditure. The coefficient of 'stability' indicator is predicted to be negative for both total patent applications and R&D expenditure. As mentioned above, the indicator of stability, 'bank credit to bank deposits ratio' represents instability rather than stability. That means that the smaller the value of the index, the more stable financial system is. A stable financial system is expected to promote innovative activity, so the coefficient on stability is predicted to be negative.

Table 4. Summary of regression models

Study Number	Table number	Sample	Dependent variables	Specification	Model
1	Table 6	Full Sample	Patent, R&D	(1)	Fixed-Effect Model
2	Table 7	WE & CEE	Patent, R&D	(1)	Fixed-Effect Model
3	Table 8	Full Sample	Patent	(2)	Fixed-Effect Model

4	Table 9	Full Sample	R&D	(2)	Fixed-Effect Model
5	Table10	WE Group	Patent	(2)	Fixed-Effect Model
6	Table 11	CEE Group	Patent	(2)	Fixed-Effect Model
7	Table12	WE Group	R&D	(2)	Fixed-Effect Model
8	Table 13	CEE Group	R&D	(2)	Fixed-Effect Model
9	Table 14	Full Sample	Patent, R&D	(3)	System GMM Model

4.3.2.1 Fixed-effect models

In the past literature, some panel data research techniques have been adopted to explore the relationship between financial development and innovation, including random effect models (Tee et al., 2014), fixed effect models (Bhatti et al., 2013; Hsu et al., 2014), and generalized method of moments (GMM) (Law et al., 2018; Zhu et al., 2020), etc. This paper will apply the fixed effect model and system GMM model to conduct the empirical study. As some techniques for panel data analysis such as random effect models and fixed effect models have been widely used in the previous studies (Bhatti et al., 2013; Tee et al., 2014; Hsu et al., 2014). Fixed effects models, random effects models, and pooled models are all commonly used methods when dealing with panel data problems. Fixed effect model is chosen for this study.

In addition to the explanatory variables and control variables that have been considered in this study, there are other unobserved factors that affect the level of innovation, such as institutional factors. Therefore, heterogeneity analysis and some tests are used to determine whether the fixed effects should be included. Heterogeneity tests detect whether there is sufficient variation across countries or over time so that country-specific or time-specific fixed effects need to be added to the model. The heterogeneity analysis considers the variables varying across countries without change over years and variables varying over years but remain stable across countries. The results are shown in Figures 22-23. and 24-25. The scatter diagram in figure 22-23 presents that there is heterogeneity across 40 European countries. The fluctuations indicate the imbalance of

the number of patent applications (in logarithmic form) and R&D expenditure among these countries. It suggests that differences exist in innovation levels among European countries. In addition, Figure 24-25. show that the number of patent applications and R&D expenditure vary greatly between different years. Therefore, both country fixed effects and time fixed effects are suggested to be retained into the model.

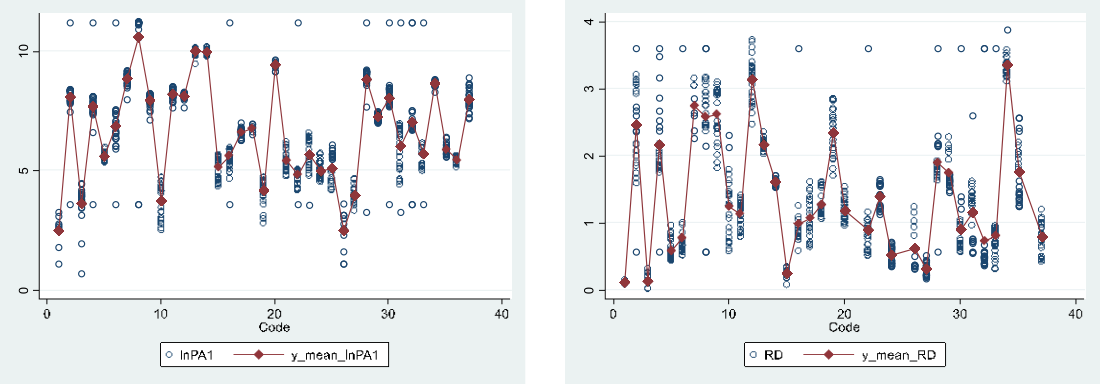

Figure 22-23. Analysis of heterogeneity across countries.

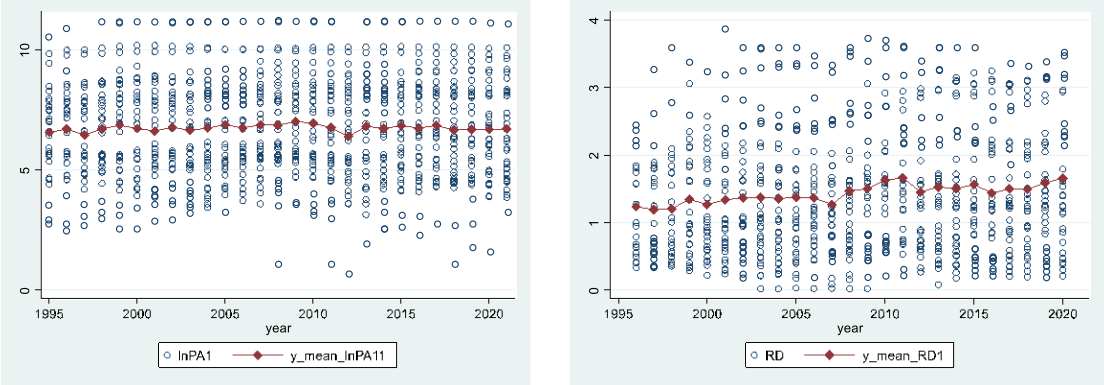

Figure 24-25. Analysis of heterogeneity across time.

Moreover, whether there is the necessity to contain the fixed effects needs to be further examined by Chow F test and Hausman test. As shown in the Table below, for Chow F test, the P-value (0.00) and the F-statistics (84.59) indicate that at the significance level of 1%, the null hypothesis that the coefficients of all countries are jointly equal to zero should be rejected. This means that the fixed effects model is preferred instead of the pooled model. For the Hausman test, the result delivers that $P=0.0014<0.01$, indicating that the null hypothesis is rejected. It suggests that the fixed effect model is more appropriate than the random effect model. Therefore, the fixed effects model is finally chosen to conduct the empirical study.

Table 5. The results of Chow F-Test and Hausman Test

Test Methods	Statistics	P-value
Chow F-Test	F= 84.59	p= 0.000
Hausman Test	Chisq= 41.22	p= 0.0014

4.3.2.2 System-GMM models

According to Zhu et al. (2020), the investigation of financial development's impact on innovation can be complicated by endogeneity issues arising from reverse causality between the two variables. Endogeneity refers to a correlation between explanatory variables and the error term, implying that while explanatory variables influence the dependent variable, they can also be influenced by it, leading to biased estimation. The endogeneity problem in this study arises because increased innovation levels can drive the advancement of financial products and services, enhancing the efficiency of financial institutions and creating a feedback loop. To address this concern, the researchers employed the system Generalized Method of Moments (GMM) as it is a widely acknowledged and effective technique for analysing panel data. Several scholars have already utilized the system GMM to investigate the relationship between financial development and innovation (Bhatti et al., 2013; Law et al., 2018; Zhu et al., 2020; Trinugroho et al., 2021). The application of system GMM helps tackle endogeneity and heterogeneity in panel data, providing more accurate and robust estimations. To specifically address the endogeneity problem, the study introduced a one-period lag of the dependent variable (innovation). This approach ensures that the correlation between explanatory variables and the error term is attributed to the lagged one-period innovation rather than endogeneity, strengthening the validity of their findings.

5. Empirical Results

Table 6 presents the results of study 1, applying the fixed-effect model with specification (1) to examine the impact of the overall level of financial development on the level of innovation in the pooled sample, including the number of total patent applications and R&D expenditure.

Table 6. Effect of Overall Financial Development on 'Patent' and 'R&D' (Full Sample)

	(1)	(2)
	Patent	R&D
FD	4.299***	2.895***
	(4.838)	(7.084)
Education	-0.421	0.329
	(-0.631)	(0.780)
GDP per capita	-1.442**	-0.998***
	(-2.130)	(-2.831)
GOV_EXP	-4.268	-0.707
	(-1.095)	(-0.359)
PS	-0.452**	-0.240*
	(-2.071)	(-1.838)
Trade	0.651	0.737***
	(1.463)	(3.536)
Country	Yes	Yes
Year	Yes	Yes
_cons	18.930***	8.675**
	(2.784)	(2.512)
N	618	609
R^2	0.287	0.494
Adj. R^2	0.254	0.470

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

The results show that, in the full sample, the coefficients of financial development indicator are positive at the 1% significance level for both ‘Patent’ and ‘R&D’, indicating that an improvement in the level of financial development can significantly contribute to an increase in the number of patent applications (innovation output) and R&D expenditure (innovation input). To be more specific, one unit increase in the overall level of financial development will result in a 430% increase in the number of total patent applications (Noticeably, the index of ‘Patent’ is in the form of logarithm). If there is one unit increase in the overall level of financial development, R&D expenditure is expected to increase by 2.90. In other words, financial development can promote innovation activities, and its effect on the number of total patent applications (innovation output) is greater than that on R&D expenditure (innovation input). Among the control variables, the results deliver that the coefficients of ‘Education’ and ‘GOV_EXP’ for both ‘Patent’ and ‘R&D’ are not significant, which indicates the change in education level and government expenditure cannot contribute to the change in innovation level. Inconsistent with the expectation, it seems that the increase in economic development results in the decrease in the number of total patent applications and R&D expenditure since the coefficients of ‘GDP per capita’ for both ‘Patent’ and ‘R&D’ are significant and negative. In addition, the significant and negative coefficients of political stability implies that the improvement in the level of political stability is associated with the decreased number of patent applications and reduced R&D expenditure. The coefficient of ‘Trade’ is not significant for ‘Patent’ and significantly positive for ‘R&D’. It delivers that the increase in trade volume is linked with a rise in R&D expenditure and leads to improving the innovation input, while it cannot influence the number of total patent applications and contribute to innovation output.

Table 7. Effect of Overall Financial Development on ‘Patent’ and ‘R&D’
(WE group and CEE group)

	WE Patent	WE R&D	CEE Patent	CEE R&D
FD	4.145**	2.087*	5.169***	3.496***
	(2.159)	(1.946)	(5.143)	(9.034)
Education	2.212***	1.991***	-2.397**	-0.723
	(4.636)	(3.138)	(-2.936)	(-1.541)

GDP per capita	0.423	0.022	-0.186	-0.791
	(0.397)	(0.030)	(-0.160)	(-1.492)
GOV_EXP	-5.135	1.490	-6.835	-2.174
	(-0.485)	(0.356)	(-1.415)	(-0.886)
PS	-0.366	-0.082	-0.502	-0.278*
	(-1.593)	(-0.324)	(-1.659)	(-1.838)
Trade	1.273**	0.145	0.082	0.538**
	(2.405)	(0.346)	(0.164)	(2.207)
_cons	-0.117	-1.386	8.039	6.915
	(-0.009)	(-0.165)	(0.747)	(1.432)
Country	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
N	320	315	298	294
R^2	0.413	0.438	0.367	0.644
Adj. R^2	0.359	0.386	0.303	0.607

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 7 presents the results of study 2, which examines the impact of overall financial development on two innovation indicators (‘Patent’ and ‘R&D’) for two groups of countries (WE group and CEE group). The first two columns show the results for WE group, and the last two columns deliver the results for CEE group. The first column displays that in the WE group of countries, when the dependent variable is ‘Patent’, the coefficient of the overall financial development indicator is positive at the 5% significance level. It indicates that in WE countries, a one-unit increase in the level of financial development leads to a 414.5% rise in the number of patent applications. The second column shows that the coefficient of the overall financial development for R&D expenditure is positive at the 10% significance level for countries in the WE group. It suggests that in WE countries, a one-unit improvement in the level of financial development contributes to an increase in R&D expenditure by 2.087. The last two columns reveal significant findings for CEE countries, indicating a positive relationship between overall financial development and both 'Patent' and 'R&D' indicators at the 1% significance level. Specifically, an increase of one unit in financial development leads to a remarkable surge of 516.9% in patent applications and a substantial rise of 3.50 in R&D expenditure. Interestingly, within the WE group, enhanced financial development

predominantly influences the number of patent applications, reflecting the innovation output, as opposed to R&D expenditure, representing the innovation input. A similar pattern emerges within the CEE group, with financial development showing a more pronounced impact on the number of patent applications in contrast to R&D expenditures. Moreover, a notable distinction is observed between the two groups: the influence of financial development on patent applications in CEE countries (coefficient 5.169) exceeds that in WE countries (coefficient 4.145), underscoring a higher potency of financial development in driving innovation output in CEE countries. Similarly, the effect of financial development on R&D expenditures in CEE countries (coefficient 3.496) surpasses that in WE countries (coefficient 2.087), highlighting a greater propensity for financial development to spur innovation input in CEE nations.

Table 8. Effect of four dimensions on 'Patent'

(Full Sample)

	(1)	(2)	(3)	(4)
	Patent	Patent	Patent	Patent
Depth	3.547***			
	(4.603)			
Access		2.540***		
		(3.666)		
Efficiency			3.257**	
			(2.611)	
Stability				-0.760***
				(-3.148)
Education	-0.200	-0.377	-0.413	0.496
	(-0.287)	(-0.621)	(-0.726)	(0.890)
GDP per capita	-0.365	-1.712**	-1.622**	-0.482
	(-0.587)	(-2.456)	(-2.498)	(-1.045)
GOV_EXP	-3.836	-4.469	-2.611	-3.638
	(-1.050)	(-1.252)	(-0.759)	(-1.358)
PS	-0.238	-0.368	-0.274	-0.384**
	(-1.382)	(-1.686)	(-1.488)	(-2.299)
Trade	0.528	0.644	0.756*	0.187
	(1.255)	(1.499)	(1.833)	(0.482)
Country	Yes	Yes	Yes	Yes

Year	Yes	Yes	Yes	Yes
_cons	9.377	22.381***	20.538***	15.025***
	(1.486)	(3.213)	(3.313)	(3.512)
N	618	618	618	555
R^2	0.272	0.234	0.148	0.185
Adj. R^2	0.239	0.198	0.109	0.144

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

The results of the third study are presented in Table 8. It investigates the impact of four dimensions of financial development (depth, access, efficiency, and stability) on the number of patent applications in the full sample. The coefficients of 'Depth' and 'Access' are positive at the 1% level of significance, the coefficient of 'Efficiency' is positive at the 5% significance level, and the coefficient of 'Stability' is negative at the 1% significance level. As mentioned above, the index of 'Stability', 'bank credit to bank deposits ratio', reflects instability rather than stability. The negative coefficient indicates that the stability of financial development is positively associated with the number of patent applications. Therefore, the coefficients of all four dimensions are in line with expectations, which means that the improvement of the four dimensions of financial development can stimulates innovation output. Specifically, a one-unit increase in the level of depth of financial systems will result in a 354.7% increase in the number of patent applications. Similarly, if the level of financial access improves by one unit, patent applications will increase by 254%. Given the 'Efficiency' index is increased by one unit, a 325.7% rise in the number of patent applications can be expected. One percent improve in 'Depth' tends to increase the number of patent applications by 0.76 %. (Noticeably, the index of 'Stability' is in the form of logarithm). In general, according to the first column of Table 6 and Table 8, the positive effect of financial development on innovation output is reflected in each dimension. Among the four dimensions of financial development, depth, efficiency, and access have a greater impact on promoting the number of patent applications (innovation output), while stability has a relatively small role.

Table 9. Effect of four dimensions on 'R&D'
(Full Sample)

	(1) R&D	(2) R&D	(3) R&D	(4) R&D
Depth	2.623***			
	(7.053)			
Access		1.401***		
		(4.291)		
Efficiency			1.695***	
			(4.469)	
Stability				-0.155
				(-1.176)
Education	0.403	0.378	0.329	0.440
	(0.917)	(0.956)	(0.956)	(1.049)
GDP per capita	-0.337	-1.043**	-0.973***	-0.362
	(-1.272)	(-2.666)	(-2.969)	(-1.268)
GOV_EXP	-0.619	-0.371	0.863	0.386
	(-0.383)	(-0.172)	(0.396)	(0.175)
PS	-0.085	-0.136	-0.082	-0.159
	(-0.734)	(-0.978)	(-0.580)	(-1.299)
Trade	0.660***	0.690***	0.765**	0.415
	(3.189)	(2.954)	(2.605)	(1.368)
Country	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
_cons	2.813	9.777**	8.586***	4.748
	(1.099)	(2.572)	(2.793)	(1.692)
N	609	609	609	550
R^2	0.529	0.325	0.228	0.176
Adj. R^2	0.507	0.294	0.192	0.134

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 9 describes the results of the relationship between the four dimensions of financial development and R&D expenditure in the full sample, which is obtained from a fixed-effect model. Among the four dimensions of financial development, the

beneficial and significant effects of depth, access and efficiency are reflected in the results since their coefficients are positive at 1% significance level. To be more specific, if the index of depth improves by one unit, R&D expenditure will increase by 2.623. A one-unit rise in the level of financial access may contribute to increasing the R&D expenditure by 1.40. Similarly, one-unit increase in financial efficiency tends to improve the R&D expenditure by 1.70. On the other hand, it seems that the stability of financial systems cannot exert a substantial influence on R&D expenditure. Therefore, it can be noticed that the significant coefficient of overall financial development for 'R&D' (as shown in Table 6) is attributed to the significance of the three dimensions, including depth, access, and efficiency. The improved functioning of financial systems in terms of depth, access, and efficiency has a contribution on R&D expenditure (innovation input). Comparing the results of Table 8 and Table 9, it can also be found that the four dimensions of financial development all have a greater impact on the number of patent applications (innovation output) than on R&D expenditure (innovation input). Because the coefficients of 'Depth', 'Access' and 'Efficiency' for 'Patent' are larger than that for 'R&D', and the coefficient of 'Stability' is even insignificant for 'R&D'.

Table 10. Effect of four dimensions on 'Patent'

(WE group)

	(1)	(2)	(3)	(4)
	Patent	Patent	Patent	Patent
Depth	1.772			
	(1.223)			
Access		1.900**		
		(2.216)		
Efficiency			3.605*	
			(1.890)	
Stability				-0.780*
				(-1.943)
Education	2.287**	1.667**	1.377*	1.184
	(2.646)	(2.743)	(1.801)	(1.558)
GDP per capita	-0.083	0.629	-0.866	0.106
	(-0.096)	(0.663)	(-0.897)	(0.097)
GOV_EXP	-8.439	-2.232	-6.624	-1.944

	(-0.882)	(-0.262)	(-0.796)	(-0.199)
PS	-0.212	-0.329	-0.122	-0.215
	(-0.938)	(-1.451)	(-0.584)	(-0.660)
Trade	0.866	0.946*	1.025*	0.295
	(1.394)	(2.060)	(1.911)	(0.433)
Country	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
_cons	7.568	-0.670	14.154	9.796
	(0.719)	(-0.061)	(1.346)	(0.785)
N	320	320	320	279
R^2	0.287	0.378	0.379	0.363
Adj. R^2	0.221	0.321	0.322	0.294

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 10 presents the results of study 5, which analyses the contribution of four dimensions of financial development (depth, access, efficiency, and stability) on the number of patent applications in the group of Western and European countries. It delivers that the coefficient of 'Depth' is not significant, suggesting the enhanced level of financial depth is less likely to increase the number of patent applications in the WE countries. On the other hand, the improvements in financial access, efficiency, and stability leads to a higher number of patent applications and fosters more innovation activities at some degrees. Specifically, at the 5% significance level, financial access exerts a favourable effect on innovation output, and given the index is increased by one unit, a 190 % growth in the number of patent applications can be expected in the WE countries. In addition, enhanced stability in financial systems can effectively promote the innovation output. In the WE countries, if there is a one-unit rise in the proxy of 'Stability', a 360.5% increase in the number of patent applications can be predicted at a 10% significant level. In terms of financial stability, the negative and significant coefficient indicates the beneficial impact of improved stability on stimulating innovation activities. To be more specific, enhancing financial stability by 1% results in a 0.78% rise in the number of patent applications. When comparing the results from Table 8 and Table 10, it can be observed that the impact of the four dimensions on the number of patent applications is less significant in the WE group than in the pooled sample, especially for the indicator of financial depth, which is significant in the full

sample but not significant in the WE group. Additionally, by comparing the results from Table 10 and the first column of Table 7, it is evident that although the coefficient of the overall financial development is significant for the number of patent applications in the WE group of countries, only the improvement in the access, efficiency, and stability dimensions of the financial system can foster innovation output, while the increase in financial depth has no favourable effect.

Table 11. Effect of four dimensions on 'Patent'
(CEE group)

	(1)	(2)	(3)	(4)
	Patent	Patent	Patent	Patent
Depth	4.943***			
	(8.720)			
Access		3.712***		
		(4.031)		
Efficiency			3.668**	
			(2.301)	
Stability				-0.770**
				(-2.278)
Education	-2.599***	-1.679**	-1.676*	-0.129
	(-3.602)	(-2.354)	(-1.881)	(-0.151)
GDP per capita	0.688	-0.408	-0.631	0.616
	(0.755)	(-0.324)	(-0.682)	(1.060)
GOV_EXP	-4.577	-8.511	-1.833	-4.421
	(-1.104)	(-1.626)	(-0.446)	(-1.438)
PS	-0.278	-0.412	-0.367	-0.465*
	(-1.063)	(-1.320)	(-1.392)	(-1.865)
Trade	-0.425	0.545	0.616	0.307
	(-1.062)	(0.839)	(0.961)	(0.632)
Country	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
_cons	1.151	10.200	10.151	4.199
	(0.138)	(0.874)	(1.211)	(0.798)
N	298	298	298	276

R^2	0.423	0.316	0.142	0.161
Adj. R^2	0.366	0.247	0.056	0.070

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 11 presents the results of an empirical analysis that explores the relationship between financial development and the number of patent applications in the CEE group of countries, focusing on four dimensions: depth, access, efficiency, and stability. Among the four dimensions, the coefficients of 'Depth' and 'Access' are positive at the 1% significance level. At the 5% significance level, the coefficients of 'Efficiency' and 'Stability' are positive and negative, respectively. This suggests that in the CEE group of countries, the improvements in the depth, access, efficiency, and stability of the financial system contribute to an increase in the number of patent applications and promote innovation activity. In CEE countries, a one-unit enhancement in financial depth results in a 494.3% increase in the number of patent applications. For one unit increase in financial access in CEE countries, the number of patent applications increases by 371.2%. Similarly, given a one-unit rise in the index of 'Efficiency', the number of patent applications is expected to increase by 366.8%. In CEE countries, if the coefficient of financial stability improves by 1%, the number of patent applications will increase by 0.77%. In addition, the results of the third column of Table 7 and Table 11 show that for CEE countries, not only the overall financial development is significant, but also each of the four dimensions can significantly stimulate the number of patent applications. Comparing the results of Tables 10 and 11, it can be found that the coefficients of the four dimensions of financial development on the number of patent applications are more significant in CEE countries than in WE countries. Moreover, enhanced depth, access, and efficiency of the financial system have a greater impact on the number of patent applications in CEE countries than in WE countries. Because in CEE countries, the effect of financial depth is significant, and the coefficients of 'Access' and 'Efficiency' are larger than those in WE countries (3.712>1.90, and 3.668>3.605, respectively). On the other hand, the absolute value of the stability index in WE countries is greater than that in CEE countries, indicating that the effect of financial stability on promoting innovation output is slightly greater in WE group than in CEE group. By analysing the results in Tables 8, 10, and 11, it can be noticed that when studying the full sample, the substantial impact of financial depth,

access, and efficiency on patent applications in CEE countries becomes diluted, likely due to the inclusion of WE countries in the analysis. Conversely, the effect of financial stability increases with the addition of WE countries. Thus, it is essential to differentiate European countries into WE and CEE groups to avoid overgeneralization and ensure conclusions are applicable to specific country clusters. Overall, these findings underscore the critical role of distinct financial dimensions in driving innovation and emphasize the need for tailored policies and strategies based on the specific economic and financial conditions of each group of countries.

Table 12. Effect of four dimensions on 'R&D'
(WE group)

	(1)	(2)	(3)	(4)
	R&D	R&D	R&D	R&D
Depth	1.600**			
	(2.183)			
Access		0.846*		
		(1.787)		
Efficiency			1.869**	
			(2.726)	
Stability				-0.196
				(-0.838)
Education	2.220***	1.757***	1.491***	1.662***
	(3.428)	(3.255)	(2.962)	(3.182)
GDP per capita	-0.400	-0.025	-0.429	-0.145
	(-0.690)	(-0.037)	(-0.785)	(-0.196)
GOV_EXP	-2.440	3.063	1.274	3.692
	(-0.714)	(0.745)	(0.338)	(0.813)
PS	-0.022	-0.086	0.029	-0.081
	(-0.091)	(-0.354)	(0.141)	(-0.309)
Trade	0.051	-0.015	0.112	-0.233
	(0.157)	(-0.043)	(0.325)	(-0.871)
Country	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
_cons	4.034	-0.051	3.684	2.729

	(0.644)	(-0.007)	(0.618)	(0.348)
N	315	315	315	280
R^2	0.423	0.401	0.428	0.338
Adj. R^2	0.369	0.345	0.375	0.267

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 12 shows the results of study 7, which investigates the interplay of R&D expenditure and four dimensions of financial development, including depth, access, efficiency, and stability, in WE group of countries. The results deliver that in WE countries, the depth of the financial system will positively affect R&D expenditure at a significance level of 5%. Given a one unit increase in the 'Depth' index, a 1.60 unit increase in R&D expenditure can be expected. An increase in the level of financial access can boost R&D expenditure at a significance level of 10%. A one-unit enhancement in financial access results in a 0.846 unit increase in R&D expenditure. Moreover, the higher efficiency of the financial system has a positive effect on R&D expenditure at the 5% significance level. If the 'Efficiency' index rises by one unit, R&D expenditure will improve by 1.869. On the other hand, changes in the stability of financial systems cannot significantly lead to changes in R&D expenditure. The results from Table 12 and the second column of Table 7 suggest that in WE countries, the significant effect of overall financial development on R&D expenditure is attributed to the significant impact of the three dimensions of depth, access and efficiency, and the stability of the financial system will not increase the level of R&D expenditure. Upon a thorough analysis of Table 9 and Table 12, it becomes evident that the significance level of the depth, access, and efficiency coefficients is noticeably weaker in the WE group when compared to the full sample. Interestingly, it is worth noting that the stability of the financial system does not appear to exert a significant impact on R&D expenditure, both within the pooled sample and the WE group. Moreover, when comparing the outcomes of Table 10 and Table 12, it is evidenced that in WE countries, the effect of access, efficiency, and stability of the financial system on the number of patent applications (innovation output) is greater than the impact on R&D expenditure (innovation input). Because the coefficients of 'Access' and 'Efficiency' on 'Patent' are larger than the coefficients on 'R&D', and the effect of financial stability on R&D expenditure is not significant. On the other hand, in WE countries, improved financial

depth can significantly increase R&D expenditure, but it cannot affect the number of patent applications.

Table 13. Effect of four dimensions on 'R&D'
(CEE group)

	(1) R&D	(2) R&D	(3) R&D	(4) R&D
Depth	3.341***			
	(16.622)			
Access		2.051***		
		(5.036)		
Efficiency			1.804***	
			(3.300)	
Stability				-0.101
				(-0.657)
Education	-0.950**	-0.174	-0.165	-0.018
	(-2.805)	(-0.338)	(-0.334)	(-0.038)
GDP per capita	-0.233	-0.889	-0.916**	-0.301
	(-0.636)	(-1.527)	(-2.263)	(-0.727)
GOV_EXP	-0.588	-2.975	1.197	-1.158
	(-0.387)	(-1.008)	(0.496)	(-0.495)
PS	-0.108	-0.169	-0.142	-0.211
	(-0.936)	(-0.905)	(-0.696)	(-1.382)
Trade	0.206	0.845**	0.996**	0.746**
	(0.890)	(2.830)	(2.917)	(2.260)
Country	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
_cons	2.533	7.940	7.020*	3.350
	(0.794)	(1.490)	(1.961)	(0.898)
N	294	294	294	270
R^2	0.738	0.412	0.198	0.162
Adj. R^2	0.712	0.352	0.117	0.069

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 13 delivers the results on how the four dimensions of financial development (depth, access, efficiency, and stability) contribute to R&D expenditure in the CEE group of countries. The results show that in CEE countries, the coefficients of 'Depth', 'Access' and 'Efficiency' are all positive at the 1% significance level, indicating that the improvement in depth, access, and efficiency of financial systems in these countries will increase R&D expenditure and stimulate innovation input. To be more specific, in CEE countries, a one-unit rise in the coefficient of 'Depth' leads to an increase in R&D expenditure by 3.341. If the level of financial access enhances by one unit, R&D expenditure is expected to increase by 2.051 units. Similarly, a one-unit increase in financial efficiency results in a 1.804 unit increase in R&D expenditure. On the other hand, in Central and Eastern European (CEE) countries, achieving greater stability in financial systems may not always directly translate into a significant increase in investments in research and development (R&D) or foster a substantial boost in innovation activities. While ensuring stability is a crucial step, these countries also need to address other critical factors such as creating an environment that encourages and supports research and innovation, fostering collaboration between academia and industry, and investing in human capital and cutting-edge technologies. The results from the last column of Table 7 and the Table 13 suggest that in CEE countries, the significant impact of overall financial development on R&D expenditure is attributed to the significant effect of the three dimensions of depth, access, and efficiency, while the enhancement of the stability in financial systems will not increase the level of R&D expenditure and promote innovation input. Based on the results of Table 9 and Table 13, it delivers that the results in the full sample and CEE group are consistent, indicating that the three dimensions of the financial system, depth, access, and efficiency, all have a positive impact on R&D expenditure at the 1% level of significance, while enhanced financial stability cannot lead to an increase in R&D expenditure. However, when studying the full sample, the great influence of the depth, access, and efficiency dimensions of financial development on the R&D expenditure in CEE countries is diluted by the inclusion of WE countries (all coefficients of three dimensions are smaller in the pooled sample). Comparing the results in Table 12 and Table 13, it can be found that in terms of significance level, the effect of depth, access, and efficiency on R&D expenditure is more significant in CEE countries than in WE countries. In terms of the effect of these three dimensions on R&D expenditure, financial depth and access have a greater influence on R&D expenditure in CEE countries, while financial

efficiency has a greater impact on R&D expenditure in the WE countries. On the other hand, in both the WE group and the CEE group, the effect of financial stability on R&D expenditure is not significant, which is cope with the insignificant coefficient of ‘Stability’ index in the full sample. In comparing the results from Table 11 and Table 13, it is apparent that in CEE countries, improvements in the four financial system dimensions have a greater influence on the number of patent applications compared to their impact on R&D expenditure. Among the four dimensions, depth, access, and efficiency have more pronounced effects on 'Patent' than on 'R&D', while the 'Stability' index's coefficient remains insignificant concerning R&D expenditure.

6. Robustness Checks

In this section, the system GMM model is applied to test the robustness of the results on how overall financial development contributes to the level of innovation level (including the two dependent variables 'Patent' and 'R&D') in the full sample. As mentioned in the methodology section, to address the endogeneity issues, the first-order lag of the endogenous variable is included into the model as an instrumental variable. Table 14 presents the results of the robustness tests.

Table 14. Results of System GMM Model

	(1)	(2)
	Patent	R&D
L.Patent	0.015	
	(1.193)	
L.R&D		-0.082***
		(-9.832)
FD	8.584***	0.994***
	(39.504)	(5.555)
Education	1.903*	-0.093
	(1.885)	(-0.258)
GDP per capita	-0.332	0.080
	(-1.675)	(0.820)
GOV_EXP	-8.356**	12.658***
	(-2.671)	(10.818)
PS	0.134	-0.009
	(0.971)	(-0.100)
Trade	-0.630*	0.883***
	(-1.747)	(5.527)
_cons	5.876***	-3.256***
	(2.813)	(-4.157)
N	607	570
AR(1)	z=-2.11	z= -2.61
	p= 0.035	p= 0.009
AR(2)	z= 1.58	z= -1.00

	p= 0.113	p= 0.319
Sargan test	CHi2= 2.14	CHi2= 6.81
	p=1.000	p=1.000
Hansen test	CHi2= 25.79	CHi2= 28.11
	p= 0.530	p= 0.823

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Consistent with the results of the fixed-effect model (as shown in Table 6), the impact of the overall financial development on 'Patent' and 'R&D' is significantly positive, with coefficients of 8.584 and 0.994, respectively. Therefore, it is proved that the positive effect of financial development on the number of patent applications and R&D expenditure is robust.

Some necessary tests are adopted to check whether the model specification and instrumental variables are reasonable and effective. To test autocorrelation, the Arellano-Bond test of first-order serial correlation and second-order serial correlation is employed to ensure the rationality and validity of the model. In addition, in system GMM model, the overidentification test is used to assess the validity of instrumental variables, which is achieved by the Sargan test and the Hansen test. The null hypothesis of the Sargan test is that all instrumental variables are exogenous so that no endogeneity problem exists in the model. The null hypothesis of the Hansen test assumes that the model does not suffer from overfitting issues, which means that all parameters in the model are accurately estimated. By conducting these two tests, it can be evident that the instrumental variables employed in the system GMM model are valid, and the estimations of parameters in the model are accurate. For autocorrelation, the p-values of the second-order serial correlation test AR (2) of the regression model of the two variables ‘Patent’ and ‘R&D’ are 0.113 and 0.319, respectively, both greater than 0.05, implying that there is no second-order serial correlation in the regression model. The results of the Sargan test deliver that the p-values for the chi-square statistics of both dependent variables are 1.000, larger than 0.05. This indicates that the null hypothesis cannot be rejected. Therefore, it suggests that the instrumental variables employed in the model are valid, and there is no evidence of endogeneity. The results of the Hansen test present that the p-values for the chi-square statistics of the dependent variable ‘Patent’

and ‘R&D’ are 0.530 and 0.823, respectively, both of which are larger than 0.05, indicating that the null hypothesis cannot be rejected. Consequently, there is no evidence of overidentification in the model. In conclusion, the model's specification is reasonable, and the instrumental variables employed prove to be effective.

7. Discussion

7.1 Principal Findings

This section summarizes the principal findings from analysing the empirical results and answers the three research questions of this study (as mentioned in Chapter 3).

Question 1: How does financial development affect the level of innovation?

The first question delves into the analysis of a comprehensive sample of 40 European countries, examining the relationship between overall financial development and four specific dimensions with their respective effects on the number of patent applications and R&D expenditure. The findings provide valuable insights into this complex relationship. Firstly, it is evident that overall financial development exerts a substantial and positive influence on both patent applications and R&D expenditure. Secondly, the enhancement of each of the four financial system dimensions, namely depth, access, efficiency, and stability, correlates positively with increased patent applications (innovation output). Thirdly, concerning innovation input, the improvement of three dimensions - depth, access, and efficiency - significantly contributes to the promotion of R&D expenditure, while financial stability exhibits no discernible impact on R&D spending. Fourthly, among these dimensions, depth, efficiency, and access have the most significant influence on improving innovation levels, pertaining to both the number of patent applications and R&D expenditure, in that order. Lastly, irrespective of overall financial development or the four specific dimensions, financial development demonstrates a more pronounced role in influencing the total number of patent applications (innovation output) as opposed to R&D expenditure (innovation input). These findings are pivotal for policymakers, researchers, and stakeholders in developing policies and strategies that stimulate innovation and promote economic growth within the European countries.

Question 2: How does the contribution of financial development to innovation differ in these two groups of countries (Central and Eastern European countries and Western European countries)?

The second question delves into exploring the distinct effects of financial development on patent applications and R&D expenditure in the WE group and the CEE group. The findings reveal three significant implications. Firstly, the analysis of each group independently indicates that an improved financial system fosters innovation, as evidenced by a notable increase in both patent applications and R&D expenditure. Secondly, the positive impact of financial development on both patent applications and R&D expenditures is comparatively higher in CEE countries than in their WE counterparts. Lastly, the influence of financial system development is more substantial on the total number of patent applications as opposed to R&D expenditure, evident in both the WE and CEE groups. These insights contribute to a better understanding of the interplay between financial development and innovation in these regions.

Question 3: How do the four dimensions (depth, access, efficiency, and stability) of financial development affect the level of innovation in these two groups of countries (Central and Eastern European countries and Western European countries)?

The third question aims to figure out how the four dimensions of the financial system influence the number of patent applications and R&D expenditure in WE countries and CEE countries. Seven principal findings as follows can be concluded for the third question. First, in CEE countries, the improvement of each of the four dimensions of the financial system can increase the number of patent applications, while only financial depth, access and efficiency can promote R&D expenditure, financial stability has no effect on R&D expenditure. Second, in WE countries, the enhancement of three of the four dimensions, including access, efficiency, and stability, contributes to the rise in the number of patent applications. Regarding innovation input, the increase in the level of financial depth, access, and efficiency can stimulate R&D expenditure. Third, in CEE countries, three of the four dimensions, depth, access and efficiency exert a greater positive effect on the level of innovation, in terms of both the number of patent applications and R&D expenditure. Fourth, in WE countries, the stimulation of financial development on the number of patent applications and R&D expenditure is mainly achieved through the improvements in financial efficiency and access. Fifth, whether with regard to innovation output or innovation input, depth, access, and efficiency of financial systems have a greater impact on promoting innovation in CEE countries than in WE countries. Sixth, in both the CEE group and the WE group, the stability of the

financial system only increases the number of patent applications but has no effect on R&D expenditure, and the positive impact of financial stability is almost the same in the two groups of countries. Seventh, in both CEE and WE countries, financial development plays a more significant role on the total number of patent applications (innovation output) than on R&D expenditure (innovation input).

7.2 Policy Implication

The above empirical research on how financial development influences innovation in CEE countries and WE countries is of practical significance and can provide policy recommendations. As mentioned in the literature review section, innovation as a source of economic development has been confirmed by numerous previous literature (Aghion et al., 2005; Levine, 2005; Aghion and Howitt, 1992; Meierrieks, 2014). This thesis examines and confirms the positive and significant effect of financial development on innovation. Therefore, improving the functioning of the financial system is extremely essential, both for enhancing innovation level and further fostering economic growth. According to the implication of the empirical results, some policy recommendations are proposed to improve the level of innovation. Considering the differences between CEE countries and WE countries, these suggestions will also be discussed separately according to the situation of the two groups of countries.

First, for CEE countries, although compared with WE countries, the financial development and innovation level of CEE countries are at a lower level, the positive effect of financial development on innovation is more significant in CEE countries than in WE countries. Therefore, the benefits obtained through improving the functioning of the financial system are more significant, which is advantageous for CEE countries to catch up with WE countries in terms of innovation. According to the empirical results, it can be found that the depth, access, and efficiency of the financial system play a significant role in promoting the innovation level of CEE countries, suggesting that CEE countries should strive to enhance financial depth, access, and efficiency. Specifically, CEE countries can expand the scale of financial markets, diversify financial institutions, and increase the types of financial products and services, which contributes to increasing financing channels for enterprises and individuals, thereby stimulating innovation activities. Moreover, the increased market size, products and

services will attract more international financial institutions to enter the market, further improving financial depth, in which way, more investments support and promote innovation activities. At the same time, CEE countries should also strengthen financial regulation and enhance public awareness of the financial system. More stringent supervision of the financial system can ensure its smooth operation, protect the rights and interests of investors, and enhance the trust of individuals in financial products and services. Improving public awareness of the financial system allows people to rationally choose more suitable financial products, contributing to greater demand for financial products, promoting investment, and stimulating innovation activities. In addition, Central and Eastern European countries can take measures to lower the entry threshold of financial institutions and increase the popularity of financial services. CEE countries can establish more financial institutions to offer a wider range of convenient financial services. Financial institutions can expand the service scope and diversify financial products to meet the financing needs of different groups and enterprises. Increased access to financial services makes it easier for innovative enterprises to obtain financial support. Moreover, considering that the improvement of the efficiency of the financial system benefits in higher innovation input and output, the CEE countries should optimize the operation process of financial institutions and strengthen the transparency of financial supervision to improve the efficiency of the financial system, contributing to promoting the effective allocation of resources and letting resources flow to innovative activities efficiently.

Second, in WE countries exhibit a relatively high level of financial development and innovation, which plays an essential role in their economic growth. However, sustaining and gradually enhancing the functionality of the financial system is essential. Empirical findings reveal that the positive influence of financial development on innovation is comparatively smaller in WE countries when compared to Central and Eastern European (CEE) countries. In CEE countries, greater financial depth significantly fosters innovation, but in WE countries, it primarily boosts R&D expenditure rather than patent applications. This could be attributed to the already well-established financial systems in WE countries, resulting in limited marginal benefits from further financial depth for innovation. Nevertheless, optimizing financial system accessibility and efficiency remains vital to elevate the innovation landscape in WE countries. A key focus should be on improving financial access for individuals and businesses alike,

while financial institutions should cater to the diverse needs of startups and expand their services to support innovative endeavours. Additionally, to augment innovation levels, WE countries can enhance the efficiency of their financial systems. Given their already advanced financial development, this improvement may require more significant breakthroughs. For instance, promoting the digital transformation of financial institutions and offering online banking services can lead to a more efficient financial system. Embracing digital finance and smart financial products, like mobile payments, online banking, and digital wallets, will deliver more convenient and streamlined services, further encouraging innovative activities.

Overall, CEE countries and WE countries should promote financial development at different dimensions to provide stronger support for innovation activities.

7.3 Contributions and Limitations

This study makes important contributions in two key areas. Firstly, it conducts a comparative analysis by categorizing European countries into two distinct groups: CEE countries and WE countries. Through this approach, the research aims to determine whether the influence of financial development on innovation varies between these two groups. This comparative investigation sheds light on potential regional differences in the relationship between financial development and innovation. Secondly, the study takes a comprehensive approach by quantifying the level of financial development across four crucial dimensions of financial systems, namely depth, access, efficiency, and stability. By examining the impact of each dimension on innovation, the thesis provides valuable insights into the specific aspects of financial development that are most influential in driving innovative activities in the European context. Overall, this research offers a nuanced understanding of the intricate relationship between financial development and innovation, presenting implications for policymakers and businesses aiming to foster and support innovation in the region.

However, this paper has three limitations. First, this thesis constrains the analysis to the role of financial institutions in the financial system without considering the financial market. The previous literature has confirmed the role of the stock market in the

financial market in promoting innovation activities, however, this paper only discusses the theoretical aspects of how the financial market affects innovation without including the stock market in the empirical analysis. This is because the financial markets of CEE countries are not well-developed, and the data of financial market is too inadequate and superficial to support the quantitative analysis. Second, the indicators selected in this paper are not sufficient to reflect the process of innovation. Although this thesis has selected two indicators to capture innovation input and innovation output, innovation is considered as a complex process that involves the development, application and diffusion of new products or technologies. And the actual impact and economic significance of different types of innovations are also different. Third, this paper does not differentiate innovation by different industries to conduct industry analysis to examine the varying effects of financial development on innovation across industries. As Hsu et al. (2014) believe that innovation varies significantly across industries, so that it is necessary to conduct industry research.

8. Conclusion

This thesis aims to investigate the impact of financial development on innovation. A review of the literature shows that although previous theoretical studies have elaborated on the mechanisms by which financial development influences innovation, the conclusions of related empirical studies are inconsistent, and some gaps exist in previous analysis. Most of previous papers analyse numerous countries as a pooled sample, including developing and developed countries, which may contribute to biased results due to the existence of heterogeneity. In addition, most studies choose different indicators to represent the level of financial development, which may contribute to divergent results and is not convenient to provide more detailed policy recommendations. To fill these gaps, a panel dataset of 40 European countries over the period 1995-2021 is applied by this thesis to investigate how financial development affects innovation. Considering the heterogeneity of these European countries, they are divided into two subgroups (Central and Eastern European countries and Western European countries) to carry out a comparative study to determine whether the impact of financial development on innovation is different in the two groups of countries. Moreover, considering that the functions of the financial system are multi-dimensional, except for the overall indicator of financial development, this thesis also measures the development of the financial system from four dimensions, consisting of depth, access, efficiency, and stability. This paper selects two indicators for the measurement of innovation, the number of patent applications and R&D expenditure, to capture innovation activities from the perspectives of innovation output and innovation input, respectively. With respect to methodology, the fixed-effect model is adopted by this thesis as the main model to investigate how the four dimensions of financial development affect the innovation output and innovation input, and the system GMM technique is employed to evaluate the robustness of the results. To answer three research questions, this paper designs 3 specifications and 9 studies to carry out quantitative analysis. The principal findings of the empirical results are concluded as follows.

(1) Overall financial development can increase the number of patent applications (innovation output) and R&D expenditure (innovation input) in the pooled sample, as well as within the CEE group and the WE group.

(2) In CEE group of countries, the improvement of each of the four dimensions of the financial system can increase the number of patent applications, while only financial depth, access and efficiency can promote R&D expenditure, financial stability has no effect on R&D expenditure.

(3) In WE group of countries, the enhancement of three of the four dimensions, including access, efficiency, and stability, contributes to the rise in the number of patent applications. With regard to innovation input, the improvement in the level of financial depth, access, and efficiency can stimulate R&D expenditure.

(4) In CEE countries, three of the four dimensions, depth, access and efficiency have a greater positive impact on the level of innovation, in terms of both the number of patent applications and R&D expenditure.

(5) In WE countries, the stimulation of financial development on the number of patent applications and R&D expenditure is mainly achieved through the improvements in the financial efficiency and access.

(6) Whether with regard to innovation output or innovation input, depth, access, and efficiency of financial systems exert a greater influence on promoting innovation in CEE countries than in WE countries.

(7) In both the CEE group and the WE group, the stability of the financial system only increases the number of patent applications but has no effect on R&D expenditure, and the positive impact of financial stability is almost the same in the two groups of countries.

(8) In both CEE and WE countries, financial development exerts a more significant influence on the total number of patent applications (innovation output) than on R&D expenditure (innovation input).

Based on the implications derived from the study, several policy recommendations are put forth to foster and encourage innovative activities within CEE and WE countries. For CEE countries, it is recommended to focus on expanding the scale of their financial markets, diversifying financial products and services, strengthening financial regulation, lowering the entry threshold of financial institutions, and optimizing their operational processes. By doing so, they can achieve enhanced financial depth, improved access to financial resources, and increased overall efficiency, leading to a conducive environment for innovation. On the other hand, for WE countries, the suggested approach involves expanding the scope of financial services, promoting the digital

transformation of financial institutions, and facilitating the provision of online banking services. This strategy aims to create a more accessible and efficient financial system, ultimately fostering innovation. In conclusion, this paper critically examines the potential contributions and limitations of these policy recommendations, paving the way for further research in the field.

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List of appendices

Appendices

Appendix 1: Correlation Matrix

	Patent	R&D	FD	Depth	Access	Efficiency	Stability	Education	GDP per capita	GOV_EXP	PS	Trade
Patent	1											
RD	0.601***	1										
FD	0.474***	0.613***	1									
Depth	0.604***	0.831***	0.837***	1								
Access	0.188***	0.130***	0.770***	0.345***	1							
Efficiency	0.259***	0.271***	0.335***	0.322***	0.175***	1						
Stability	0.013	0.277***	0.197***	0.313***	-0.065	-0.089**	1					
Education	0.232***	0.408***	0.148***	0.267***	-0.068	0.161***	0.427***	1				
GDP_per_capita	0.394***	0.637***	0.691***	0.723***	0.345***	0.335***	0.117***	0.397***	1			
GOV_EXP	0.261***	0.569***	0.382***	0.565***	0.001	0.199***	0.384***	0.303***	0.379***	1		
PS	0.162***	0.566***	0.448***	0.545***	0.123***	0.207***	0.148***	0.222***	0.627***	0.405***	1	
Trade	-0.224***	-0.047	0.034	-0.013	0.062	0.085*	-0.453***	-0.127***	0.291***	0.187***	0.178***	1

***. Correlation is significant at the 1% level, i.e. p<0.01
**. Correlation is significant at the 5% level, i.e. p<0.05
*. Correlation is significant at the 10% level, i.e. p<0.1

Appendix 2: List of Two Groups of Countries

WE group of countries			CEE group of countries			
Austria	Ireland	Spain	Albania	Georgia	North Macedonia	Ukraine
Belgium	Italy	Sweden	Belarus	Hungary	Poland	
Denmark	Liechtenstein	Switzerland	Bosnia and Herzegovina	Kosovo	Romania	
Finland	Luxembourg	United Kingdom	Bulgaria	Latvia	Russia	
France	Netherlands		Croatia	Lithuania	Serbia	
Germany	Norway		Czech Republic	Moldova	Slovakia	
Iceland	Portugal		Estonia	Montenegro	Slovenia	