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Innovation, Regional Growth, and Housing Prices: Do Housing Prices Affect Local Innovation?

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In this study, we examine the effect of regional innovation with the number of registered patents as a proxy for innovation on regional growth in South Korea. We use economic and housing price data from 17 regions from 2012 to 2021 to examine the interrelationships among housing market and local innovation and regional growth. We adopt the 2-stage least squares method to overcome the endogeneity issue of our regional growth and housing price models while controlling for housing price appreciation and regional specific characteristics. Our findings reveal that while innovation has a significantly positive effect on both the local residential real estate market and regional growth, housing price does not affect regional innovation. We find that a 1% increase in patents increases the gross regional domestic product per capita by 0.188%. Innovation has a positive impact on the housing market, with a 10% increase in patent increases leading to an increase of 0.329% in housing prices. Our findings have a policy implication: innovative activity stimulates regional growth and innovation driven growth increases housing demand, thus emphasizing the need to ensure housing affordability and adequate supply.

Keywords

Regional growth, Housing price, Housing market, Patent, Innovation

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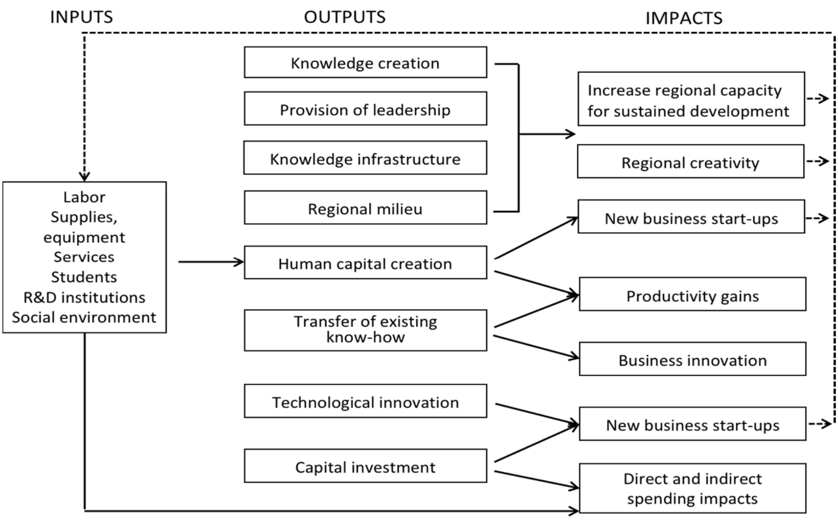
1. Introduction

In the face of increasing global social and economic competition, innovation is a critical driving force that leads to the economic development of both regions and countries. Regions with a higher number of registered patents, which serve as a proxy for higher innovation levels, grow faster than other regions. Knowledge-based activities, such as teaching and fundamental basic research, have substantially positive effects on a variety of measures of regional economic progress. Innovation-related activities, such as research and technological development, generate significant knowledge spillovers that are captured within the regional environment and result in enhanced regional economic development (Acosta et al. 2009). Specifically, universities serve as a driving factor for innovation, and provide labor resources, equipment services, and R&D institutions as depicted in Figure 1. These institutional factors lead to regional economic development via the eight following functions: knowledge creation, provision of leadership, knowledge infrastructure, regional milieu, human capital creation, transfer of existing knowledge, technological innovation, and capital investment (Drucker and Goldstein 2007, Lendel 2010).

Figure 1 University Outputs and Expected Economic Impacts



***Sources*:** Goldstein et al. (1995) and Lender (2010)

Universities increase knowledge production through human capital, innovations and scientific research which results in patents, products, and services, thus contributing to the growth of innovative regional economies (Power and Malmberg 2008). University patents, in particular, may influence regional innovation in two different yet complementary ways. First, after new patented knowledge is licensed to private firms, private innovation is stimulated and later promotes regional economic growth. Second, new university patents allow the exchange of technological knowledge between universities and private firms, which indirectly contributes to regional innovation. Thus, a city that is more innovative becomes more attractive to different types of resources, such as skilled labor, capital, and technology. As a result, the workforce and capital will be increasingly concentrated in cities with higher innovation.

However, little attention has been given to the bi-directional causal relationship between housing market and urban innovation vitality. Research on the potentially causal relationship between housing prices and innovation has been conducted during a housing boom in recent decades. The increased housing prices have had a positive impact on the innovation of firms during a housing boom through the increased value of collateral assets via external financing (Rong et al., 2016). The impact of housing prices on regional innovation capacity, however, shows an inverse U-shaped relation. This finding implies that urban innovation as a proxy for total factor production, research and development (R&D) expenditure, and patent registration has a positive relation with housing prices initially; after exceeding a certain threshold, housing prices erode the innovative vitality of a city (Yu and Cai, 2021). Regional growth and housing prices are closely related since the economic growth of a region will drive demand for housing which can lead to housing price increase. Thus, policymakers need to consider the relationship between housing prices and economic growth as they promote economic and regional development via innovation (Zhang, 2020).

However, there are few available studies in the literature on the interrelation between innovation and the role of housing prices in the context of regional growth in South Korea. In response, we first examine the interrelation between university patents, which serve as a proxy for innovation, and regional development, by considering housing market fluctuations in South Korea. As we mentioned earlier, housing price fluctuation makes it difficult to access a highly skilled labor force due to the high cost of living and access to capital resources due to relatively high operating costs. Furthermore, the lack of affordable housing in urban areas results in high levels of housing insecurity, particularly for the younger generation. The disparities between the urban and rural areas continue to widen and consequently exacerbate disparities in the regional labor supply. This labor supply mismatch will reduce the efficiency and productivity of more rural firms and slow down regional development. These disparities are also associated with university and regional developments in South Korea. Although rural universities exist, highly educated and skilled experts may relocate to urban regions to seek more business collaborations, entrepreneurial support, and opportunities, which results in the brain drain phenomenon in rural areas. Thus, most of the universities are concentrated in Seoul and its surrounding metropolitan area, which potentially leads to a concentration of highly skilled experts in this area at the potential expense of slow rural regional development[1].

Correspondingly, the first objective of this study is to empirically examine the effect of innovation on regional economic growth in South Korea. Utilizing the number of registered patents as a proxy for regional innovation (Bonander et al., 2016, Johnson and Brown, 2003, Zhang, 2020), we measure the marginal effect of regional innovation on regional economic growth. We note the role of research universities as the main driving factor for regional growth along with the regional restructuring of land use plans in South Korea. Thus, our findings on the marginal effect of innovation on regional growth allow policymakers to allocate limited resources to facilitate regional innovation through regional flagship universities in the context of restructuring land use plans that seek to enhance competitiveness.

The second purpose of this study is to examine the connection between regional flagship universities and innovation. We provide empirical evidence that universities are actively contributing to technological advancements, which is reflected in the number of patents and regional economic growth in South Korea. We consider the following factors as catalysts for innovation: the amount of R&D funding, number of available faculty members, number of research projects per faculty member, and the number of universities in the region. Thus, our research contributes to identifying the effective optimal productive threshold of innovative activity for universities in South Korea.

The third purpose of this study is to examine the interaction between the housing market and regional innovation. We provide empirical evidence that innovation has no significant impact on regional housing prices in South Korea. Notably, housing price appreciation has stimulated firms to enter the real estate industry, which negatively influences the ability of a typical firm to secure patents for inventions (Rong et al., 2016, Yu and Cai, 2021). We consider the following factors as variables related to innovation: the total new supply of houses, number of construction permit approvals, and new construction in the region.

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[1] Universities in South Korea with large total enrollments of undergraduate students obtained from the Ministry of Education include: Kyounghee University (approximately 26,000 students), Kyungpook National University (approximately 21,000 students, Daegu), Yeungnam University (approximately 20,000, Daegu), Korea University (approximately 20,000 students, Seoul), Gachon University (approximately 19,370 students, Gyeonggi), Busan National University (approximately 19,250 students, Busan), Yonsei University (approximately 19,230 students, Seoul), Choseon University (approximately 18,341 students, Gwangju), Sungkyunkwan University (approximately 18,298 students, Seoul), Chung-Ang University (approximately 15,000 students, Seoul), Donga University (approximately 17,887 students, Daegu), and Chonbuk University (approximately 17,561 students, Jeonju). This list is based on the approximate undergraduate student enrollments in 2021 and not exhaustive.

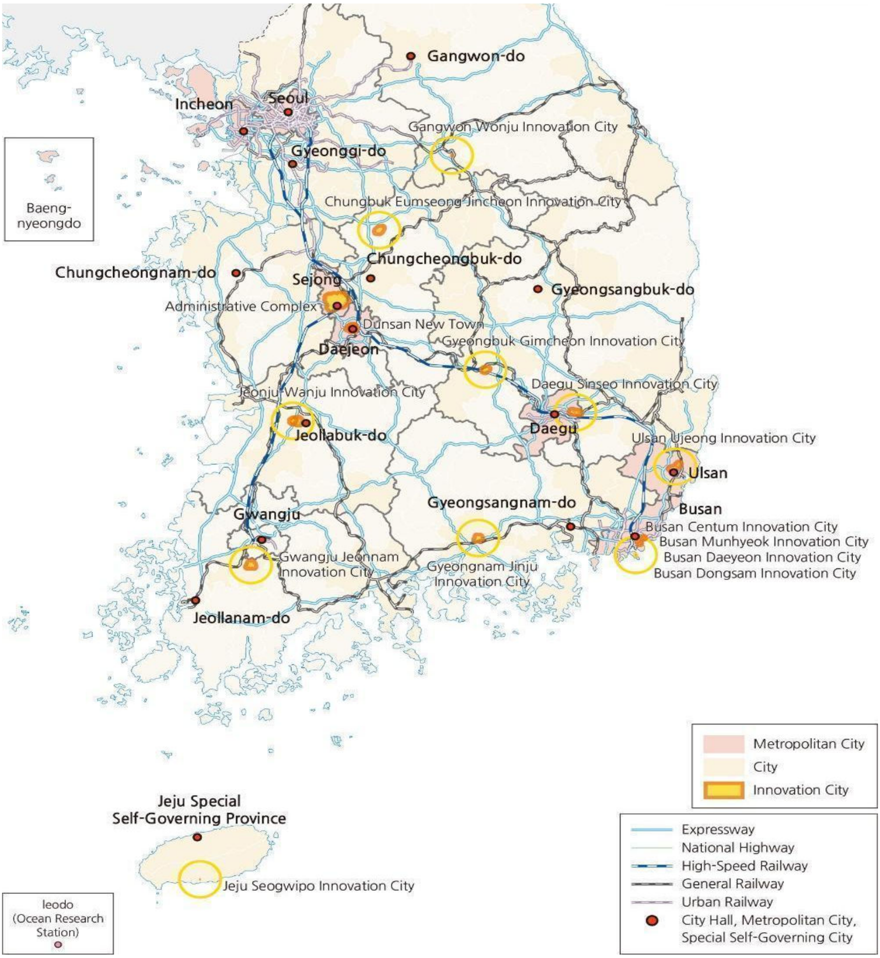
This paper consists of the following sections: Section 2 describes the literature and theoretical framework; Section 3 describes the data; Section 4 outlines the methodology; Section 5 presents the empirical results and robustness measures; and Section 6 draws conclusions from the results.

1.1 Implementation of Innovative City Project in South Korea (2004–2012)

The Innovative City Project by the Ministry of Land and Transportation was established to address overpopulation in the Seoul and Gyeonggi-do metropolitan areas and balance regional development (see Figure 2). The Balanced National Development Act, launched in 2004, was foundational for this initiative, including the relocation of central government agencies as a major strategic focus. The plan designated ten innovation cities and six districts for development, with newly developed cities like Daegu and Ulsan. The Innovation City Act of 2007 formalized these efforts, which allowed for collaboration between the central and local governments. This was the first plan of South Korea to integrate public institution relocation, city construction, and regional growth. Following the relocation completion in the 2010s, the "Innovation City Season 2" was launched, which combined infrastructure enhancement with local industrial development strategies under the 2018 Comprehensive Development Plan. The Regional Revitalization Project, launched in December 2018, targets 14 areas across South Korea (including Jeollabuk, Jeollanam, Gwangju, Busan, Daegu, Gyeongsangbuk, and Gyeongsangnam) to restore industrial ecosystems and boost economic recovery through R&D, investment, and global collaboration. Its goal is to boost local economies, create jobs, and foster innovation by relocating 153 public institutions from the Seoul metropolitan area to 10 designated regions across the country. Each innovative city focuses on its regional strengths, such as the financial district in Busan, medical district in Daegu Metropolitan City and Wonju, and energy related industry in Gwangju and Naju. The purpose of this relocation policy is to support local economies, create jobs, and promote balanced regional growth through specialized industries.

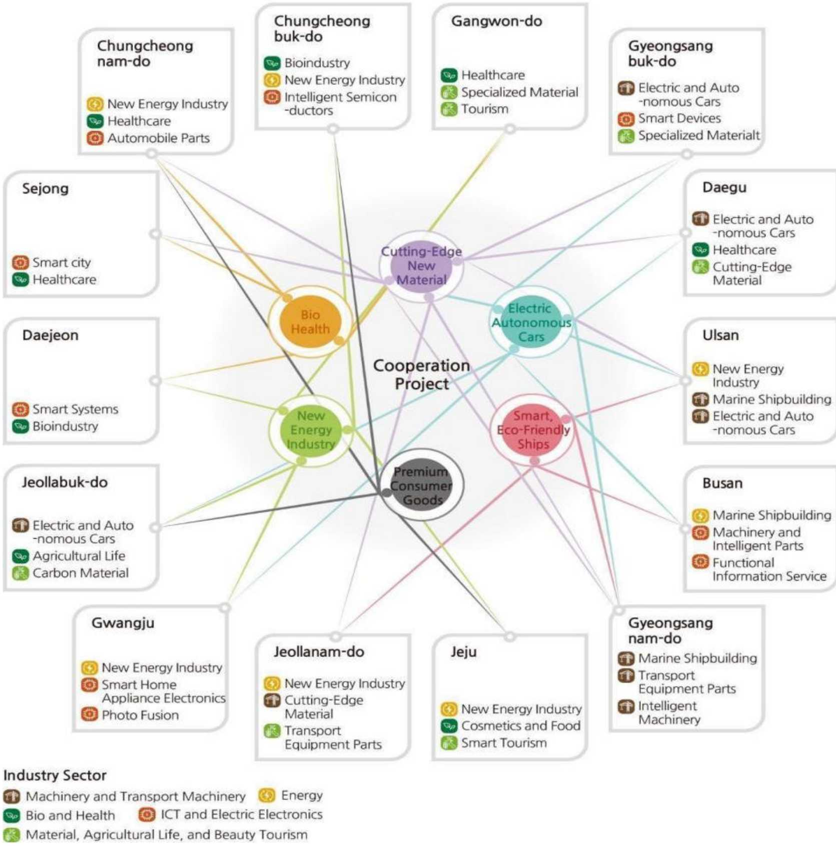
Since 2018, the National Innovation Cluster Project has been implemented in 14 cities to establish innovation hubs near industrial and research facilities; see Figure 3. Each cluster spans 15 km^2 within a 20 km radius and includes government-led R&D projects, locally proposed tasks, and non-R&D initiatives aligned with regional needs, such as investment attraction and global cooperation. The project aims to draw companies from the Seoul area, thus creating a regional production base connected to the innovation cities. Under the "Regional Balanced New Deal", the government supported 48 key industries in these clusters from 2021 to 2025.

Figure 2 Distribution of Innovative Cities and Relocation of Public Institutions



Notes**:** Source from the National Atlas of Republic of South Korea III, 2021, http://nationalatlas.ngii.go.kr/pages/page_2563.php.

Figure 3 Major Industrial Development Network



***Notes*:** Notes: Source from the National Atlas of Republic of South Korea III, 2021, http://nationalatlas.ngii.go.kr/pages/page_2658.php

2. Literature Review

2.1 Effect of Regional Innovation on Regional Economic Growth

In the context of increasing competition among global cities, it is essential to improve and maintain the innovation vitality of each city (Yu and Cai, 2021). Regions with higher patent intensity, as a proxy for innovation, grew faster than the other regions, as determined from a study of 4580 European colleges and universities from 1998 to 2004 (Acosta et al., 2009). Acosta et al. (2009) investigate the relationship between regional patterns of technological diversity and specialization in European universities and their impact on new technological patents. They find that a diversified strategy of regional university technological knowledge production favors subsequent new university patents, and that specialization has a positive and significant impact in high-tech sectors (Acosta et al., 2009). Also, regional innovative policies, such as smart city policies, have attracted relevant attention and funding for regional growth. Caragliu and del Bo (2019) conduct a study on the impact of smart city policies on urban innovation. They hypothesize that direct use of technology in smart city policies might result in spillover effects on technological innovation. Adopting propensity score matching estimates to control for the heterogeneity between sample groups, the study finds that the cities enacted smart city policies at a level higher than the European average and tended to apply for a larger number of patents. Similar research work has been conducted in non-European countries.

Innovation plays a pivotal role in fostering economic growth, as evidenced by various studies across different regions and time periods. Crosby (2000) examines the importance of innovation for economic growth in Australia. The study explores the causal relationship between the increase in patenting activity in Australia and its impact on labor productivity and economic growth. The study emphasizes the role of government subsidies on R&D activity and finds that a decline in R&D subsidies will lead to a decline in domestic innovation and a reduction in economic growth.

Building on this understanding of innovation dynamics, Simonen and McCann (2008) have also explored the relationship between firm innovation and human capital mobility. They define firm innovation as the launch of new or substantially-improved products in the previous 2 years. They consider human capital mobility as a critical determinant factor in firm-specific innovation. These interrelated findings show that innovation is not an isolated effort, but deeply influenced by various factors, including government support, human capital mobility and collaborative networks. Understanding these developments is crucial for formulating policies to effectively cultivate and maintain innovation at the company and regional levels.

Innovation plays a critical role in driving economic growth and competitiveness, with innovation clusters serving as key hubs for high-tech and creative industry innovations. The specific functions and spatial characteristics of these innovation districts can vary widely depending on local contextual factors. Yigitcanlar et al. (2020) classify innovation districts into three categories based on the key characteristics of function, feature, and space use. To analyze these districts, Tan et al. (2020) examine data from 309 European Union (EU) cities and focus on the differences in adopting smart city policies. The study indicates that cities that exceed the EU average in implementing smart city policies tend to show higher levels of innovation.

The relationship between physical distance and innovation with the workplace, and how commuting distance affects the productivity of inventors have been discussed in depth. Xiao et al. (2021) analyze data from 60 combined statistical areas across 23 U.S. states between 1993 and 2012 and incorporate over 195 million housing transactions. They find a notable negative impact of commuting distance on the output of inventors. The results of this study indicate that commuting distance has a significantly negative impact on the productivity of inventors. Specifically, for every 10 kilometers of commuting distance, the number of patents decreases by 5% each year, and the quality of the patents decreases by 7%. The effect is more pronounced among high-performing inventors. Xiao et al. (2021) suggest that firms encourage inventors to live closer to their workplace and consider commuting distance when making decisions about office location, with particular consideration given to optimizing the productivity of their top-performing inventors.

In this context, the role of high-tech companies, student mobility and youth entrepreneurship increasing the attractiveness of cities in Italy has also been explored. Marchesani et al. (2022) analyze the data of 30 Italian cities over a decade (2009-2019) and use the spatial group data model to explore how the presence of high-tech firms in cities affects the inflow of students, thus considering the moderating role of youth entrepreneurship. They show that the innovation ability of cities plays a crucial role in attracting knowledge and students. Additionally, the study reveals that youth entrepreneurship positively contributes to this relationship, thus indicating that cities with vibrant young entrepreneurial ecosystems are more attractive to students. This shows that there is synergy between local high-tech industries and youth entrepreneurship in improving the attractiveness of a city, thus providing decision makers with insights to promote city development and innovation.

2.2 Universities and Innovation

There have been a few studies in the literature that examine how higher education and research universities contribute to regional economic development. Goldstein and Renault (2004) identify the marginal effects of teaching, basic research, technology development, technology transfer, and other factors. They adopt a quasi-experimental approach to explain the variation in the change in average earnings per job across 312 metropolitan statistical areas in the United States (US) that spanned the years 1969-1986 and 1986-1998. The authors put forth five assumptions and tested their hypotheses. First, their findings indicate that research universities significantly contribute to regional economic development. Second, the mechanisms for university R&D activities to stimulate economic development are broader than patenting and licensing activities. Third, human capital creation and environmental functions of universities are important contributors to regional economic development. However, Goldstein and Renault (2004) find that the contribution of research and technology development activities of universities to regional economic development is relatively minor compared to other control factors.

Fritsch and Slavtchev (2007) expand on this understanding and emphasize the importance of the intensity and quality of university research in promoting regional innovation. To measure innovative output, they use the number of regional patent applications from 1995-2000, obtained from the German Patent Office database. Their study reveals that the research intensity and quality of universities have a more significant impact on regional innovation output than private R&D. Furthermore, this effect decreases as regional proximity decreases. Thus, they suggest that a policy that aims to promote regional innovation processes through university development should prioritize the intensity and quality of research.

Further reinforcing the economic significance of universities, Valero and van Reenen (2019) show that an increase in the number of universities per capita is positively correlated with regional gross domestic product (GDP) growth. They argue that an increase in spending by students and faculty could lead to a noteworthy increase in the regional GDP, as universities tend to purchase local goods and services. They find that a 10% increase in the number of universities per capita in a region is correlated with a 0.4% increase in future GDP per capita. This further enhances the economic significance, which highlights the role of universities as catalysts for economic development, not only through direct academic contributions, but also by strengthening the regional labor force and supporting local enterprises.

Moreover, the complexity of university contributions to regional development is further illustrated in the context of government-university collaborations in smart city projects. Guenduez et al. (2024) use a mixed-method approach that combines qualitative comparative and thematic analyses of interviews and secondary data to explore how outputs, institutional, relationship, and framework factors affect the success of these collaborations. The study finds that all four factors must be positively evaluated so that collaboration can be considered successful. On the contrary, a negative assessment of any one of these factors is enough to consider the collaboration unsuccessful. This highlights the complexity and delicate balance required to effectively manage such partnerships. It also emphasizes the importance of strategic management and a strong project framework to navigate the challenges and take advantage of the benefits of government-university partnerships in developing smart cities and governments.

In order to attract innovation-related investment and reduce regional differences, the South Korean government implemented the Balanced National Development Act in 2004 and an innovative city project in the past two decades since 2004, through the relocation of public institutions and the establishment of special regional clusters. In addition, the National Innovation Cluster Project (2018-2025) carries out investment incentives in 14 designated areas, including tax cuts, land supply and government-led R&D funds. The government intervenes to improve innovation hubs in different regions through land use planning, infrastructure development and targeted relocation of public institutions. This spatial difference was officially implemented in the Innovative Cities Act of 2007, and the state played a role in regulating regional innovation in South Korea, rather than act as a passive promoter.

2.3 Housing Market Prices and Regional Innovation

Our research focuses on the local impact of innovation on the economic growth and housing market in each region. The reference literature shows that innovative activities, research institutions and talent flow produce intellectual externalities that transcend administrative boundaries (Acosta et al., 2009; Fritsch and Slavtchev, 2007). For example, patent activities and R&D investment in metropolitan centers such as Daegu or Daejeon may stimulate innovation in the surrounding small cities through labor mobility and supplier networks. However, our current model does not explicitly incorporate the spatial econometric framework to explain this interregional dependence.

From 2004 to 2012, the development of the innovative city policy of South Korea can be divided into three stages: (1) planning stage (2004-2006): After the promulgation of the Balanced National Development Act in 2004, the South Korean government launched a master plan for innovative cities, which aimed to transfer administrative, research and industrial functions from the Seoul metropolis to ten other candidate cities. Each candidate city was selected according to regional comparative advantages, such as agriculture in Jeonbuk and energy technology in Gwangju, (2) legal basis and institutional relocation (2007-2010): The adoption of the Innovative Cities Law in 2007 provided a legal basis for 153 public institutions to relocate to designated innovative cities. In the three years from 2007 to 2010, detailed relocation, land acquisition and infrastructure plans were carried out, and (3) initial operation (2010-2012): Public institutions began to relocate to their innovative cities and work on the infrastructure of the city. The panel data for the period from 2012 to 2021 are provided and used in this study.

Recent studies on innovation and the role of the housing market have generally shown a positive correlation among innovation, real estate prices, and regional economic growth, such as Crosby (2000). Crosby (2000) finds a positive relationship between real estate prices and regional economic growth, with higher housing prices leading to increased investment in local businesses and infrastructure. In a similar vein, Yu and Cai (2021) explore the connection between real estate prices and regional growth. Using panel data from 288 cities in China from 2001 to 2016, they adopt a simultaneous equation model to empirically evaluate the interplay between housing prices and urban innovation vitality. Their research reveals an inverted U-shaped relationship of the impact of housing prices on urban innovation, which means that as housing prices increase, the vitality of urban innovation initially increases but then begins to decrease. Furthermore, Yu and Cai (2021) identify the point of inflection, where the positive impact of urban housing prices on urban innovation transitions to a negative effect.

Wu and Deng (2024) find that urban renewal also has a positive impact on housing prices in the Bao'an District, in Shenzhen, China. They use a mixed method with a difference-in-difference model to utilize a comprehensive dataset of housing transactions from 2010 to 2021. Their findings show that industrial renewal has the most significantly positive impact on the surrounding housing prices and scale of renewal projects, and its proximity plays a crucial role in determining its impact on housing prices. Rong et al. (2016) conclude that the appreciation of housing prices creates profitable real estate investment opportunities, which would encourage manufacturing firms to diversify into the real estate industry. Nonetheless, diversifying into a non-core sector, like real estate, may result in less investment in innovation as the firm may allocate its (finite) resources toward real estate instead of its core specialization. Utilizing firm-level data from the Annual Survey of Industrial Firms of China between 1999 and 2007, Rong et al. (2016) provide empirical evidence that regional housing price appreciation subsequently negatively affects innovation among regional manufacturing firms. According to their argument, the increase in housing market prices motivates firms to allocate their assets into the real estate sector, including real estate investment, which leads to a decline in invention patents. Rong et al. (2016) also explore the mechanism that underlies this relationship by examining the probability of listed firms diversifying into real estate and the subsequent impact on their patenting activity. The magnitude of this adverse impact becomes more pronounced in regions where there is a higher growth rate of housing prices. The relationship between the regional housing market and local innovation is worthy of examination as different studies have yielded different results.

Contrary to the negative effects observed by the manufacturing industry, the relationship between innovation and house prices in the US shows different dynamics. Beracha et al. (2022) examine the relationship between local innovation and its impact on the housing market. Using comprehensive patent information from the United States Patent and Trademark Office from 1926 to 2010, they not only quantify patenting activity with the number of patents but also assess its quality by considering the number of citations. Furthermore, they determine the residency of inventors to aggregate local innovation. The findings suggest a positive correlation between innovation quality and subsequent appreciation in local real estate prices. Additionally, the extent of housing price appreciation is more significant in regions with limited land available for new construction.

2.4 Contribution of Our Research

Our contribution to the literature is to identify the interrelationship between local innovation and regional growth in South Korea. There is a lack of clear understanding on the relationship among local innovation, the housing market, and regional growth in the current literature, and no studies have been conducted on this topic in South Korea. Hence, our main goal is to investigate and establish the links among these research variables. The topics of local innovation, the housing market, and regional growth are especially important in South Korea since the South Korean government established government-driven innovative cities in 2014 as part of an effort to relocate government agencies and government-sponsored enterprises to local areas and foster more rural economic growth and reduce population and employment density in the Seoul Metropolitan Area[2].

Thus, we first examine the impact of local innovation on local gross regional domestic product (GRDP). We formulate the research hypotheses with the expectation of finding statistically significant relationships between the changes in housing prices and patent activity, as well as regional growth. To avoid problems related to endogeneity, we employ the two-stage least squares (2SLS) method to estimate the causal relationships between an endogenous variable and other exogenous variables. Therefore, we identify the instrumental variables (IVs) that specifically and predominately affect the endogenous variables, particularly innovation and the residential housing market, but not regional growth.

The second contribution of this paper is that we examine the relationship between local housing prices and local innovation growth following the implementation of the public sector relocation in 2014, and Balanced Regional Development Act in South Korea. We expect that the increase in housing prices and innovation growth will have a positive impact on the GRDP. However, we find that housing prices have no significant impact on regional innovation growth. Excessive housing prices have been found to potentially hinder innovation by creating difficulties for young people and startups to access affordable housing. This, in turn, may lead to a loss of talent in the area,

[2] The South Korean government has implemented policies to decentralize public agencies, with the aim to distribute central government functions and offices and drive the growth of local cities. The key policies implemented include: i) relocation of central government agencies. Specific central government agencies and their offices are moved from the capital region to cities outside the metropolitan area. This strategic relocation aims to stimulate regional economic growth and encourage population dispersal, ii) dispersion of public institutions. Public institutions are dispersed across various regions to strengthen the capabilities of local cities and support regional economic development. This involves establishing branch offices or facilities of public institutions in different locations, and iii) relocation of national universities. Some campuses of national universities are relocated from the capital region to cities beyond the metropolitan area. The intention of this move is to enrich the educational landscape in local cities and enhance the academic prowess of regional universities. These policies form part of the commitment of the South Korean government to achieving a more balanced distribution of administrative functions, fostering regional development, and promoting innovation within local cities (http://www.molit.go.kr/).

commonly referred to as a "brain drain". In particular, insufficient research has been conducted to investigate the relationship between the number of patents (innovation) and regional housing prices. Therefore, this study assumes that the number of faculty members, number of research projects, and research funds of universities will have a positive impact on the number of patents, thus improving regional economic growth, and that the number of patents will also have an impact on regional housing prices. With this approach, this research clarifies the potentially bi-directional relationship between house prices and the number of patents.

Table 1 shows the summary statistics of the national proportion of relative changes of the major variables between 2012 and 2021, according to the descriptive statistics of the GRDP of the 17 major regions. We include 17 regions that correspond to the first-level administrative division of South Korea, which are designated as the locations of innovative cities according to the Balanced National Development Act launched in 2004. The government has a policy for each region to foster a specialized industry. For example, Gwangju and Naju focus on energy-based innovation clusters, Daegu focuses on medical R&D, and Jeonbuk focuses on agricultural technology. The heterogeneity of cross-regional policies enables us to take advantage of the time and spatial changes in innovative activities. These areas include highly urbanized metropolitan areas (such as Seoul, Busan and Daegu) and underdeveloped provinces (such as Gangwon and Jeonnam), thus providing substantial differences in GDP, innovation intensity and housing price. In particular, the proportion of the GRDP in Gyeonggi Province increased the most, from 23.55% in 2012 to 25.56% in 2021, a relative increase of 2.01%. Among the 17 local regions, the economic size of Seoul and Gyeonggi accounted for approximately 46.68% and 48.43% of the GRDP in 2012 and 2021, respectively. The GRDP in only 7 of the regions shows relative growth, and the remaining 10 cities show relative decreases. Economic development is concentrated in the capital area, but patents are not. The economic development of Seoul and Incheon decreased, but Gyeonggi increased, and Gangwon and Chungbuk increased as in the case of the GRDP. The economic development of Chungnam increased, but Daejeon decreased significantly, and Gyeongbuk and Jeonbuk decreased.

After we divide the number of patents by the GRDP which represents the number of patents per regional GRDP, Seoul, Gyeonggi, Daegu, and Daejeon (big cities) show significantly negative relative changes compared to 2012 and 2021. Sejong, Jeju, Jeonnam, Gyeongnam, Gwangju, and Busan (small cities) show a relative increase in the number of patents per GRDP in the last 9 years. It is worth noting that the number of patents per GRDP of Sejong has increased significantly. The data for Sejong began in 2013. The number of patents in Sejong increased from 86 in 2013 to 1,046 in 2021, thus showing a relative growth of 476.92% over the period of 9 years. Comparing the relative growth rate of the GRDP and increase in the number of patents, we find that the capital areas — Seoul, Gyeonggi, and Incheon, show a significantly higher relative

Table 1 **Summary Statistics of National Proportion in 2021 and Relative Change between 2012 to 2021(%)**

Region	Proportion of GRDP	Proportion of Patents	#Pat. per GRDP (KRW million)	R&D Funds (KRW million)	Number of Faculty members	Number of Projects
Gyeonggi	25.56%(Δ2.01)	31.21%(Δ1.37)	11.0%(Δ-22.54)	6.61%(Δ21.81)	10.35%(Δ12.89)	7.80%(Δ8.44)
Seoul	22.87%(Δ-0.26)	29.16%(Δ-0.88)	11.5%(Δ13.53)	44.84%(Δ49.84)	30.02%(Δ7.57)	35.17%(Δ21.96)
Chungnam	6.04%(Δ-0.48)	3.93%(Δ0.41)	5.8%(Δ5.45)	3.03%(Δ26.80)	7.27%(Δ0.37)	5.38%(Δ17.83)
Gyeongnam	5.43%(Δ1.38)	3.76%(Δ0.42)	6.2%(Δ24.00)	2.46%(Δ54.40)	4.37%(Δ14.42)	2.71%(Δ-10.08)
Gyeongbuk	5.47%(Δ-0.96)	3.63%(Δ-1.31)	6.0%(Δ24.05)	5.15%(Δ4.77)	6.29%(Δ-2.36)	7.88%(Δ22.01)
Incheon	4.75%(Δ0.16)	3.83%(Δ-0.33)	7.2%(Δ-22.58)	2.18%(Δ36.34)	2.05%(Δ-7.13)	2.54%(Δ-14.80)
Busan	4.78%(Δ-0.14)	3.51%(Δ0.49)	6.6%(Δ4.76)	4.79%(Δ27.05)	7.92%(Δ-2.40)	7.11%(Δ4.84)
Jeonnam	4.28%(Δ-0.18)	2.19%(Δ0.95)	4.6%(Δ64.29)	1.42%(Δ3.91)	2.01%(Δ-2.67)	1.57%(Δ42.38)
Chungbuk	3.63%(Δ0.48)	2.35%(Δ0.38)	5.8%(Δ-9.38)	2.43%(Δ66.00)	4.34%(Δ6.47)	3.58%(Δ-16.09)
Ulsan	3.77%(Δ-1.07Δ)	1.19%(Δ-0.98)	2.8%(Δ-39.13)	3.16%(Δ175.43)	1.91%(Δ15.80)	2.12%(Δ59.18)
Daegu	2.95%(Δ-0.15)	2.72%(Δ0.13)	8.3%(Δ-3.49)	3.61%(Δ96.54)	3.31%(Δ18.07)	3.66%(Δ53.13)
Jeonbuk	2.69%(Δ-0.16)	2.35%(Δ-0.04)	7.9%(Δ-8.14)	3.69%(Δ34.29)	4.32%(Δ-4.74)	4.89%(Δ9.63)
Gangwon	2.46%(Δ0.07)	1.56%(Δ0.29)	5.7%(Δ5.56)	2.70%(Δ42.40)	4.82%(Δ-2.34)	3.43%(Δ44.01)

(*Continued…*)

(Table 1 Continued)

Region	**Proportion of GRDP**	**Proportion of Patents**	**#Pat. per GRDP (KRW million)**	**R&D Funds (KRW million)**	**Number of Faculty members**	**Number of Projects**
Daejeon	2.25%(Δ-0.02)	6.14%(Δ-1.43)	24.6%(Δ-27.65)	8.61%(Δ73.89)	5.70%(Δ4.97)	6.43%(Δ31.19)
Gwangju	2.11%(Δ0.05)	1.92%(Δ0.30)	8.2%(Δ2.50)	4.45%(Δ59.11)	4.27%(Δ5.94)	4.87%(Δ84.58)
Jeju	0.97%(Δ0.06)	0.56%(Δ0.23)	5.2%(Δ36.84)	0.86%(Δ80.33)	1.04%(Δ14.62)	0.87%(Δ-16.09)
Sejong	0.67%(Δ0.24)	0.50%(Δ0.39)	7.5%(Δ476.92)	N/A	N/A	N/A
Total	100.00%(Δ1.03)	100.00%(Δ0.39)	100.00%(Δ513.87)	100.00%(Δ852.87)	100.00%(Δ79.48)	100.00%(Δ342.12)

***Notes*:** The percentage here refers to the proportion of the region variables of the national total of that year. The relative change in parentheses refers to the rate of change in 2021 compared with the variables in 2012. Busan: Financial Innovation City (Korea Asset Management Corporation, etc.), Daegu & Naju, Jeollanam-do: Medical Innovation City (Korea Gas Corporation, etc.), Gwangju: Energy Innovation City (Korea Power Exchange, etc.), Ulsan: Automotive and Shipbuilding Innovation City (Korea Energy Economics Institute, etc.), Wonju, Gangwon: Medical Device Innovation City (Health Insurance Review and Assessment Service, etc.), Jincheon-Eumseong, Chungcheongbuk-do: Information and Communication Innovation City (Korea Information Society Development Institute, etc.), Jeonju, Jeollabuk-do: Agriculture and Food Innovation City (National Pension Service, etc.), Gimcheon, Gyeongsangbuk-do: Railroad and Transportation Innovation City (Korea Expressway Corporation, etc. Proportion of GRDP is gross regional domestic product (100 billion KRW), Proportion of Patents is number of patents per capita, # Pat per GRDP is denoted as the number of patents divided by amount of GRPD (million KRW), R&D funds are research funds (million KRW) owned by all universities in the region, Number of Faculty is the number of faculty of all universities in the region, Number of projects is the number of research projects. 1 USD = 1,417 KRW.

growth rate of the GRDP, whereas the growth in the number of patents is more pronounced in Jeonnam and Gyeongnam. In other words, it is determined that the number of patents has different information than the GRDP. Research funding has risen across the 17 regions, notably in Ulsan (175.43%), Daegu (96.54%), and Jeju (80.33%), with Gyeongbuk and Jeonnam seeing smaller increases. Despite fewer universities, funding growth supports research and innovation, which result in new technology and patents. Six of the seven metropolitan cities, excluding Busan, received more funding than the provincial areas. Faculty numbers have generally increased, and Daegu, Ulsan, Jeju, Gyeongnam, and Gyeonggi show more obvious increases, while Incheon and Busan experienced decreases. Faculty members can generate patents through their own research activities and cooperation projects to further increase the number of patents. Of the 7 metropolitan cities, all have a higher number of faculty members compared to the provincial numbers, with the exception of Incheon.

Almost all regional university projects show an upward trend, while Gyeongnam, Incheon, and Chungbook show a downward trend. It is noteworthy that the number of university projects in Jeju increased by 131.77% during the 9 years. The increase in research funds support universities to carry out more research projects and experiments and further improve the number of patent outputs.

3. Data

3.1 Data Sources

We aggregate a comprehensive annual dataset of the 17 regions, which spans the period of 2012 to 2021. This dataset encompasses three distinct categories, namely indicators that reflect innovation, the housing market, and regional economic growth. First, we consider the number of patents as a fundamental indicator of regional innovation, which serves as a metric to evaluate technological progress by using data from the Korean Intellectual Property Office[3]. Gaining an understanding of the factors that influence the number of patents can offer valuable insights for policymakers, researchers, and enterprises who wish to foster innovation and technological advancement. In this study, we consider the determinant factors that affect innovation, including the number of universities in the region, total number of faculty members employed by these universities, number of research projects conducted by these universities, and research funding received by these universities. The data were drawn from the Korean Statistical Information Service[4] and the Statistical Data of Higher Education in Korea from 2012 to 2021.

[3] Korean Intellectual Property Office (kipo.go.kr)
[4] Korean Statistical Information Service (www.kosis.go.kr)

As a proxy for the residential market, we adopt the regional housing market index from 2012 to 2021 from the Korea Real Estate Board[5]. In analyzing the regional housing market, we also consider control variables such as total new supply, and the number of new constructions. Land use approvals indicate compliance with planning and land management regulations for efficient land utilization and development. The number of approvals directly impacts new housing construction. Sufficient land use area fosters new housing developments, which increase housing supply and potentially influence prices. Conversely, restrictions on approvals can limit new housing construction, thus creating a supply-demand imbalance and driving up prices. The number that represents new housing supply encompasses various types of housing units available for sale or rent. Multiple factors, including land availability, construction activity, government policies, and market demand, influence housing supply. New construction, including single-family houses, apartments, rental properties, and affordable housing, can increase supply and meet housing demands, thus potentially stabilizing, or adjusting prices.

3.2 Variable Selection

In our study, we utilize the regional GRDP as a proxy to gauge regional economic growth. To account for regional variation, we control several macroeconomic variables, including regional export and import amounts, regional population, number of employees and companies, and the presence of public cultural amenities[6], as well as the total budget allocated per region[7]. The GRDP serves as a valuable measure to evaluate regional economic performance. It provides insights into the production and value added within a region, which highlight its contribution to the national GDP. Controlling for macroeconomic factors is crucial to understand regional disparities. Variables such as amount of regional exports and imports, population, workforce and business counts, budget allocation, and public cultural amenities help to evaluate the diverse impacts on regional growth. An examination of the total budget allocated per region especially unveils investment and infrastructure development levels, thus identifying regions with more financial support and, consequently, greater economic growth; see Table 2.

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[5] Korea Real Estate Board (www.reb.or.kr)
[6] Korean Statistical Information Service from 2012 to 2021
[7] Local Finance Integrated Open System

Table 2 Descriptive Statistics

Variable	Definition	Obs.	Min.	Max.	Mean	Std.Dev.
ln(Pat)	Log number of patents	170	6.208	10.965	8.609	1.0308
ln(GRDP)	Log gross regional domestic product (100 billion KRW)	170	9.487	13.175	11.237	0.792
ln(Hp)	Log housing price index	170	4.582	0.153	4.050	5.100
ln(Pop)	Log number of populations of the region	170	13.292	16.449	14.685	0.727
ln(Com)	Log number of companies of the region	170	10.012	13.181	11.346	0.745
ln(Emp)	Log number of employees	170	11.948	15.336	13.4934	0.782
ln(Usearea)	Log usearea (number of approvals)	170	13.885	17.961	15.586	0.793
ln(HS)	Log number of total new supply (m^2)	170	9.682	13.704	11.244	0.823
ln(Con)	Log number of new constructions	170	7.6309	10.952	9.094	0.839
ln(Bud)	Log amount of the regional budget	170	0.840	2.6735	1.667	0.417

(*Continued…*)

(Table 2 Continued)

Variable	Definition	Obs.	Min.	Max.	Mean	Std.Dev.
ln(Pub)	Log number of public cultural amenities in the region	170	3.367	6.381	4.906	0.668
ln(Exp)	Log regional export amounts (million KRW)	170	16.359	26.610	23.529	2.347
ln(Imp)	Log regional import amounts (million KRW)	170	17.669	27.005	23.144	2.158
ln(Fac)	Log number of faculty members employed by all universities in the region	170	6.517	10.076	8.111	0.775
ln(Pro)	Log number of research projects	170	5.9506	10.510	8.299	0.835
ln(R&D fund)	Log research funding (millions of KRW) obtained by all universities in the region	170	10.435	14.973	12.268	0.856
ln(Univ)	Log number of universities in the region	170	1.386	4.127	2.807	0.732

Notes**:** This dataset encompasses three distinct categories, namely indicators that reflect innovation, the housing market, and regional economic growth. We aggregate a comprehensive annual dataset of 17 regions that span 2012 to 2021. 1 USD = 1,417 KRW.

4. Model

4.1 Two-Stage Least Squares Method

The 2SLS method is an IV regression technique used to estimate the causal relationship between an endogenous variable and an exogenous variable in the presence of endogeneity (Angrist and Imbens, 1995). We use the 2SLS method to address the endogeneity issue in our regional growth, innovation, and housing price models, while controlling for housing price appreciation and region-specific characteristics. The panel model for analyzing the impact of patents and housing prices on the GRDP is explained, by considering endogeneity through a reduced-form equation, as follows:

$$Pat_{i,t} = f\begin{pmatrix} Pop_{i,t}, Bud_{i,t}, Exp_{i,t}, Imp_{i,t}, Fac_{i,t}, \\ Pro_{i,t}, R\&D\ fund_{i,t}, Uni_{i,t}, uni\#res_{it}, U_i, T_t \end{pmatrix} \quad (1)$$

$$Hp_{i,t} = f(Pop_{i,t}, Bud_{i,t}, Exp_{i,t}, Imp_{i,t}, HS_{i,t}, Con_{i,t}, U_i, T_t) \quad (2)$$

The subscript i refers to the 17 individual regions, and t corresponds to the time from 2012 to 2021. $Y_{i,t}^{Pat}$ represents the primary indicator of regional innovation and $Pop_{i,t}$, $Bud_{i,t}$, $Exp_{i,t}$ and $Imp_{i,t}$ represent the population size of the region, total budget, and amount of regional exports and imports in millions KRW[8], respectively. $Fac_{i,t}$ denotes the number of facilities and $Pro_{i,t}$ and $R\&D\ fund_{i,t}$ represent the number of research projects and amount of research funds. $Uni_{i,t}$ denotes the number of universities in the region and the interaction effect is denoted as $uni\#res_{i,t}$. U_i represents the unobserved characteristics specific in the panel estimation and T_t denotes the unobserved characteristics over time. $Y_{i,t}^{Hp}$, $HS_{i,t}$ and $Con_{i,t}$ represent the housing price, total new supply (m^2), and new construction, respectively.

$$GRDP_{i,t} = f(\widehat{Pat}_{it}, \widehat{Hp}_{it}, Pop_{i,t}, Bud_{i,t}, Exp_{i,t}, Imp_{i,t}, U_i, T_t) \quad (3)$$

To mitigate the potential endogeneity of patents and housing prices, a reduced-form regression equation for the GRDP is constructed as follows, and Equation (3) is estimated by using the 2SLS method.

4.2 Model Specification

We use the 2SLS method to overcome the potential endogeneity of the variables for our regional growth, innovation and housing price models while controlling for housing price appreciation and regional-specific characteristics.

4.2.1 First-stage Regression Model Specification

The instruments for the patents are from the data related to the research activities of local universities such as the number of faculty members (Fac),

[8] 1 USD = 1,417 KRW

number of projects (Pro), amount of R&D funds ($R\&D\ fund$), and number of universities (Uni). The reduced form of the patent model is as follows:

$$\begin{aligned} ln(Pat)_{it} = \gamma_0 + \gamma_1 ln(Pop)_{it} + \gamma_2 ln(Bud)_{it} + \gamma_3 ln(Exp)_{it} \\ + \gamma_4 ln(Imp)_{it} + \gamma_5 ln(Fac)_{it} + \gamma_6 ln(Pro)_{it} \\ + \beta_3 ln(R\&D\ fund)_{it} + \beta_4 ln(Uni)_{it} + \beta_5 uni\#res \\ + u_i + v_{it}^{p} \end{aligned} \tag{4}$$

The variable of $uni\#res$ is the interaction term between the number of universities and amount of R&D funds. The instrument variables for housing price are from housing construction related data such as housing supply (HS) and the number of new constructions (Con). The reduced form model of housing price is as follows:

$$\begin{aligned} ln(Hp)_{it} = \pi_0 + \pi_1 ln(Pop)_{it} + \pi_2 ln(Bud)_{it} + \pi_3 ln(Exp)_{it} \\ + \gamma_4 ln(Imp)_{it} + \alpha_1 ln(HS)_{it} + \alpha_2 ln(Con)_{it} \\ + u_i + v_{it}^{h} \end{aligned} \tag{5}$$

To determine the effect of regional innovation and housing price on regional growth, a second-stage regression model is constructed.

4.2.2 Second-stage Regression Model

$$\begin{aligned} GRDP_{it} = \beta_0 + \beta_1 ln(\widehat{Pat})_{it} + \beta_2 ln(\widehat{Hp})_{it} + \beta_3 ln(Pop)_{it} \\ + \beta_4 ln(Bud)_{it} + \beta_5 ln(Exp)_{it} + \beta_6 ln(Imp)_{it} + u_i \\ + \epsilon_{it} \end{aligned} \tag{6}$$

where $GRDP_{it}$ is explained by $\widehat{Pat}(ln)_{it}$, which is the predicted value of the patent model, $ln(Bud)_{it}$ of the local government, $ln(Exp)_{it}$, and $ln(Imp)_{it}$, which are well known to be closely related to the GRDP. Variables such as patents and housing price are the focus of this paper and investigated whether they affect the GRDP. These two variables may have endogeneity in that they are correlated with ϵ_{it}. That is, they increase if there is a relative positive change in the GRDP. Therefore, instrument variable estimation is necessary to estimate Equation (6).

The reason why we estimate by using log-transformed values in the case of patents and housing price is that they tend to exhibit serial correlation over time. As such, even when lagged values are used, delayed correlation may persist, thus implying that endogeneity concerns remain relevant. Although the use of lagged variables avoids simultaneity bias, the potential influence of the IVs may still be present. Therefore, we conclude that it is appropriate to use the current set of instruments to control for endogeneity when incorporating these lagged values. As the primary objective of this study is to examine the contemporaneous relationships between the three variables, the explanation of the lead–lag analysis should be retained as the current explanation, and a more detailed investigation into the dynamic relationships is proposed as a direction for future research.

5. Empirical Results

To carry out the IV estimation of Equation (6), we first estimate the reduced form of the innovation model proxy by using the number of patents, as shown in Equation (4) and Table 3. The dependent variable is the natural logarithm of the number of patents and the dependent variables include population, amount of exports and imports, amount of regional budget, amount of R&D funds, number of research projects, number of universities, and other housing-related factors. We find that the explanatory variables of regional budget, amount of R&D funds, number of research projects, and cross-item of number of universities and amount of research funds ($uni\#res$) are statistically significant at the 5% level.

The log amount of the regional budget, $ln(Bud)$, shows a negative impact of -0.772 on innovation, which suggests that regions with cities that are not research oriented with moderate budgets tend to show more innovation. The amount of the research funds does not guarantee more innovation since the coefficient of size of research funds shows a negative effect on the number of patents. Furthermore, the interaction between number of universities and research projects shows a substantial and positive impact on patents with a magnitude of 0.19, which implies that if there is a university with sufficient research projects, we can expect a higher level of innovation activity through the number of patents. In the model, we also consider bias from annual growth and regional characteristics by controlling for year and region. Population has a marginally positive impact on housing prices.

We also confirm that the variables, such as log research funding (millions of KRW) obtained by all universities in the region ($ln(R\&D\ fund)$), the number of research projects and universities, and $uni\#res$ are jointly qualified as instrumental variables. Although we do not report the instrument validation test result, we find from the null hypothesis that they all have zero coefficients with an F-value of 85.45, which means that they have an appropriate explanatory power as instruments for the patents. In addition, we conduct a Hausman test, which confirms the choice of the fixed effects panel data analysis. By using the Hausman test, we analyze the F-value for the IVs under the null hypothesis: number of faculty members, amount of R&D funds, number of research projects, number of universities, and $uni\#res$. An F-value that exceeds 10 indicates that the IVs in the model are valid.

Equation (5), the reduced form model for housing price, is estimated in Table 4. The explanatory variables of population, regional budget, housing supply, and new constructions are significant at the 5% level. Consistent with the literature, we find an increase in population has a statistically positive impact on the housing market with a coefficient of 1.844. This will lead to an increase in the demand for housing and promote activity in the housing market. The housing supply proxy for log number of total new supply(m^2) shows a negative relation to housing price with a coefficient of -0.231 and new construction proxy as arrival of newly constructed housing has a positive impact on housing prices with a coefficient, of 0.081.

Table 3 Estimation Results: First Stage Regression of Innovation Model

Dependent Variable: ln(Patents)	Coef.	Std. Err.	t-stat.	p-value
ln(Pop)	0.794*	0.454	1.750	0.083
ln(Exp)	0.057	0.065	0.870	0.388
ln(Imp)	0.022	0.030	0.730	0.466
ln(Bud)	-0.772***	0.193	-3.980	0.000
ln(R&D fund)	-1.075***	0.188	-5.720	0.000
ln(Fac)	-0.124	0.158	-0.79	0.434
ln(Pro)	0.190**	0.070	2.680	0.008
ln(Uni)	-0.445	0.524	-0.85	0.396
uni#res	0.395***	0.079	4.950	0.000
ln(HS)	-0.041	0.062	-0.660	0.511
ln(Con)	-0.023	0.025	-0.930	0.356
Constant	-2.268	6.065	-0.37	0.709
City FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Standard Deviation	0.759	R-squared	Within	0.660
Within-subject Standard Deviation	0.083		Between	0.866
			Overall	0.863

***Notes*:** Significance at p-values of 10%, 5%, and 1% is denoted as *, **, and ***, respectively. ln(Patents) is the number of patents per capita, ln(Pop) is population in the area, ln(Exp) and ln(Imp) are the regional exports/imports (millions KRW), ln(Bud) is total budget amount (millions KRW) of each region, ln(R&D fund) is research funds (million KRW) owned by all universities in the region, In(Fac) is the number of faculty members, ln(Pro) is number of research projects, ln(Uni) is the number of universities in the region, uni#res is a cross-item of the number of universities and amount of research funds, ln(HS) is total new supply (m^2), and ln(Con) is the total number of new constructions. City FE denotes a city specific fixed effect which controls for time-invariant fixed characteristics specific to each city, Year FE denotes a year fixed effect that controls for shocks or factors that are constant across all cities in a given year. The between R^2 is the variance between the separate panel units, within R^2 is the variance within the panel units and R^2 overall is the weighted average of these two.

Table 4 Estimation Results: First Stage of Housing Price Model

Dependent Variable: ln(Hp)	Coeff.	Std. Err.	t-stat.	p-value
ln(Pop)	1.844***	0.399	4.620	0.000
ln(Exp)	0.079	0.057	1.370	0.174
ln(Imp)	0.015	0.026	0.590	0.555
ln(Bud)	1.405***	0.170	8.250	0.000
ln(R&D fund)	-0.271*	0.165	-1.640	0.103
ln(Uni)	-0.296	0.460	-0.640	0.520
ln(Pro)	0.306***	0.062	4.910	0.000
ln(Fac)	-0.228	0.139	-1.64-	0.105
uni#res	0.060	0.070	0.860	0.391
ln(HS)	-0.231***	0.055	-4.20	0.000
ln(Con)	0.081***	0.022	3.650	0.000
Constant	-24.323	5.329	-4.56-	0.000
City FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Standard Deviation	1.315	R-squared	Within	0.793
Within-subject Standard Deviation	0.073		Between	0.191
			Overall	0.055

***Notes*:** Significance at 10%, 5%, and 1% levels is denoted as *, **, and ***, respectively. ln(Hp) is the housing price index, ln(Pop) is the population in the area, ln(Exp) and ln(Imp) are regional exports/imports (millions KRW), ln(Bud) is the total budget amount (million KRW) for each region, ln(R&D fund) is research funds (million KRW) owned by all universities in the region, ln(Uni) is the number of universities in the region, In(Fac) is the number of faculty members, ln(Pro) is the number of research projects, Univ# R&D is a cross-item of university and research funds, ln(HS) is total new supply(㎡), and ln(Con) is the total number of new constructions. City FE denotes a city specific fixed effect which controls for time-invariant fixed characteristics specific to each city, Year FE denotes a year fixed effect that controls for shocks or factors that are constant across all cities in a given year. The between R^2 is the variance between separate panel units, within R^2 is the variance within the panel units and R^2 overall is a weighted average of these two.

We initially proposed variables in Table 4 such as approvals and use area as explanatory variables but excluded them from the estimation. This decision was made because these variables did not pass the instrument validity tests for the dependent variable of the second-stage regression, the GRDP. To simplify the analysis, they were omitted. However, the null hypothesis that these variables have zero coefficients is rejected with an F-value of 24.44, thus indicating that they possess sufficient explanatory power to serve as instruments for patents.

Now we are ready to estimate Equation (6) with the IV estimation having the reduced form of patents and housing price. In Table 5, a 1% increase in innovative activity (number of patents) increases the GRDP per capita by 0.188%. Typically, an increase in the number of patents is indicative of innovative activities. The increase in the number of patents can improve the innovation ability and innovation level of a region, and technological progress can lead to the improvement of production efficiency, thus promoting economic growth and development. Housing prices have a 10% significant marginal impact on the GRDP. The economic regional indicators of export and budget are statistically significant and have a positive impact on the GRDP. Due to the multicollinearity of imports, exports, and regional budget, the population shows a negative impact on regional growth.

Table 5 Estimation Results: Second Stage of Regional Growth Model

Dependent Variable: ln(GRDP)	**Coef.**	**Std. Err.**	**t-stat.**	**p-value**
$\ln(\widehat{Pat})$	0.188***	0.056	3.340	0.001
$\ln(\widehat{Hp})$	0.112*	0.059	1.900	0.058
ln(Pop)	-0.666***	0.180	-3.700	0.000
ln(Exp)	0.137***	0.180	5.990	0.000
ln(Imp)	0.021	0.011	1.820	0.068
ln(Bud)	0.328*	0.120	2.710	0.007
Constant	1.006	2.466	0.410	0.683
City FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Standard Deviation	0.274	R-squared	Within	0.930
Within-subject Standard Deviation	0.031		Between	0.334
			Overall	0.387

Notes: Significance at 10%, 5%, and 1% levels is denoted as *, **, and ***, respectively. $ln(\widehat{Pat})$ is the number of patents per capita estimated from the first stage of the innovation model. $\ln(\widehat{Hp})$ is the estimated housing price from the first model. ln(Pop) is the population in the area, and ln(Exp) and ln(Imp) are exports and imports, respectively. ln(Bud) is the total budget for each region. City FE denotes a city specific fixed effect which controls for time-invariant fixed characteristics specific to each city, Year FE denotes a year fixed effect that controls for shocks or factors that are constant across all cities in a given year. The between R^2 is the variance between separate panel units, within R^2 is the variance within the panel units and R^2 overall is a weighted average of these two.

5.1 Bilateral Relation between Housing Market and Innovation.

A comprehensive analysis of the bilateral relationship between housing prices and patents is conducted in this study. We examine the relationship between patents and their impact on housing prices in an approach similar to that of Beracha et al. (2022). Therefore, we estimate the relationship between the housing market and innovation by using the 2SLS method:

$$\begin{aligned} ln(Hp)_{it} = \pi_0 + \pi_1 \widehat{Pat}_{it} + \pi_2 ln(Pop)_{it} + \pi_3 ln(Bud)_{it} \\ + \pi_4 ln(Exp)_{it} + \gamma_5 ln(Imp)_{it} + \alpha_1 ln(HS)_{it} \\ + \alpha_2 ln(Con)_{it} + u_i + v_{it}^h \end{aligned} \quad (7)$$

$$\begin{aligned} ln(Pat)_{it} = \gamma_0 + \gamma_1 ln(Hp)_{it} + \gamma_2 ln(Pop)_{it} + \gamma_3 ln(Bud)_{it} \\ + \gamma_4 ln(Exp)_{it} + \gamma_5 ln(Imp)_{it} + \beta_1 ln(Fac)_{it} \\ + \beta_2 ln(Pro)_{it} + \beta_3 ln(R\&D\ fund)_{it} \\ + \beta_4 ln(Uni)_{it} + \beta_5 uni\#res + u_i + v_{it}^p \end{aligned} \quad (8)$$

Equation (7) is used to determine the effect of patents on housing price. The reduced form model of patents, Equation (4), can be used again to consider the endogeneity of patents. Equation (8) is used to determine the effects of housing price on patents. The reduced form model of housing price, Equation (5), can be used again to consider its endogeneity. With this approach, we examine a directional relationship between innovation and the housing model. The effect of innovation on housing prices is reported in Table 6, which is the estimation result of Equation (7). It is found that the number of patents has a strong positive impact on housing prices.

The increase in new construction has a statistically positive impact on the housing market, but housing supply does not. We build on previous research that suggests the number of universities influences innovation. However, unlike previous studies, we treat the number of universities as a control variable for population and define the analysis units as separate, independent markets. Furthermore, we adopt 2SLS to model the indirect effects of the presence of universities on innovation.

To empirically disentangle the effect of universities and innovation on housing prices, we extend our model by simultaneously including both university-related variables (number of universities, research funding, number of faculty members) and the innovation proxy (number of patents) in the second-stage regression of the housing price model. This allows us to isolate the direct institutional demand pressure created by universities from the broader regional innovation effect. We also find a similar result in Beracha *et al.* (2022) who find a positive correlation between innovation quality and subsequent appreciation in local real estate prices. Our result also confirms a positive relation between innovation and housing price, thus indicating that local innovation attracts more talent whose demand for housing drives up prices.

Table 6 Estimation Results: Second Stage Regression of Housing Price (First Stage Regression of Patent Model is Omitted)

Dependent Variable: ln(Hp)	Coef.	Std. Err.	t-stat.	p-value
ln($\widehat{Pat}$)	0.329**	0.136	2.410	0.016
ln(Pop)	1.846***	0.381	4.840	0.000
ln(Exp)	-0.028	0.054	-0.520	0.601
ln(Imp)	0.022	0.027	8.430	0.406
ln(Bud)	1.553***	0.184	8.420	0.000
ln(HS)	-0.158**	0.051	-3.070	0.002
ln(Con)	0.110***	0.022	4.990	0.000
Constant	-27.249	5.15	-5.29	0.000
City FE	Yes	Yes	Yes	
Year FE	Yes	Yes	Yes	
Standard Deviation	1.525	R-squared	Within	0.786
Within-subject Standard Deviation	0.073		Between	0.191
			Overall	0.050

Notes: Significance at 10%, 5%, and 1% levels is denoted as *, **, and ***, respectively. For conciseness, we do not report the estimation result of the first-stage regression of the innovation model but it is available upon request. ln(Hp) is the housing price in the region. ln($\widehat{Pat}$) is the number of patents per capita estimated from the first-stage of regression of the innovation model, and ln(Exp) and ln(Imp) are exports and imports, respectively. ln(Bud) is the total budget amount for each region. ln(HS) is total new supply(㎡), ln(Con) is the total number of new constructions. City FE denotes a city specific fixed effect which controls for time-invariant fixed characteristics specific to each city, Year FE denotes a year fixed effect that controls for shocks or factors that are constant across all cities in a given year. The between R^2 is the variance between separate panel units, within R^2 is the variance within the panel units and R^2 overall is a weighted average of these two.

The effect of housing prices on innovation is reported in Table 7, which is the estimation result of Equation (8). The housing price index has no significant effect on innovative activity. The regional budget shows a negative impact on the number of patents, thus indicating that regions with smaller budgets experience more innovation with an increased number of patents. The interaction effect of the number of universities and amount of R&D funds shows a stronger and more positive impact on the number of patents but is offset by the amount of R&D funds. The latter have a negative relationship with the housing market.

Table 7 Estimation Results: Second Stage Regression of Innovation Model (First Stage Regression of HP Model is Omitted)

Ln(Patents)	Coef.	Std. Err.	t-stat.	p-value
$\ln(\widehat{Hp})$	-0.018	0.217	-0.090	0.931
ln(Pop)	0.812	0.518	1.570	0.117
ln(Exp)	0.039	0.065	0.600	0.546
ln(Imp)	0.020	0.030	0.650	0.512
ln(Bud)	-0.791**	0.364	-2.170	0.030
ln(R&D fund)	-1.092***	0.186	-5.860	0.000
ln(Univ)	-0.389	0.519	-0.750	0.453
ln(Pro)	0.173	0.091	1.890	0.058
ln(Fac)	-0.124	-0.159	-0.780	0.433
uni#res	0.403***	0.079	5.070	0.000
Constant	-4.283	7.416	-0.580	0.564
City FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Standard Deviation	0.839	R-squared	Within	0.652
Within-subject Standard Deviation	0.084		Between	0.854
			Overall	0.851

***Notes*:** Significance at 10%, 5%, and 1% levels is denoted as *, **, and ***, respectively. For conciseness, we do not report the estimation result of first-stage regression of housing price model but it is available upon request. ln(Patents) is the number of patents per capita, $\ln(Hp)$ is the estimated housing price from the first model. ln(Pop) is the population in the region. ln(Exp) and ln(Imp) are exports and imports, respectively. ln(Bud) is the total budget for each region, ln(R&D fund) is amount of research funds, ln(Pro) is number of research projects, In(Fac) is the number of faculty members, ln(Univ) is number of universities in the region, uni#res is a cross-item of university and research funds. City FE denotes a city specific fixed effect which controls for time-invariant fixed characteristics specific to each city, Year FE denotes a year fixed effect which controls for shocks or factors that are constant across all cities in a given year. The between R^2 is the variance between separate panel units, within R^2 is the variance within the panel units and R^2 overall is a weighted average of these two.

5.2 Exclusion Restriction Test of Regressions between Innovation and Housing Prices

We adopt a Sargan test to confirm whether the exclusion restriction is satisfied in the test of the endogeneity in the result. In Equations (6), (7) and (8), we examine whether the condition $Cov(Z, e) = 0$. To determine the validity of the instrument variables, the Sargan test is employed, guided by Hill et al. (2018). In Equation (6), there are 7 IVs and 2 endogenous variables. Therefore, the degrees of freedom for the test statistic is 5. As a result, the value of the Sargan test statistic is 7.95, with a corresponding p-value of 0.159. Therefore, the exclusion restriction is satisfied and not further required in this regard. Since this p-value exceeds the 10% significance level, the null hypothesis that the instruments are valid is accepted —that is, not correlated with the error term and correctly excluded from the estimated equation. Thus, the exclusion restriction for the instruments in Equation (6) appears to be satisfied.

Similarly, we also examine Equation (7), where there is one explanatory variable examined as an endogenous variable, and there are 5 IVs. We find a degree of freedom of 4 and the Sargan test statistic value is 11.81, with a p-value of 0.0188. Since the p-value is below the 5% significance level, the null hypothesis—that the instruments are valid — can be rejected. This suggests that at least one instrument may be invalid. As a result, we remove one variable, the number of faculty members, from the set of instruments, and we re-estimate Equation (7). We find a 3.688 Sargan test statistic with a p-value of 0.2970 thus indicating that the null hypothesis is accepted. Therefore, the exclusion restriction for the instruments in the re-estimated Equation (7) is considered to be satisfied.

Also, we examine Equation (8), where there is one endogenous explanatory variable and two IVs, thus resulting in one degree of freedom for the Sargan test. We find the value of the test statistic is 0.6678, with a p-value of 0.413. Since the p-value exceeds the 10% significance level, the null hypothesis that the instruments are valid is accepted, that is, they are uncorrelated with the error term and properly excluded from the equation. Therefore, the exclusion restriction for the instruments in Equation (8) is considered to be satisfied. Among Equations 6, 7 and 8, one of the three equations does not change much even when there are lead–lag relationships, but in the case of housing price and patents, there will be a notable change when the lag is set and analyzed[9].

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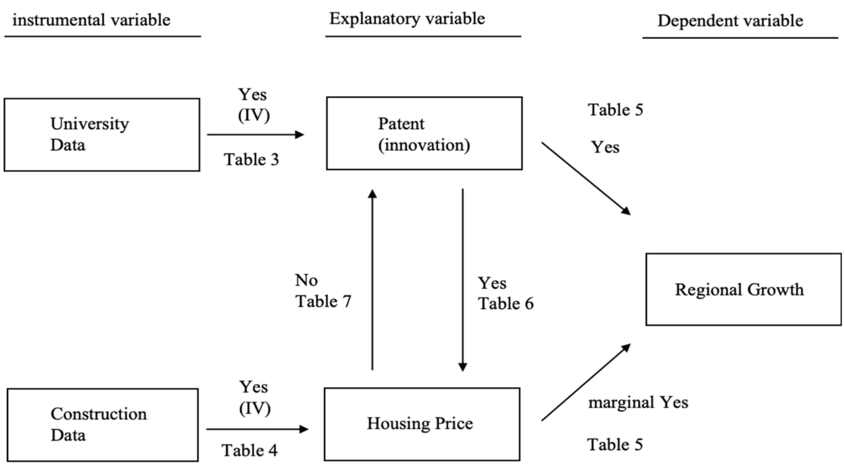
[9] It is reasonable to attempt to explain the model based on lead and lag relations among our main research variables - housing price, patents and GRDP, estimated in Equations 6,7 and 8. Therefore, we also explore these lead and lag relations among these research variables. As a result, we find that the relation between housing price and lag GRDP shows similar results with the current 2SLS model controlling for endogeneity issues, and vice versa. However, we find that housing price and number of patents have a significant endogeneity problem when applying lag variables in each model. We attribute this radical change to a strong serial correlation in each variable that affects

The overall empirical results are summarized in Figure 4; note that 'Yes' denotes that the variable affects the target variable significantly and 'No' denotes that the variable does not significantly affect the target variable. The main objective of this study is to examine the impact of patents and housing prices on regional growth. To handle the endogeneity of innovation and housing price, we utilize the university data as reported in Table 3, and construction-related data as reported in Table 4 as the instrument variables. Then we find that innovation affects regional growth while housing price does not, which is shown in Table 5. In addition, we find that innovation affects housing prices in Table 6, but housing prices do not affect innovation in Table 7. In summary, innovation proxied by the number of patents affects regional growth and housing prices, but housing price does not affect innovation.

Figure 4 Interrelations among Housing Price, Innovation, and Regional Growth



6. Conclusion

This study explores the multifaceted relationships among innovation, residential real estate, and economic growth, thus highlighting the key drivers and their implications for regional development, and provides insights for policymakers. We find that innovation (measured by the number of patents) has a significantly positive impact on housing prices and regional growth, while housing prices have no impact on innovation and regional growth. The results

each other if we do not control for endogeneity as we have done so in the study. Thus our analysis is relying on the 2SLS models to identify interrelationship among our research variables and we consider that our 2SLS analysis is not biased by endogeneity issues.

show a statistically positive impact of innovation on the GRDP. The number of patents, which serves as a proxy for regional innovative activities, reflects the degree of regional innovation. A 1% increase in innovative activity, measured by the number of patents registered, leads to a 0.188% increase in the GRDP per capita. The increase in the number of patents can improve the innovation capacity and innovation level of a region, and technological progress can improve production efficiency, thus promoting economic growth and development. This finding implies that innovation plays a crucial role in driving regional economic growth and development. However, housing prices have no statistical impact on regional growth, as measured by the GRDP.

The number of patents has a statistically positive impact on housing prices. This means that an increase in the number of patents is positively related to an increase in house prices, and an increase in innovation activities may promote the economic prosperity of the region, thus raising house prices. In addition, we confirm that population growth has a positive impact on the housing market. With population increase, the demand for housing inevitably increases, thus confirming the law of supply and demand. Population growth can be an important factor in explaining for changes in the housing market. In addition, there is a positive correlation between areas with large regional budgets and the strength of the housing market, with areas that have large budgets also tending to have higher housing prices. Regardless of the significant relationship between macroeconomic variables and the housing market, there is a marginal impact of the house price index on innovation activities. However, the regional budget is estimated to have a negative impact on the number of patents. We speculate that areas with more restrictive budgets have more innovation activities, which have led to an increase in the number of patents. In addition, although the interaction between the number of faculty members and the amount of R&D funding has a negative impact on the number of patents, when the amount of R&D funding further increases, its positive impact is diminished.

This conclusion effectively outlines the three research objectives of this study. First, the number of registered patents is utilized as a proxy for measuring innovation, and innovation significantly influences regional economic growth, with research universities playing a vital role as the primary driving force for regional development. Consequently, an examination of the marginal impact of innovation on regional growth enables policymakers to allocate limited resources strategically to promote regional innovation, thus enhancing competitiveness, within the framework of regional land-use planning. Second, we present empirical evidence of the positive contributions of universities to innovation in South Korea, as evidenced by the increase in the number of patents. We argue that amount of R&D funding, and number of faculty members, research projects, and universities within a given region act as catalysts for innovation. As a result, our study contributes to determining the most effective production threshold for innovation activities in South Korean universities. Thirdly, we have provided evidence of the interplay between the housing market and regional innovation. The quantity of innovation has a statistically significant influence on regional housing prices in South Korea. Also, housing prices affect regional innovation.

For policy consideration, we interpret that public sector relocation and the Balanced Regional Development Act in South Korea could have encouraged local innovation and supported balanced regional growth. Our findings suggest that increased patent activity in a region signifies growth in innovation, which may attract high-tech companies and research institutions, thus generate new jobs and stimulate economic growth. During the relocation period of 2012 to 2021, we find relatively stable regional housing prices in regional innovative cities. Thus, we consider that it is important to maintain stable housing prices to support local innovation as exorbitant housing costs can pose obstacles to innovation and create difficulties for young individuals and startups. Therefore, it is important for local governments to ensure housing affordability and provide an adequate housing supply.

In this research work, the result is limited to identifying the dynamic relationships among variables. That is, we adopt the number of patents as a proxy for innovation while the number of patents may not capture the full extent of the dynamic nature of innovation activities. This limited interpretation of innovation (number of patents) assumes that a patent primarily impacts the region in which it is registered. For example, a patent of a new semiconductor may directly impact a semiconductor manufacturing factory in a different region. However, other patents issued to smaller companies will have a negligible impact on the GDP of other regions.

This study does not distinguish detailed information on the industrial classification of innovation between new patents of a shrinking industry and patents of a growing industry. Thus, we cannot identify the impact of regional industry-specific innovation on regional growth. Also, the classification of R&D funding based on whether the funds are from the government or corporates is not specified. With detailed information on research funds, we can further identify the economic sensitivity of a cost and benefit analysis on the different characteristics of government funding to promote local innovation. Therefore, further research needs to be undertaken to mitigate the limitations of this work.

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