



Business innovation modes in China's firms: Technological swing and the value of social capital

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Abstract

This paper studies business innovation in China, a country that has become an economic power in recent years. The literature on innovation in “business innovation modes” has come to the forefront for its capacity to identify archetypical sets of business practices (bundles of internal and external drivers) that firms adopt to stimulate innovation. This is a strand that moves away from the analysis of the impact of individual factors (e.g., R&D, human capital) and instead identifies the impact of bundles of resources, capabilities and practices that firms and their entrepreneurs/teams apply to attain their competitiveness objectives. Specifically, these are the STI (science and technology-based innovation) and DUI mode (innovation based on learning-by-doing, by-using, and by-interacting) or a combination of the two. Therefore, it is very important from a practical perspective as it provides a reliable framework where businesses can learn from relevant empirical findings and benefit from implementing appropriate policy measures. Based on panel data from Chinese provinces 2016–2023, we first analyze how firms use these innovation modes to impact technological and non-technological innovation. These modes are effective; however, they focus on the technological side (product innovation). A further contribution of this study is the inclusion of social capital as a moderating factor for innovation, particularly for the DUI innovation mode, which relies on effective interaction across personnel and the supply chain. We find a significant impact of bonding social capital for process innovation when using the DUI mode.

Keywords STI and DUI innovation modes · Technological and non-technological innovation · Bonding and bridging social capital · China

JEL Classification 030 · 032 · 033 · Z10

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1 Introduction

Over the past two decades, several scholars raised the debate on “business innovation modes” as a means to query the way firm innovation is produced across countries and regions (Asheim and Gertler 2005; Jensen et al. 2007). After decades of emphasis on the role of R&D and patents for innovation (Cohen and Levinthal 1989; Stam and Wennberg 2009), the above scholars realized that some countries took different routes to innovation and were equally successful. This was the case for Denmark and Norway. Other countries like Sweden and Finland based their success on the traditional “business innovation mode” centered on R&D expenditure and collaborations with universities (the typical Science and Technology-based Innovation or STI mode). Denmark and Norway relied upon practice and interactions, the so-called innovation mode based on learning-by-doing, by-using, and by-interacting -DUI mode- (Jensen et al. 2007). This is a mode based on internal-to-the-firm drivers such as teamwork, bottom-up communications, on-the-job training, and external-to-the-firm drivers such as collaborations with suppliers, service providers, and buyers (Parrilli and Radicic 2021; Alhusen et al. 2021; Haus-Reve et al. 2022).

The critical aspect of this approach is the focus. Differently from most research strands on innovation, which focus on identifying the impact of specific factors (e.g., R&D, collaborations with universities or with suppliers and buyers), in this case the focus is on identifying archetypical practices implemented by firms, i.e. different bundles of drivers that firms adopt depending on the mindset, skills and capabilities handled by the owner and/or the business team that drive the firm’s innovation strategy (Jensen et al. 2007; Parrilli et al. 2025). While the study of individual factors may appeal to policymakers who need to set up specific policy instruments, this approach responds to business owners/teams that need to understand how to improve the effectiveness of their innovation strategy and the bundle of factors they rely upon.

Over the past 15 years, a lot of research has been developed to study the way firms and organizations prepare themselves for innovation (Isaksen and Karlsen 2010; Thomä 2017; Alhusen et al. 2021), the effectiveness of such “business innovation modes” (Jensen et al. 2007; Fitjar and Rodríguez-Pose 2013; Nunes and Lopes 2015; Parrilli and Alcalde 2016; Haus-Reve et al. 2019), in general and across specific industries (Chen et al. 2011; Trott and Simms 2017; Lee and Miozzo 2019), their complementarity or substitutability (Haus-Reve et al. 2019; 2022), their impact on technological vs. non-technological innovation (Parrilli and Alcalde 2016; Parrilli et al. 2020), the geography of their application and impact (Fitjar and Rodríguez-Pose 2013; Parrilli et al. 2020, 2025; Doloreux and Shearmur; 2023), the relevance of the DUI mode across SMEs (Thomä 2017; Trott and Simms 2017; Parrilli and Radicic 2021; Alhusen et al. 2021), amongst others. Such a spread of studies has covered a significant landscape of research questions and clarified the way these business innovation modes operate across firms, industries, and countries.

Despite such a large deployment of studies, new research questions arise. These respond to the need to better understand the potential applications of these

innovation modes and the interaction that these have with the environment where firms operate. The research question that we raise in this paper refers to the so-called “meso” level of the economy (Esser et al. 1994) and one of its relevant drivers, social capital. The meso level represents the level at which industries, territories, and institutions operate between the macro and micro levels. It is the level of territorial and industrial concentrations of firms (i.e., the so-called clusters and industrial districts), where smaller firms become extremely competitive individually, and collectively within their local and regional territories (Porter 1985; Becattini 1990). Within these contexts, the literature has identified the importance of social capital as a set of values, norms and routines that boost the development of trust and cooperation amongst local socio-economic agents, thus re-creating the economies of scale and scope that SMEs are not able to produce autonomously (Becattini 1990; Putnam 1993).

This literature on social capital has not stopped producing relevant contributions. For instance, Malecki (2012) emphasized the role of regional interactions among socio-economic agents benefiting from this homogeneous fabric. Dei Ottati' (2018) studied the evolution of industrial districts and the way this social fabric changed in response. D'Ambrosio et al. (2019) assessed the way social capital can help to improve the local innovation performance, and Korosteleva et al. (2024) identified the synergies that can grow across different communities within bounded local/regional economies.

Echoing the work of Bischoff et al. (2023), in this paper we combine this critical meso driver of development with the archetypical business innovation modes as we expect these modes to benefit from the positive moderation exercised by social capital. As social capital activates networking and collaboration, we expect to find an important correlation between high levels of social capital and its impact on the effectiveness of these innovation modes, particularly the DUI innovation mode. In this case, social capital is expected to have the highest impact as it entails the widest participation and cooperation. For instance, the STI mode may develop cooperation activities that refer to a bounded teamwork within R&D departments, which include highly skilled scientists sharing and developing their advanced codified knowledge through the implementation of scientific-technological experiments. In contrast, within the DUI mode, teamwork involves all the personnel in a company and along the supply chain, engineers, technicians, managers, administrators, and others who participate and contribute to the innovation process. Social capital helps share not only advanced scientific knowledge, but also motivations and joint plans, values and norms of conduct, and experience/tacit-based knowledge. Therefore, it is expected to produce higher impact through activities that are shared across a larger community, which is what the DUI mode is about.

We discuss these aspects in the context of China, a huge country that has become an economic superpower. As China graduated from developing-country status to an emerging economy and, more recently, an economic superpower, its leapfrogging innovation pathway becomes extremely relevant for many other catching-up economies. It helps to understand what business innovation mode firms have adopted to undergo such a competitive transformation. Moreover, it may help to identify the prospective impact of this meso-level driver (i.e., social capital) within a country

that has recently undergone an intense social transformation (internal migration waves). Many dynamic countries in Asia, Africa, and Latin America, as well as in Southern and Eastern Europe, may gather useful lessons from this successful case. We use a special database that the government holds on China's 31 provinces, and that delivers an original perspective on the application of these business innovation modes across firms, in particular because it includes data on social capital that help us understand the way social capital interacts with these business modes to catalyze impact on technological and non-technological innovation. Through data taken between 2016 and 2023, we have formed panel data that are used to test arguments and hypotheses. The results suggest that social capital has a nuanced impact in both innovation modes and across the different types of innovation output, although overall it seems to matter less than in Western economies (Bischoff et al. 2023, for Germany; Muringani et al. 2021, across European regions). This suggests that the analysis applied here opens the way to more thorough investigations about the importance of this meso driver of innovation and competitiveness across several economies, and particularly in catching-up economies.

In the next section, the business innovation modes literature is presented with reference to the key areas of research and their outputs, and in relation to their context specificity. Social capital is also discussed here together with its relation to innovation. After discussing the selected hypotheses, the Methodology section follows and the empirical evidence with a final section of main findings, discussion, and conclusions.

2 The business innovation modes lenses

This literature has developed on the basis of the initial, insightful contributions by Jensen et al. (2007). Their work was based on the identification of the innovation paradox where countries and regions investing a relatively lower volume of resources in R&D were able to extract a similar or even higher amount of innovation output and economic performance than economies that were investing a significantly higher volume of resources in R&D (Asheim and Gertler 2005). Jensen et al. (2007) discovered that some countries were developing innovation thanks to a novel business innovation mode not based on R&D investments. They identified the learning-by-doing, by-using, and by-interacting innovation mode (DUI), which proves very effective in such economies thanks to the adoption of effective teamwork, on-the-job training, bottom-up communications internally to the firm, and supply chain collaborations outside the firm (Parrilli and Radicic 2021; Alhusen et al. 2021; Haus-Reve et al. 2022).

This initial contribution verified the importance of the DUI innovation mode and, in addition, showed the possibility for firms to implement a combined innovation mode that pulls together both modes, DUI and STI. This combined innovation mode was shown to be more effective than the individual modes alone (Ibid.). Several scholars have enriched this emerging literature. Isaksen and Karlsen (2010) confirmed this insight through their identification of the Complex and Combined Innovation (CCI) mode. The additive combination of the STI&DUI mode was queried by

Haus-Reve et al. (2019), who found a substitution effect between the two, once marginal effects were considered. Parrilli and Alcalde (2016) and Parrilli et al. (2020) identified the technological nuances of innovation as they found that the STI mode is more effective for product innovation while the DUI mode is more effective in process, commercial and organizational innovation.

In relation to the DUI mode, Tripl (2011) and Trott and Simms (2017) found that this mode is particularly important in traditional industries that develop through incremental innovations. In the German context, Thomä (2017) found the importance of the DUI mode for SMEs where R&D capacities are limited. In Belarus, Apanasovich et al. (2016) found a similar outcome for non-technological (organizational) innovation where the DUI mode alone matters. A few other studies seemed to question the effectiveness of the DUI mode. In Spain, Parrilli and Elola (2012) did not find any significant impact of internal drivers of the DUI mode on product innovation, while in Portugal, Nunes and Lopes (2015) found that only the firms that adopt the STI mode contribute significantly to innovation. These outcomes raised questions on the conditions for the implementation of effective innovation modes. Is it related to the selected industry? Is it related to the economic, institutional, and technological context? Such questions opened new avenues for further research.

In relation to the geographical context, Fitjar and Rodríguez-Pose (2013) found that global DUI collaborations were more effective than local DUI collaborations thanks to strong interactions across supply chain agents in Scandinavian countries. Similar results were found by Doloreux and Shearmur (2023) in the Montreal City-Region, where firms that adopt the STI mode benefit from thick local collaborations, whereas firms adopting the DUI mode benefit from non-local collaborations. In contrast, in the Basque/Spanish context, Parrilli and Alcalde (2016) found a stronger impact of local collaborations, both STI and DUI, thus showing that in a very tight social community (the Basque), local relations matter more than elsewhere. More recently, Parrilli et al. (2020) developed a pan-European study and found that the application and effectiveness of the innovation modes vary depending on the innovation progress of the regions. The innovation-leading regions adopt the combined STI&DUI mode very effectively and extract the highest economic performance; “moderate innovators” and “modest innovators” exploit this combination to a much lower extent.

However, very little has been studied in the geography of emerging countries. In Colombia, Malaver (2017) found that most firms and SMEs adopt the DUI mode with very poor effectiveness, while a tiny minority of firms adopted the STI mode and extracted a significant innovation output. In China, in the mid-2000s, Chen et al. (2011) divided high-tech vs traditional industries and spotted the relevance of the DUI mode in the latter and a combined mode in the former type of industries. This limitation makes it clear that further studies are needed in the context of emerging and developing economies.

In the following section, we introduce the “social capital” concept that has been found to have a direct impact on innovation activities (Laursen et al. 2012; Bischoff et al. 2023).

3 Social capital and innovation

A few decades ago, social capital was identified as a complementary driver of collaboration and competitiveness. It is the pool of values, norms, and routines that are shared across a community and that stir the possibility to develop trust and cooperation also in the business environment (Fukuyama 1995). Granovetter (1973; 1985) laid the foundations of this concept by talking about “the social embeddedness of economic action” and stressed the relevant distinction and value of “strong ties” and “weak ties” within the socio-economic firm context. Bourdieu (1986) emphasized the importance of social capital for the formation of bounded groups of agents engaging in cooperative networks, and Coleman (1990) stressed the possibility of using it for economic purposes through business cooperation. This concept was adopted in the debate on Marshallian industrial districts as the basis for trust and cooperation in local and regional SME-based economies (Becattini 1990; Putnam 1993; Humphrey and Schmitz 1998).

In her study of the textile Prato industrial district, Dei Ottati (2002: 449) found that “the competitiveness and dynamism of industrial districts’ firms are dependent on social integration. Social integration, however, is the result of a conscious coordination among local institutions, i.e., the high road to competitiveness is not the outcome of market mechanism, but of a combination of market and concerted collective action”. This argument was echoed by Malecki (2012) who stressed the importance of social capital for the formation of a “regional collective personality” that strengthens the economic development of the regions and their firms.

While discussing the decline of social capital in the US, Putnam (2000) identified different types of social capital, in particular, bonding and bridging. The former is the traditional concept of values, norms, and routines shared across a homogeneous community, while the latter represents a novel concept that refers to trust and cooperation arising among heterogeneous people coming together as a result of migration or mobility to different areas of the country (e.g., large cities). These two concepts differ significantly and may also explain the poor performance of social capital in the US. Studying these aspects in Europe, Cortinovis et al. (2017) identified the importance of bridging social capital, rather than bonding, for regional diversification into new industries, particularly through the work of informal institutions. Similarly, Muringani et al. (2024) found the driving role of bridging social capital, which is connected to higher levels of economic growth, particularly within low-skills regional economies.

Social capital also helps to impact innovation. As Malecki (2012: 1023) acknowledged, “Innovative milieus, industrial districts and knowledge economies are among the regions with extraordinary pools of social capital”. In their study of Wales, Ireland and Denmark, Cooke and Wills (1999: 219) stressed that “social capital (is) associated with enhanced business, knowledge and innovation performance” thanks to an embedded institutional basis that helps the SMEs to benefit from external innovation networks. In the Spanish regions of Valencia (Molina-Morales and Martinez-Fernandez 2010) and the Basque region (Aragon et al. 2019), social capital was found to have a positive association with the

effectiveness of the regional innovation system by helping to close relevant intra-firm, inter-firm and institutional gaps.

In the context of developing countries, Dakhli and De Clercq (2004) studied the impact of social capital on a large set of countries, including a significant number of developing countries. They found that although human capital had the highest impact on innovation activities, social capital was positively connected to innovation through the impact of generalized trust and associational activities. Allameh (2018) found similar outcomes in Iran. He studied the impact of both human capital and social capital on technological and non-technological innovation via knowledge sharing and intellectual capital. Overall, he found evidence of a strong impact of both, with the prevalence of human capital. In China, Zhou et al. (2022) studied the relation between structural, cognitive and relational social capital and product innovation via the quality of the knowledge transferred, and they found a positive impact, primarily through cognitive and relational social capital.

Recently, Bischoff et al. (2023:1) focused on the role of “generalized trust” for firm innovation, where the former represents “a situation where an individual expects honest behavior of other people”. They connected generalized trust to the business innovation modes literature with the expectation of an important impact of trust on innovation outputs, particularly when using the DUI mode across SMEs. Their study across German regions found an important moderation of generalized trust on the use of the DUI mode for innovation. This represents the basis of our study that extends this debate through a more specific conceptualization of social capital. We move beyond the concept of “generalized trust” where different and often conflicting aspects of social capital are collapsed together. Echoing the contribution of Granovetter (1973; 1985) on weak ties vs strong ties, and Putnam (2000) on bridging vs bonding social capital, we move towards a conceptualization of social capital that acknowledges its positive impact, but also its negative effects when it becomes a glue among homogeneous people that pushes away dis-homogeneous people and prevents firms from developing smoother cooperation activities (Anderson and Jack 2002). Going back to Putnam’s contribution, bonding social capital can be very supportive of homogeneous communities, while creating a barrier to cooperation within heterogeneous social and business contexts (e.g., cities prone to migration waves). For this reason, we apply this debate with the intention to differentiate among social capital forms and their impact on business innovation in the peculiar Chinese context.

4 Main argument and hypotheses

From several studies, we have learned that the innovation modes can have a significant impact on innovation performance. We have learned that there are nuances in the impact of business innovation modes. The STI mode, driven by very specialized human capital and expenditure in R&D, tends to have a strong impact on product innovation (Parrilli and Alcalde 2016), while the DUI mode, mostly pushed through supply-chain interactions and intra-firm collaborations across all the personnel (not just scientists) tend to support process innovation as well as non-technological

innovation (Trippel 2011; Trott and Simms 2017). To different extents, both produce a good impact on all types of innovation, especially within advanced economies (Parrilli et al. 2020).

In the context of emerging economies outside Europe, the number of studies is pretty limited (Chen et al. 2011; Malaver 2017). These studies exhibited more controversial outcomes, for instance, the study on China of Chen et al. (2011) showed the specific impact of the DUI mode in the case of traditional industries (e.g., footwear, furniture), which represent most businesses, while in Colombia, Malaver (2017) found that only the STI mode has a significant impact on product innovation, while the DUI mode – despite being applied by a larger group of firms – was mostly ineffective. On such thin bases, we cannot take for granted any specific outcome in emerging economies.

Our study focuses on China, which is a country with unique features and a peculiar history. Since the 1980s, huge efforts have been made through the publication of “Outlines” for innovation, development, and economic performance, which have generated a much stronger innovation capacity across firms, e.g., “*Outline of the National Strategy of Innovation-Driven Development*” (China 2016). The STI mode has been very much supported, as earlier identified by Chen et al. (2011), within high-tech industries. As China is very much oriented towards international markets, we expect firms to be very strongly oriented towards product innovation, while process and non-technological innovation is likely to be less important due to the usual cost advantage of Chinese firms.

It is worth noting that the STI mode is not merely about R&D intensity but represents a systemic approach to science-based innovation that integrates firms’ investment in R&D with formal collaboration with universities and research institutes. This configuration emphasizes the role of scientific knowledge and institutional cooperation, which goes beyond the effect of R&D expenditure. In line with previous studies on the technological nuances of business innovation modes (Fitjar and Rodríguez-Pose 2013; Parrilli and Alcalde 2016), we expect that firms in regions with a stronger use of the STI mode will primarily enhance product innovation, especially in high technology industries and in industries whose goods are highly demanded by international buyers (Chen et al. 2011). Meanwhile, in traditional industries, DUI collaborations include a broader spectrum of partners (various supply chain agents) and are usually focused on incremental process improvements, supply chain coordination, and organizational routines (Chen et al. 2011). As a result, and again according to the technological nuance argument (Parrilli and Alcalde 2016), we expect the DUI mode to contribute more strongly to business process innovation, while its direct impact on product innovation is comparatively limited. To test our argument, we introduce the following hypotheses:

H1. The STI mode primarily boosts product innovation.

H2. The DUI mode primarily boosts business process innovation.

As mentioned above, this study offers a new contribution to the literature on business innovation by connecting it with social capital. It is expected to produce effective cooperation (Putnam 1993), and innovation (Molina-Morales and

Martinez-Fernandez 2010; Laursen et al. 2012; Aragon et al. 2019). However, the STI mode requires a more “selective” type of trust and cooperation than the DUI mode (Humphrey and Schmitz 1998; Bischoff et al. 2023). In the former, it is cooperation among specialized scientists and technologists within the company (i.e., the R&D department) or outside (e.g., collaboration with universities and research centers), where the most important variables are the advanced codified knowledge they offer and the availability of significant research infrastructures. Social capital may influence the effectiveness of the STI mode, though if it does, it does to a lower extent than human capital (Dakhli and De Clercq 2004; Allameh 2018). Within the DUI mode, cooperation occurs across the whole personnel and departments (in the firm) and in collaboration with suppliers and buyers. In this case, as Bischoff et al. (2023) found, “extended trust” catalyzes broader collaboration that fosters tacit knowledge exchanges, mutual learning, and teamwork that represent effective avenues to innovation. These are important considerations but are still generic. As indicated in section three, the relevant literature indicates that social capital may have positive and negative impacts, and this is what we are investigating here.

Echoing Granovetter's (1973; 1985) distinction between weak and strong ties, and Putnam's (2000) perspective around bridging and bonding social capital (BrSC, BoSC), we stress nuances in the way social capital works in different firm contexts. While in the context of socially homogeneous societies we expect BoSC to stir cooperation activities (as people have known each other for years and share family and friendship ties as well as values, norms and routines), in more heterogeneous economies (migration-prone regions) BoSC has more limited effects as their more heterogeneous people share fewer commonalities. Here, BoSC can become a restraint to effective cooperation, as people may not trust other businesspeople, managers, or workers who do not reflect their original values, norms, and routines (Anderson and Jack 2002); thus, they prefer to stay in a closed loop with like-minded people. As such, BoSC may hamper innovation within the STI mode that requires different people with high human capital. Instead, within the DUI mode, BoSC may still be able to bring homogenous groups together and facilitate the transmission of tacit and managerial knowledge, thus producing impact on business process innovation primarily.

Our selected context (China) is quite different from Western economies. For many years, the Hukou system prevented free movement of people across China. This changed over the past 20 years as this restraint has been eased, thus allowing an increasing mix of population in the export-oriented coastal areas of the country and their large cities. This process has led to the formation of a more heterogeneous society in the coastal areas of China, which are also the most business-driven. For this reason, we separate the impact of BoSC from BrSC to verify their impact on how innovation modes produce innovation outputs. In relation to BoSC, we expect it to promote interactions across all types of workers (managers, technicians, administrators), especially in more homogeneous regional contexts and in traditional industries (Becattini 1990; Putnam 1993; Molina-Morales and Martinez-Fernandez 2010). As a result, it is more likely to generate process innovation and non-technological innovations (Bischoff et al. 2023). Bonding social capital, reflected in dense and cohesive trust-based ties, enhances coordination and tacit knowledge sharing within local networks (Aragon et al. 2019).

In the Chinese context, such cohesion is expected to primarily strengthen the DUI mode's contribution to process innovation, as it facilitates supply-chain interaction and incremental improvements but is unlikely to have direct effect on STI-related product innovation that relies on codified scientific knowledge and highly skilled human capital (Muringani et al. 2021). For this reason, we establish the following hypotheses:

H3a. BoSC is expected to expand the impact of the DUI mode primarily on business process innovation.

H3b. BoSC is not expected to support the impact of the STI mode on either type of innovation output.

BrSC is likely to produce a significant impact on the DUI mode as it permits people to connect beyond their traditional kinship and to find common aims and objectives disregarding their kinship or ethnic origin (Putnam 2000). Therefore, it is likely to have a significant impact in heterogeneous environments such as the coastal cities of the country that received important waves of internal migration with the fall of the Hukou system. Here, BrSC is likely to pull together different people with the aim of working together for the development and prosperity of the locality/city and the communities where they live. Here they can elicit effective engagement in political activities and voluntary work in charities as a means to promote broader community development (Putnam 2000; Cortinovis et al. 2017; Muringani et al. 2021).

Overall, BrSC represents a more open and outward-oriented type of trust that connects firms to diverse, non-redundant partners (Cortinovis et al. 2017; Muringani et al. 2021). This broader orientation is expected to foster the STI mode's impact by improving interactions with universities, research institutes, and technologically advanced partners. In fact, BrSC is expected to have a stronger impact across people valued for their scientific knowledge and capabilities (human capital), thus in the process, the STI mode produces innovation outputs, which are usually oriented towards product innovation (Parrilli and Alcalde 2016). Simultaneously, BrSC is expected to bolster DUI collaborations within more heterogeneous regional economies that will derive into both process improvements and product innovation (Cortinovis et al. 2017; Muringani et al. 2021). On these bases, we establish the following hypotheses:

H4a. BrSC is expected to expand the impact of the DUI mode on both product and business process innovation.

H4b. BrSC is expected to expand the impact of the STI mode on both product and business process innovation.

5 Methodology

5.1 Data source

In this research, we formed a panel dataset. Data on innovation modes, drivers, and outputs are collected from the China Enterprise Innovation Survey (CEIS,

2016–2023), which is produced by the Bureau of Statistics, China. CEIS was first conducted in 2014 and, since 2016, on an annual basis. The survey questionnaire collects basic information on firms, their innovation activities, and their innovation technological (product and process) and non-technological outputs (organizational and marketing innovation). The sample of CEIS covers 31 provinces of China with over 700,000 firms, making it suitable for innovation studies. This survey only covers enterprises above the designated size threshold, which ensures that small firms are excluded and avoids the potential bias of overweighting numerous micro firms. Second, social capital-related data are collected from the National Blood Centre, China Civil Affairs Statistical Yearbook, China Enterprise Survey, and China's General Social Survey. Data on control variables are drawn from China's Statistical Yearbook. The final dataset covers 31 provinces in China, from 2016–2023 for a total of 248 provincial observations per selected variable.

5.2 Selected variables

5.2.1 Dependent variable: Innovation outputs

Innovation outputs are technological and non-technological innovation (OECD 2018). Previous research on innovation modes has largely focused on technological innovation (Fitjar and Rodríguez-Pose 2013; Jensen et al. 2007), while recent studies have been covering non-technological attributes too (Bischoff et al. 2023; Parrilli et al. 2020). In line with the most recent version of the Oslo Manual (OECD 2018), this research defines innovation outputs as 1. Product Innovation: new or improved goods or services and 2. Business Process Innovation: new or improved business processes for one or more business functions, such as process, organizational, and marketing functions.

In our analysis, product innovation (PRI) is a continuous variable that measures the percentage of firms in a given province that only introduced product innovation in the past year; business process innovation (BPI) is the cumulative percentage of firms that introduced process, organizational, or marketing innovations. Similar measurements of innovation have been adopted by Abdul Basit and Medase (2019) and Opazo-Basáez et al. (2022).

5.2.2 Explanatory variable: Innovation modes

The modes of innovation are assumed to affect innovation outputs in different manners. Following Jensen et al. (2007), Parrilli et al. (2020) and Doloreux and Shearmur (2023), the science and technology-based innovation (STI) relies mostly on codified knowledge and is achieved through regional measures of; 1) aggregate R&D intensity of firms (i.e., the ratio of firms' R&D investment to their revenue), 2) their collaboration with universities (percentage of firms that collaborate with universities), and 3) collaboration with research institutions (percentage of firms that collaborated with research institutions). According to previous research (Jensen et al. 2007; Fitjar and Rodríguez-Pose 2013; Parrilli et al. 2020), the learning by doing,

using and interacting (DUI) mode, which exploits tacit knowledge for innovation, is achieved through regional measures of 1) the provinces' percentage of firms that collaborate with suppliers and that 2) collaborate with customers, 3) the percentage of firms purchasing external technology and 4) the percentage of firms providing innovation training.

Considering that both STI and DUI consist of multiple indicators, the entropy weight-TOPSIS method is adopted to obtain the final score of the modes of innovation in a province. Developed by Shannon (1948), entropy serves as a quantitative metric for assessing both the level of disorder within a system and its effectiveness in information-theoretic analyses. The entropy-weighting approach assigns weights to indicators according to the amount of information and variation they contain, thereby reducing subjective weighting bias. Introduced by Chen and Hwang (1992), the TOPSIS method refers to the Technique for Order Preference by Similarity to Ideal Solution, which, in this study, it evaluates how close each province is to an "ideal" innovation mode profile by simultaneously considering the distance from both the optimal and worst-performing reference points. A higher score therefore indicates a stronger STI or DUI innovation mode.. Given its advantages in ensuring the authenticity and reliability in evaluating multiple indicators when constructing the selected variable, the entropy weight-TOPSIS method has been widely used in innovation studies (for example, see Liu and Jiang (2024), Sati (2024) and (Chen et al. 2020)). A detailed step-by-step calculation process of the entropy weight-TOPSIS method is attached in Appendix 1. According to previous literature (Salomon and Shaver 2005; Parrilli and Alcalde 2016), this study applies a one-period lag to all explanatory variables based on the acknowledgment that investments in innovation activities take time to transform into innovation outputs.

5.2.3 Moderating variable: Regional social capital

In relation to social capital, the relative novelty of this concept makes measuring social capital less straightforward than more standard variables. Often proxy indicators related to individual's preferences, opinions, and attitudes are used (Westlund et al. 2010). Such indicators come from large-scale surveys such as the World Values Survey, or the Eurobarometer. Based on Fukuyama's (1995) acknowledgement of social capital as the pool of values, norms and routines that are shared across a community and that promote trust and cooperation, and Putnam's (2000) and Hasan's et al. (2022) contributions, this research selects four proxy indicators to construct the variable of regional social capital including: 1) voluntary blood donation; 2) participation in NGOs; 3) strangers trustworthiness, and 4) business trustworthiness.

Following Putnam (2000), the first three represent BrSC, the fourth is instead representative of BoSC. In fact, in China, voluntary blood donation is operated by branches of the National Blood Centre on a voluntary basis. As such, it reflects citizens' feelings of reciprocity and civic-mindedness (Putnam 2000). This indicator was measured by the milliliters of blood donated in a province divided by its population in 2011, the most recent available census data. The second indicator, NGO participation, refers to the number of people registered in NGOs per thousand population in a province (Putnam 2000). Non-governmental organizations operate

to reduce poverty, protect the environment, and assist disadvantaged groups; thus, this indicator reflects local residents' civic engagement and commitment to the public. Relevant data were collected from the China Civil Affairs Statistical Yearbook 2016–2023. The third indicator measures the degree of trust towards strangers; this indicator is derived from the Chinese General Social Survey 2017, which encompasses over 12,000 Chinese residents in 28 provinces. Specifically, our data comes from the survey question “From 1 (strongly disagree) to 5 (strongly agree), do you agree that most people can be trusted”. We then calculate the average score based on the respondents' province. It reflects an open and cohesive environment (trust) within society. The fourth indicator was elicited from the China Enterprise Survey 2000, conducted by Ke and Zhang (2003). It was a large-scale survey covering over 5000 business managers in 31 provinces in China, though it was conducted only once. Specifically, the survey asked whether “According to your experience, could you list the top five provinces where enterprises are most trustworthy” (5 for the number one trusted, 4 for the second, and so on). It evaluates the creditworthiness of firms in other provinces, thus reflecting trust that connects homogeneous actors within regional and organizational boundaries. This SC indicator may seem a bit dated, but as trust is generally seen as a persistent cultural and institutional trait that evolves only slowly over time (Putnam 1993; Algan and Cahuc 2010). Other sources, such as the World Values Survey, also suggest that regional trust levels in China remain remarkably stable across waves. Following Li et al. (2017), we have taken the logarithm of the total score as the final score for a certain province. In our approximation to the concepts of BrSC and BoSC, according to Putnam (2000), the first three indicators demonstrate the connections between heterogeneous social groups. Afterward, the composite index BrSC is formed by applying principal component analysis (PCA) as recommended by Ang et al. (2015) and Hasan et al. (2022). The fourth indicator (business trustworthiness) is collected from business managers and measures the trust level of like-minded people (business community). This latter falls under Putnam's BoSC conceptualization as it refers to the largely socially homogeneous businesses operating in a province. While these indicators are proxies and cannot cover the full spectrum of bonding and bridging dimensions, they provide a reasonable approximation for our purposes in the Chinese context. Detailed provincial Bridging Social Capital scores based on PCA are reported in Appendix 2.

5.2.4 Regional control variables

The outputs of innovation are influenced by broader regional conditions which are considered in this study. To reduce omitted-variable bias, we refer to previous literature and include a wide set of control variables such as per capita GDP (Deng et al. 2024), societal consumption level (Reinstaller and Sanditov 2005), industrial structure (Hunt 2004), urbanization (Ciolek et al. 2022), transportation infrastructure (Mao et al. 2024), education level (Cohen and Levinthal 1989; Giménez et al. 2015), technology market development (OECD 2018), FDI (Chen and Zhou 2023), openness to trade (Saridakis et al. 2019), and population density (Shukai et al. 2021). These variables are treated as contextual controls that account for regional

economic, structural, demographic, and innovation-related heterogeneity across Chinese provinces. The persistence of the trust effect after controlling for them suggests that it captures informal social capital rather than simply substituting for formal institutions. Table 1 below summarizes all variables and their key indicators.

5.3 Model specification

For the empirical model selection, we run the Hausman test on our dataset as suggested by (Amini et al. 2012). The result shows that the original hypothesis was strongly rejected, and the fixed-effects model should be used. By controlling time fixed effect and province fixed effect, we could effectively address the impact of time-varying confounding factors and provincial characteristics. We thereby established the following model for Hypotheses 1 and 2:

$$Innovationoutputs_{i,t} = \alpha + \beta Innovationmodes_{i,t-1} + \gamma Controls_{i,t} + \lambda_i + \mu_t + \epsilon_{i,t} \quad (1)$$

Among them, Innovation outputs are the outcome variables, including product innovation and business process innovation, and i denotes province and t denotes year. α is the intercept terms. Innovation modes represent the explanatory variables STI and DUI. Controls denote all control variables, λ is the province fixed effect, μ is the time fixed effect, ϵ is the random disturbance term. In the empirical test, robust clustering standard error is adopted to cluster all regressions to the provincial level, as suggested by Lee and Yu (2010). To test the moderating effects (Hypotheses 3, 4), the model below was established:

$$\begin{aligned} Innovationoutputs_{i,t} = & \alpha_1 + \beta_1 Innovationmodes_{i,t} + \beta_2 moderator_{i,t} \\ & + \beta_3 Innovationmode * Moderator_{i,t} + \gamma Controls_{i,t} \quad (2) \\ & + \lambda_i + \mu_t + \epsilon_{i,t} \end{aligned}$$

In this model, moderator denotes the moderating variables BrSC and BoSC. $\beta_3 Innovation mode * Moderator$ represents the interaction term of the explanatory variable and the moderators. The rest stay as in Model 1.

To mitigate the potential influence of outliers on the outcomes of regression analyses, this study implemented “winsorization” at the 1st and 99th percentiles for all continuous variables in the dataset. Simultaneously, in our analysis, we first checked the variance inflation factor (VIF), and the results show that the VIF of all variables is less than 10, indicating that there are no multicollinearity issues in this research.

6 Empirical analysis

6.1 Descriptive statistics

The descriptive statistics of variables are shown in Table 2.

Table 1 Variables summary

Variable	initial	measurement
Dependent Variable		
Product Innovation	PRI	% of firms that only introduced product innovation
Business Process Innovation	BPI	% of firms that introduced process, organisational or marketing innovations
Independent Variable		
Scientific and technologically-based innovation mode	STI	1. firms' R&D investment to their revenue (%) 2. firms that collaborate with universities (%) 3. % of firms that collaborated with research institutions
The innovation mode based on learning-by-doing, by-using, and by-interacting	DUI	1. firms that collaborate with suppliers (%) 2. firms that collaborate with customers (%) 3. % of firms purchased external technology 4. % of firms provide training for innovation
Moderating Variable		
Bridging Social Capital	BrSC	1. voluntary blood donation (ml)/population 2. number of people registered in NGOs per thousand population 3. average score of respondent choice of survey question: "From 1–5, do you trust strangers?" (1 do not trust greatly, 5 trust greatly)
Bonding Social Capital	BoSC	the logarithm of total score given by managers answering the survey question: "According to your experience, could you list the top five provinces where enterprises are most trustworthy"
Control Variable		
GDP per capita	GDP	gross domestic product/total population
Consumption level	consumption	total retail sales of consumer goods/GDP
Industry structure	Industry	tertiary/secondary industry output value
Urbanisation level	urbanisation	urban population/total population
Transportation Infrastructure	infrastructure	logarithm of total highway mileage
Education level	education	total enrolment in higher education institutions/total population
Technology market level	technology market	technology market transaction value/GDP

Table 1 (continued)

Variable	initial	measurement
Foreign direct investment	FDI	foreign direct investment/GDP
Total import and export value	openness	total Import and export value/GDP
Population density	Population	permanent residents per square kilometre
Own elaboration		

This table shows a higher orientation towards product innovation than business process innovation, which reflects the significant focus of Chinese production towards the international market for goods (and parts). In relation to the business innovation modes, there is a prevalence of DUI over STI, as expected in emerging/catching-up economies. The provincial distribution of STI and DUI modes in 2023 is illustrated in Appendix 3. The correlation matrix and VIF results are reported in Appendix 4 and 5. The VIF values remain below the commonly accepted threshold of 10, suggesting that multicollinearity is unlikely to affect the estimations.

6.2 Baseline regression

Table 3 shows the baseline regression results. Our results suggest that the STI mode significantly influences product innovation, as every 1% change in STI causes a positive change of 3.41% in product innovation (column 1). Column 2 shows that the STI mode does not affect business process innovation. These results align with previous research (Fitjar and Rodríguez-Pose 2013; Orjuela-Ramirez et al. 2024; Parrilli et al. 2020), suggesting that R&D investments and research collaborations can effectively boost product innovation. Hypothesis 1 is supported. Columns 3 and 4 show that DUI drivers positively affect product innovation ($p < 0.01$) but not business process innovation. This result is at odds with other studies (in European countries) that prove the strong connection between the DUI mode and non-technological innovations (Fitjar and Rodríguez-Pose 2013; Parrilli and Alcalde 2016; Apanasovich et al. 2016; Trott and Simms 2017; Parrilli et al. 2020). Therefore, Hypothesis 2 is not supported. These findings emphasize a sort of “technological swing” that may come

Table 2 Descriptive statistics

Variable Name	Obs	Mean	SD	Median	Min	Max
PRI	248	3.53	1.80	3.100	1.100	9.800
BPI	248	3.00	0.86	3.055	0.971	4.946
STI	248	0.33	0.11	0.325	0.044	0.698
DUI	248	0.44	0.10	0.434	0.255	0.766
BondingSC	240	2.73	5.08	0.700	0.100	22.700
BridgingSC	224	3.00	1.47	2.836	0.995	7.483
GDP	248	11.08	0.41	11.014	10.218	12.207
consumption	248	0.39	0.07	0.396	0.180	0.504
Industry	248	1.53	0.78	1.350	0.755	5.690
urbanization	248	0.63	0.11	0.615	0.316	0.895
infrastructure	248	11.76	0.85	12.004	9.466	12.944
Education	248	0.02	0.01	0.023	0.006	0.048
technology market	248	0.02	0.03	0.011	0.000	0.195
FDI	248	0.02	0.02	0.014	0.000	0.101
Openness	248	0.23	0.22	0.138	0.008	0.977
Population	248	5.33	1.49	5.641	1.018	8.282

Source: own elaboration based on the data collected

Table 3 (continued)

(1)		(2)		(3)		(4)	
PRI		BPI		PRI		BPI	
(3.607)		(2.519)		(3.574)		(2.507)	
_cons	26.394						43.158***
(22.250)		(15.536)		(22.850)		(16.029)	
<i>N</i>	217						217
<i>R</i> ² (within)	0.651						0.560

Standard errors in parentheses

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

from Chinese firms' focus on the export market, where new products and parts are traded. As Table 1 shows, Chinese firms produce business process innovations, but not through DUI collaborations (probably more through other internal-to-the-firm factors). Among the control variables, urbanization is significantly connected with all innovation outputs, as it is in this context where businesses mostly push for innovation (Ciolek et al. 2022). "Openness", "consumption" and "technology market" show a positive and significant correlation with product innovation as expected from a production system oriented towards international markets (OECD 2018; Saridakis et al. 2019; Chen and Zhou 2023). Peculiarly, higher levels of education/human capital are not associated with innovation, probably due to lower involvement of skilled human capital with manufacturing activities. Population density shows a negative association with both PRI and BPI innovation. This may reflect congestion effects in highly populated provinces where rising costs and structural path dependence limit innovation potential (Shukai et al. 2021).

6.3 Moderating effects of social capital

Based on previous research on the effect of social capital on innovation (Laursen et al. 2012; Ceci et al. 2020; Bischoff et al. 2023), we argue that social capital can moderate the effect of the business innovation modes on innovation outputs, although the impact is likely to be different for BoSC and BrSC. Specifically, BoSC is not expected to influence the STI mode in its impact on innovation outputs as the use of STI drivers requires the fundamental role of human capital, while homogeneous bonds matter less; instead BrSC is expected to promote the impact of the STI mode on new product and process development as it helps connecting skilled people from different backgrounds, thus making them even more effective than through the sole use of human capital. The regression results (Table 4) support our Hypothesis 3b as columns 1 and 2 show that the interaction term, STI BoSC, negatively affects the impact of STI on any innovation output. Meanwhile, Hypothesis 4b is not supported as BrSC negatively moderates the impact of STI drivers on product innovation (in a sort of substitution effect between the two) while having no effects on business process innovation (columns 3 and 4). This outcome seems to provide evidence of a system where the STI mode relies exclusively on human capital and competition rather than on more open cooperation via SC. This might be explained by Chinese firms prioritizing production for international buyers while competing for these markets with other Chinese firms.

Table 5 is focused on the moderation of BoSC and BrSC on the impact of the DUI mode on product and business process innovation. The results generally support Hypothesis 3a as they indicate that BoSC significantly moderates the impact of DUI on business process innovation ($p < 0.1$). Instead, Hypothesis 4a is not supported as BrSC does not moderate the impact of the DUI mode on any type of innovation output. These findings show the selective nature of social capital in the Chinese context. Moreover, it shows a "technological swing," as firms tend to use STI and DUI drivers for product innovation, while SC does not enhance innovation activities to a strong extent, apart from BoSC for business process innovation.

Table 4 STI mode and social capital moderator

(1)	(2)		(3)		(4)	
	PRI	BPI	PRI	BPI	PRI	BPI
L.STI (1.191)	1.081	(0.885)	1.448	4.523**		0.968
BoSC (0.158)			0.379**		0.243**	
STI_boSC (0.298)			-1.014***		-0.552***	
BrSC (0.387)			0.855**		0.084	
STI_brSC (0.714)			-2.206***		-0.578	
GDP (0.727)	1.512**	(0.437)	1.721***	1.037		1.194***
consumption (2.113)	5.989***	(1.395)	2.690*	6.760***		3.141**
industry (0.293)	0.138	(0.194)	0.395**	-0.074		0.273*
urbanisation (3.889)	6.644*	(2.322)	1.095	6.190		0.706
infrastructure (0.306)	0.787**	(0.162)	0.245	1.151***		0.534***
education (12.412)	9.559	(9.676)	-3.829	14.755		-4.043
Technology market	23.554***		-1.927	25.728***		0.772

Table 4 (continued)

(1)	(2)	(3)	(4)
PRI	BPI	PRI	BPI
(3.699)	(2.721)	(3.864)	(2.637)
FDI	-11.726**	-5.013	-9.781**
(4.749)	(3.614)	(4.730)	(3.397)
openness	2.343*	-1.577*	2.809**
(1.312)	(0.887)	(1.313)	(0.771)
population	0.044	0.063	0.155
(0.220)	(0.115)	(0.286)	(0.119)
_cons	-30.832***	-21.526***	-32.110***
(6.332)	(3.951)	(6.553)	(3.644)
<i>N</i>	210	210	196
<i>R</i> ² (overall)	0.602	0.288	0.676
			196
			0.471

Standard errors in parentheses, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 5 DUI mode and social capital moderator

(1)	(2)		(3)		(4)	
	PRI	BPI	PRI	BPI	PRI	BPI
L,DUI (1.072)	3.501***	(0.829)	0.613	5.299**		0.500
BondingSC (0.127)						-0.141
DUI_bondingSC (0.233)						0.273*
BridgingSC (0.425)						-0.252
DUI_bridgingSC (0.677)						0.369
GDP (0.681)	1.078		1.355***	0.891		1.067***
consumption (1.973)	6.371***		2.942**	8.731***		3.322***
industry (0.263)	-0.108		0.261	-0.275		0.297*
urbanization (3.699)	7.348***		2.331	5.359		1.776
infrastructure (0.291)	0.760***		0.249	0.958***		0.515***
education (11.904)	11.667		-5.801	22.235*		-0.875
Technology market	19.665***		-2.873	23.239***		-2.049

Table 5 (continued)

(1)	(2)	(3)	(4)
PRI	BPI	PRI	BPI
(3.661)	(2.747)	(3.712)	(2.608)
FDI	-10.958**	-6.255	-7.804*
(5.033)	(3.942)	(4.577)	(3.510)
openness	2.297*	-1.536*	2.514**
(1.248)	(0.873)	(1.267)	(0.836)
population	0.061	0.098	-0.070
(0.213)	(0.115)	(0.325)	(0.133)
_cons	-27.053***	-18.041***	-27.757***
(5.772)	(3.610)	(6.390)	(3.503)
<i>N</i>	210	196	196
<i>R</i> ² (overall)	0.613	0.303	0.623
			0.455

Standard errors in parentheses, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

In relation to the control variables, FDI exhibits a negative effect on product innovation, which is consistent with the fact that in many Chinese provinces, inward FDI is concentrated in labor-intensive or assembly industries, where foreign firms rely on imported technologies and may crowd out local firms' innovation efforts. Although these results differ from conventional expectations, they are consistent with the Chinese context and do not affect the robustness of our main findings.

6.4 Robustness check

To further ensure the reliability of our empirical results, multiple robustness checks were performed, including clustering standard errors at the regional level, reconstructing the samples, and replacing the explanatory variable and instrumental variable estimation.

In addition to the baseline results, we perform a robustness check by clustering the standard errors at the regional level. This adjustment accounts for intra-regional correlations, which may arise due to similarities between provinces within the same region. By clustering the standard errors, we ensure that our estimates are robust to potential regional correlations. The results from this robustness check (Table 6) are consistent with our main findings, confirming the reliability of our conclusions. This further strengthens the validity of our model and ensures that the observed effects are not driven by unaccounted regional factors.

Second, following Kerr et al. (2017), we reconstructed our sample by excluding four municipalities (Beijing, Shanghai, Chongqing and Tianjin), which are directly governed by the central government of China and are advantaged in receiving preferential policies and financial support. Compared with other regions, these four cities have received a special government boost in terms of innovation and economic growth. Therefore, regressions with the remaining samples were conducted; the results suggest that after removing these four municipalities, our findings remain consistent as STI and DUI significantly boost product innovation, while having no effect on business process innovation (Table 7).

To further ensure the reliability of our findings, we also performed regressions with samples excluding data from 2020. This approach is justified by the unprecedented disruptions caused by the COVID-19 pandemic during this period. The pandemic likely introduced significant exogenous shocks to normal business operations, innovation activities, and market environments. These temporary shocks are not representative of the underlying theoretical relationships we aim to investigate. By removing the 2020 data, we assess whether these anomalous, pandemic-induced conditions drive our results or if they remain consistent and reflect the more stable, pre-pandemic economic context. As can be seen from Table 8, both STI and DUI significantly affect PRI ($p < 0.01$), suggesting our baseline regression result is still reliable after removing the data sample of 2020.

The third method to check the robustness of our results is to use alternative measurements for innovation modes. In this specification, we measured the STI innovation mode using a single indicator: the percentage of firms that collaborate with research institutions. This indicator reflects technological collaboration, and

Table 6 Regression with clustering SE at regional level

(1)	(2)	(3)	(4)
PRI	BPI	PRI	BPI
L.STI	3.410**	1.116	
(1.443)		(0.986)	
L.DUI	2.996**	-0.555	
(1.257)		(0.895)	
Controls	YES	YES	YES
Province FE	YES	YES	YES
Year FE	YES	YES	YES
_cons	26.394	39.482	43.158*
(30.879)		(34.301)	(24.392)
N	217	217	217
R2(within)	0.651	0.651	0.560

Standard errors in parentheses

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

Table 7 Regression results without municipalities

(1)	(2)	(3)	(4)
PRI	BPI	PRI	BPI
LSTI (1.185)	3.447***		0.926
L.DUI	2.771***	(0.826)	-0.760
(1.012)		(0.704)	
Controls	YES	YES	YES
Province FE	YES	YES	YES
Year FE	YES	YES	YES
_cons	54.682**	58.235***	63.865***
(23.568)			
N	189	(24.406)	(16.965)
R2 (within)	0.590	0.468	0.467

Standard errors in parentheses

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

Table 8 Regression results without data of 2020

(1)	(2)	(3)	(4)
PRI	BPI	PRI	BPI
L.STI			
(1.230)	3.460***	1.022	
L.DUI		(0.872)	
(1.028)	3.030***	−0.684	
Controls		(0.733)	
Province FE	YES	YES	YES
Year FE	YES	YES	YES
_cons	39.555	47.571***	52.927***
(24.823)	(17.608)	(25.311)	(18.033)
N	186	186	186
R2 (within)	0.567	0.570	0.440

Standard errors in parentheses

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

it represents firms' R&D efforts. The DUI innovation mode is re-estimated using three indicators – (1) the percentage of firms collaborating with suppliers, (2) the percentage of firms collaborating with customers, and (3) the percentage of firms purchasing external technology – excluding the indicator on firms providing training for innovation activities. This adjustment is reasonable because firm-level training reflects internal capacity-building rather than external interactive learning, which is one of the core drivers of the DUI mode. Moreover, the remaining three indicators also capture firms' network-based collaboration and knowledge acquisition behaviors. These indicators are combined using the entropy weight-TOPSIS method to form a composite DUI score. As shown in Table 9, STI and DUI retain their positive effects on product innovation (although naturally to a lower extent), underscoring the robustness of these results.

In empirical analysis, endogeneity issues may lead to biased estimates and model selection errors, thereby affecting the reliability of research conclusions. To address this, this paper employs the instrumental variable (IV) approach to mitigate endogeneity problems. The criteria for selecting an instrumental variable are: 1) the instrument must be strongly correlated with the endogenous explanatory variable; 2) the instrument should not be correlated with the error term in the outcome equation and should not directly affect the dependent variable. Specifically, the paper uses lagged public education expenditure as an instrument for STI (IV1) and lagged internet penetration rate as an instrument for DUI (IV2) and applies Two-Stage Least Squares (2SLS) for re-estimation. STI-oriented innovation activities in this study are closely related to R&D intensity and collaboration with universities and research institutions. Higher public education expenditure is expected to strengthen regional scientific and educational resources, thereby facilitating science-based innovation activities and increasing STI intensity. At the same time, after controlling for regional economic, demographic, and innovation-related conditions together with province and year fixed effects, public education expenditure is unlikely to directly affect product innovation and business process innovation except through its influence on STI activities. DUI innovation relies heavily on interactive learning, communication, and collaboration among firms, suppliers, and customers. Higher internet penetration facilitates information exchange and inter-organizational interaction, thereby contributing to the development of DUI-oriented innovation activities. Moreover, after controlling for broader regional development characteristics and fixed effects, internet penetration is unlikely to directly determine innovation outputs except through its impact on DUI-related interactions and learning processes. In Table 10, columns (1) and (3) present the first-stage regression results, while columns (2) and (4) show the second-stage regression results. The results indicate that the coefficients for both STI and DUI are significantly positive, and the validity of the instrumental variables is also confirmed. This suggests that after addressing the endogeneity concerns, the conclusions remain robust.

Table 9 Regression results with alternative measurements

(1)	(2)	(3)	(4)
PRI	BPI	PRI	BPI
L.STI	0.054**		-0.002
(0.022)		(0.015)	
L.DUI	2.658***		-0.595
(0.764)		(0.538)	
Controls	YES	YES	YES
Province FE	YES	YES	YES
Year FE	YES	YES	YES
_cons	24.278	40.187**	43.046***
(22.524)	(15.668)	(22.440)	(15.809)
N	217	217	217
R2 (within)	0.544	0.436	0.440

Standard errors in parentheses

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

Table 10 Regression with instrumental variables

(1)	(2)		(1)		(2)	
First	Second		First	Second		
L.STI	PRI		L.DUI	PRI		
L.STI			25.418*			
(15.15)						
L.DUI			11.044*			
(6.05)						
IV1			0.035*			
(0.02)						
IV2			-0.497**			
(0.20)						
Control	YES			YES	YES	YES
Province FE	YES			YES	YES	YES
Year FE	YES			YES	YES	YES
N	217			217	217	217
R-squared		-1.002			0.171	

6.5 Discussion

The findings of this study are relevant for a few reasons. First of all, it is one of the very few studies on innovation modes that focus on catching up/emerging economies (Chen et al. 2011; Malaver 2017), while most other studies focus on western economies (Jensen et al. 2007; Fitjar and Rodríguez-Pose 2013; Thomä, 2017; Trott and Simms 2017; Haus-Reve et al. 2019; Parrilli et al. 2020; Bischoff et al. 2023; Doloreux and Shearmur 2023, among others). Secondly, this study focuses on firms' attainments across the heterogeneous landscape of a country where some regions are advancing quite fast (the Pearl River Delta, the Yang-tze-Kiang region), while others are catching-up (e.g., Chongqing; Sinkiang, etc.). Thirdly, this study connects the use of social capital with the impact of business innovation modes on innovation outputs. It is an effort anticipated by Bischoff et al. (2023) and where we introduce the relevant and differentiated impact between BoSC and BrSC. Table 11 provides a summary of the tested hypotheses.

Our findings highlight China's unique position in world markets, where it has become the top global supplier in most global value chains (Baldwin 2012). As a first significant result, a "technological swing" is observed as both the STI and the DUI modes have a direct impact on product innovation, while having a more limited impact on business process innovation. This is justified by the position of Chinese firms and supply chains as focused on producing parts/components for OEM/OBM. Product innovation is their primary focus as a means to respond to demanding international buyers with high-quality and innovative products, parts, and components, while business process innovation is somewhat neglected (i.e., lower resource investments) due to their typical cost-efficiency advantage (Aghion and Jaravel 2015). Further, as the very core of its long-term strategy, the Chinese government has been committed to boosting the nation's capability of technological innovation, and it has used both R&D and non-R&D industrial subsidies as a critical tool to achieve this vision (China 2016). For instance, firms achieving more product innovation and patents are rewarded with government incentives such as tax reduction,

Table 11 Summary of tested hypotheses

Hypothesis	result
H1 The STI mode primarily boosts product innovation	Supported
H2. The DUI mode primarily boosts business process innovation	Not supported
H3a. Bonding social capital is expected to moderate primarily the impact of the DUI mode on business process innovation	Supported
H3b. Bonding social capital is not expected to positively moderate the impact of the STI mode on either type of innovation output	Supported
H4a. Bridging social capital is expected to support the impact of the DUI mode on any type of innovation output	Not supported
H4b. Bridging social capital is expected to moderate the impact of the STI mode on both product innovation and business process innovation	Not supported

which motivates them to invest further in product innovation. Even DUI-related activities are often aimed at patent development and product innovation.

In relation to the moderating role of BoSC and BrSC, as broadly expected, BoSC moderates the impact of the DUI mode on business process innovation while not having much impact on product innovation. This outcome partly confirms Bischoff's et al.'s (2023) findings in the German context and Trott and Simms (2017) in the UK context, while also reflecting the technological nuance of product innovation that is most likely to rely on STI drivers (Parrilli and Alcalde 2016; Parrilli et al. 2020). In relation to the moderating effect of BoSC on the STI mode, a negative impact is found for both product and business process innovation. This is also interesting as STI has a positive direct effect on product innovation, but a higher level of BoSC can offset this effect. This can be explained with Sargis-Roussel et al. (2017) and Anderson and Jack's (2002) argument that BoSC reinforces established routines and norms within a group, by which new product development may be slowed down or even impeded, as the latter often requires heterogeneous sources of knowledge and creativity. The STI mode implies uncertain, long-term R&D efforts that require exploration beyond familiar networks. While bonding ties enhance trust and efficient coordination, they may discourage risk-taking behavior, e.g., experimenting with unproven technologies (Andrew and Carr 2013). As such, firms with dense BoSC may prioritize incremental improvements rather than effective product innovations, limiting the impact of the STI mode. While BoSC fosters trust and cooperation, its excess hinders access to external knowledge sources, creating a potential lock-in effect (Anderson and Jack 2002). However, this is a gradual and context-specific effect, dependent on the levels of bonding SC in different sectors or regions.

Considering the moderating role of BrSC (not tested in Bischoff et al.'s study), we found that in the Chinese context it does not support the DUI mode in either type of innovation output. In practice, the DUI mode has a direct impact on product innovation (though not on process innovation), but BrSC's contribution does not add value. DUI-type collaborations with suppliers/customers help firms acquire tacit knowledge, though frequent interactions are required to make this knowledge transfer effective. However, echoing Eklinder-Frick et al. (2011), weak ties established through BrSC do not help to accumulate useful tacit knowledge that can be further exploited through the DUI mode. In relation to the STI mode, BrSC has no impact on business process innovation; simultaneously, it produces a negative moderation on product innovation. This implies that forming SC with heterogeneous people in China has no impact on non-technological innovation that requires effective tacit knowledge exchanges, which hardly happen between agents that differ in beliefs, routines, and culture. This happens, for instance, when firms lack experience in developing effective knowledge management systems when applying advanced technologies such as artificial intelligence and robotic automation (Santos et al. 2022). Besides, BrSC harms product innovation that mostly relies on skilled human capital (Parrilli and Alcalde 2016). A high level of BrSC dilutes the interaction based on high skills, thus distracting the direction of R&D efforts (similarly to what Muringani et al. (2021) found in the context of the most advanced European regions). For product innovation, R&D

teams must absorb scientific knowledge and stick to selected technology roadmaps; otherwise they suffer the so-called “paralysis by analysis” (Langley 1995). In practice, in China, excessive knowledge sources brought about by BrSC represent a burden on firms’ innovation endeavors.

Overall, the impact of social capital on business innovation modes appears more negligible when compared with what has been found in Western economies (the German case studied by Bischoff et al. 2023), as identified through a measure of generalized trust.

7 Conclusions

This study has shown important specificities of the Chinese economy in relation to the use of the business innovation modes for any type of innovation output. Specifically, both modes (STI and DUI) have a strong and significant impact on product innovation, while having a non-significant impact on business process innovation. This is likely to happen because product innovation is the most visible “face” of the firms in front of prospective international buyers (Baldwin 2012), while business process innovation is less relevant due to the traditional cost advantage of the firms in this economy (Aghion and Jaravel 2015). This is quite different from what has been found in most studies in the context of Western economies (Fitjar and Rodríguez-Pose 2013; Parrilli and Alcalde 2016; Thomä, 2017; Trott and Simms 2017; Haus-Reve et al. 2019; Parrilli et al. 2020, amongst others) and delivers original insights on how an emerging power is competing in global markets.

In China, regional differences in innovation modes are not clearly visible in this analysis but exist. They can be found in the rural–urban divide (Wang et al. 2023). Urban regions with developed infrastructure, better access to technology, and a more skilled workforce are more likely to adopt STI-driven innovation modes/drivers, such as heavy investments in R&D, collaborations with universities, and high-tech industries. Cities like Beijing, Shanghai, and Shenzhen benefit from government policies, technology clusters, and global market access, enabling faster technological advancements and successful commercialization. In contrast, rural areas, often with limited resources, rely more on DUI-based innovation, which focuses on adapting existing technologies and improving traditional industries. Innovation in rural regions is more incremental, driven by local collaborations with suppliers and farmers, and often focuses on improving agricultural practices or low-tech manufacturing processes. While these areas face challenges such as limited access to capital and technology, their innovations are still crucial for local economic development, addressing region-specific needs, and enhancing productivity.

The second key finding relates to the moderating effect of BrSC and BoSC on the impact of business innovation modes on any type of innovation output. It is found that the moderating role is limited, and that BoSC particularly hampers innovation within the STI mode, while it matters for business process innovation through the DUI mode. Bridging SC is irrelevant for innovation, except in the

STI mode, where it restrains firms' product innovation. This is also an insightful contrast as China differs sharply from Western economies in that regard (Bischoff et al. 2023; Sargis-Roussel et al. 2017).

Overall, the study of the Chinese approach to business innovation modes and the way social capital moderates their impact on product and process innovation delivers some useful theoretical implications. First of all, context specificity matters (Di Maggio and Powell, 1994; Parrilli and Alcalde 2016; Sedita et al. 2022; Sobczak et al. 2022). China has its specific approach to the adoption of business innovation modes. Here, firms are targeting product innovation eminently. Social capital matters to a lower extent than in other places (e.g., see Muringani et al. 2021 on European regions) and more for the bonding side than for the bridging one. This might depend on China's intense catching-up trajectory, where firms are very much looking for individual and country competitiveness. Innovation is still there but looks to be based more on competition than cooperation. Other emerging economies in Asia, Latin America, and Europe may learn about the possibility of following different pathways to innovation and competitiveness, with China's being a very successful one.

From a policy perspective, the indications of this study emphasize the sensitivity of firms and their regions/provinces to product innovation while process innovation is still not targeted as it should. As our findings show the importance of BoSC for business process innovation, important initiatives related to on-the-job training, teamwork, and bottom-up communication need to be supported, particularly in the most homogeneous regions of China (the rural/interior part of the country), on process and non-technological innovations, particularly through the DUI mode.

Over the period 2016–2023, STI-related indicators such as R&D intensity and collaboration with universities and research institutes show a steady upward trend, while DUI drivers (e.g., supply chain collaboration, on-the-job training) remain comparatively stable. This is consistent with China's policy emphasis on science-driven innovation (China 2016). It is also consistent with product innovation that has increased more strongly than business process innovation. Looking forward, the STI mode is expected to continue driving product innovation under the national agenda of technological self-reliance, whereas DUI will remain important for process improvements and supply-chain coordination. Social capital is likely to gain further relevance in shaping balanced regional innovation ecosystems.

This study includes a few limitations that open the way to new spaces for research. First, some of our social capital indicators are based on historical data, and a measurement based on more recent data may enhance the validity of social capital as a moderating variable. In relation to further research avenues, more studies of catching-up economies are required to verify whether the “technological swing” seen in China also works in other contexts. Larger firm-level panel data need to be analyzed to identify ongoing patterns of development in relation to innovation processes, as well as to investigate further how sectoral heterogeneity shapes STI and DUI innovation modes. The relevance of social capital needs to be studied in more depth. Identifying specific indicators to measure the impact of bonding, bridging, and perhaps even linking social capital is necessary to avoid getting bogged down in general analyses with unclear constraints in approximating the relevant variables and

impacts. Another limitation of this study is that our analysis relies on province-level indicators of STI/DUI modes derived from official statistical yearbooks and national surveys. While this approach ensures full coverage and comparability across all provinces, it does not allow us to exploit firm-level heterogeneity. Future research could therefore benefit from multi-level designs that combine firm-level observations with regional controls once richer micro-level datasets become available.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s00191-026-00978-1>.

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