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RESEARCH ARTICLE

National innovation systems and firms' capital investment around the world: a N-tuple helix approach

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Abstract We examine whether national innovation system (NIS) performance shapes firms' fixed-capital investment decisions across 93 countries from 2008 to 2020. We use firm-level data from the World Bank's Enterprise Surveys and reconstruct a helix-based composite indicator (SFIGA) to measure countries' innovation performance globally. The index integrates the roles of government, industry, academia, society, and finance. To capture the broader context, we include firm-level and country-level controls that reflect organizational, financial, and institutional factors. Probit estimates with sector, year, and country fixed effects indicate a robust positive association between national innovation performance and the propensity to invest in fixed assets. Results remain stable under instrumental variable estimation, Oster test, and propensity score matching. Mechanism tests indicate transmission through technology adoption, ICT export activities, and workforce training. Additional heterogeneity analyses show that system maturity matters. The evidence supports an actor-centered view of NISs and suggests that strengthening helix performance can crowd in corporate capital formation.

Plain English Summary Stronger national innovation systems (NISs) are associated with a higher likelihood that firms invest in machinery, equipment, and other productive assets. Using firm-level data from 93 countries, we show that well-functioning NISs, where government, industry, academia, finance, and society work in concert, are linked to greater business investment. The association is strongest for firms that adopt new technologies, export digital products, or invest in workforce training. Larger and more capability-rich firms benefit more on average, while SMEs gain where financial intermediation and governance are supportive. The actor-centered SFIGA index identifies the weakest and strongest actors (helices) within NISs. The principal policy implication is diagnostic and targeted: strengthen the weakest helix, e.g., through SME credit guarantees and co-investment vehicles, expanded vocational training and university–firm extension, or faster IP enforcement, to support conditions under which private investment is more likely.

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1 Introduction

Global patterns of firms' fixed-capital investment mirror economic development stages, institutional quality, and technological capabilities (Sun et al., 2023). In developed economies, strong institutions, mature financial markets, and effective national innovation systems (hereafter, NISs) support investments in automation, AI, and green technologies that help firms stay competitive in fast-evolving markets (Lee et al., 2022). Large emerging economies are expanding investments in technology and clean energy, though regulatory constraints limit their full potential (Andreoni & Tregenna, 2020). In contrast, developing countries often prioritize basic infrastructure, manufacturing, and agriculture, with a gradual shift toward digital and renewable technologies. However, weak institutional support and financial systems hinder large-scale investments in advanced technologies. Since capital formation underpins productivity growth and structural change, investment outcomes depend not only on firm endowments but also on systemic conditions, such as financial intermediation, knowledge diffusion, skills formation, and credible rules, that shape perceived risk, expected returns, and the timing of irreversible outlays (Herrendorf et al., 2014; Lakitan, 2013).

Within this perspective, NISs comprise the institutions, policies, and networks that mobilize innovation across governments, firms, universities, users, and financial systems (Radosevic, 2022). By structuring access to knowledge, funding, and talent, well-functioning systems support investments in machinery, technology, and R&D, while collaborative interfaces (e.g., university–industry linkages) mitigate uncertainty around high-commitment projects (Kapetaniou et al., 2018; Kergroach, 2019; Perkmann et al., 2013). Over time, the NIS framework has evolved beyond formal institutions to include informal networks, societal factors, and global linkages (Erzurumlu et al., 2022). Innovation now often arises through collaboration between government, industry, academia, and civil society, the so-called innovation helices (Leydesdorff & Smith, 2022). Globalization further shapes innovation policy and corporate strategy through international collaboration and competitive pressure, influencing corporate investment (Chundakkadan & Sasidharan, 2020).

NISs influence firms' investment decisions in several ways. They enable access to advanced knowledge, financing, and skilled labor, each essential for high-impact investment. Robust NISs facilitate collaboration with universities and research institutions, promoting knowledge flows (Perkmann et al., 2013). Effective government policies within NISs reduce the risks associated with high-cost investments, encouraging firms to invest more in R&D and technology adoption (Allard et al., 2012). Lastly, interconnected innovation actors can stimulate knowledge spillovers and collaborative ventures, which support long-term innovation-driven investment (Petraite et al., 2022).

Despite this relevance, cross-country evidence on the NIS–corporate investment link remains scarce for three related reasons. First, existing studies (e.g., Spescha & Woerter, 2021) often rely on narrow innovation proxies (e.g., R&D expenditure) that capture only fragments of system functioning and treat finance, skills, and policy as separate controls rather than as interacting system components. Second, widely used composite indices (e.g., Summary Innovation Index, Global Innovation Index, Global Knowledge Index) organize indicators into abstract "pillars" and dimensions (e.g., institutions, human resources, infrastructure) that obscure the roles of concrete innovation actors (Vetsikas & Stamboulis, 2023). In practice, pillar indices often bundle indicators tied to different actors within the same pillar, so a given pillar score cannot reveal which helix is driving performance, making policy diagnosis and accountability unclear. These actors, including governments, firms, universities, research institutes, end-users, and financial subsystems, influence investment decisions (Carayannis et al., 2018). Third, pillar-based aggregation complicates mechanism and policy interpretation because it does not map cleanly onto the actors that design policy, allocate capital, train labour, and diffuse knowledge. To address these limitations, we reconstruct an actor-centered, helix-based NIS index (Vetsikas, 2024) that preserves interpretability at two levels: an overall NIS score and five helix profiles (society, finance, industry, government, academia). This design allows us to move beyond a "black-box" national score by (i) comparing the investment association across NIS archetypes, (ii) identifying which helices are most strongly associated with firms' investment propensity, and (iii) examining channel-consistent complementarities. In practical terms, two countries with similar aggregate innovation scores can exhibit different helix bottlenecks (e.g., strong academia but weak finance), implying different constraints on firms' ability to undertake fixed-capital purchases. At the same time, we acknowledge a general limitation of composite indices: linear aggregation can embed implicit substitutability across components (Crotti et al., 2025). We therefore interpret SFIGA primarily as a transparent diagnostic benchmark to compare system configurations and locate helix-specific constraints, rather than as a structural measure of any single mechanism.

Using firm-level data from the World Bank's Enterprise Surveys (WBES) across 93 countries (2008–2020), we integrate the roles of five helices into a single diagnostic of NIS performance and estimate its association with the probability of undertaking fixed-asset purchases, controlling for organizational, financial, and institutional covariates. We find a strong positive relationship between NIS performance and firms' fixed-capital investment decisions. The findings hold across multiple robustness checks, including instrumental variable estimation, the Oster test, and propensity score matching. The impact is magnified through channels such as technology adoption, ICT export orientation, and workforce training.

Firms undertake fixed-asset purchases when finance, skills, suppliers, and rules work together. NISs matter because they shape that alignment. We therefore focus on fixed-capital investment as a behavioral decision margin linking NIS performance to production transformation, and we use an actor-centered composite indicator to keep policy interpretation tied to the helices that supply these complements.

Our contributions are threefold. First, we introduce an expanded actor-centered, helix-based NIS measure (denoted as SFIGA), grounded in the N-tuple helices framework. This NIS measure goes beyond narrow innovation proxies (e.g., R&D intensity, high-tech exports) and existing composite indices by making the roles of finance, government, industry, academia, and society explicit and by adhering to transparent composite indicator practice. Our approach allows for a more refined analysis of how aggregate performance across helices shapes firms' capital investment decisions, enriching the theoretical discourse on NIS frameworks. In our benchmarking exercises against a standard pillar-based index, the Global Innovation Index (GII), SFIGA remains robust and, crucially, reveals configuration heterogeneity, with negative associations in fragmented systems but positive associations in intermediate and mature systems, as well as helix-specific constraints that an aggregate pillar score cannot diagnose.

Second, we bridge NIS theory with the corporate investment literature by analyzing fixed-capital investment as a micro-level decision margin that is systematically shaped by NIS conditions. Fixed-asset purchases are the point at which firms turn plans into concrete upgrading. Unlike innovation proxies like patents or R&D, this decision captures whether the financing, skills, suppliers, and rules provided by the NIS fit together well enough for firms to commit to partly irreversible investments. This integration is important because the corporate investment literature primarily explains investment through firm-level financing constraints and uncertainty, while NIS research emphasizes system coordination, knowledge diffusion, and the provision of complementary inputs. Combining these perspectives clarifies how NIS performance can affect the expected returns and perceived risks of partly irreversible investment through access to finance, skills, collaboration opportunities, and a more predictable environment for upgrading. Empirically, by examining technological adoption, workforce training, and ICT exports, we document channel-consistent patterns through which NIS performance is associated with firms' strategic fixed-asset purchase decisions, thereby linking macro-level system features to micro-level investment behavior.

Third, we offer practical insights for policymakers and managers. The helix-based index can be used diagnostically to identify system bottlenecks and to guide targeted interventions. These may include credit information systems and SME lending reforms, accelerated depreciation allowances and procurement for innovation, expansion of science, technology, engineering and mathematics (STEM) education and vocational education and training (VET), cluster development programs, and digital market deepening, consistent with evidence on coherent policy mixes and demand-pull instruments. Beyond firm-level outcomes, such interventions matter because fixed-capital investment is a key conduit for technology diffusion and productivity growth. They also support the adoption of digital and cleaner production methods, including automation and sensor-enabled machinery, ICT systems such as ERP and data analytics, and energy-efficient equipment or process retrofits. In turn, these investment-enabled upgrades have implications for job quality and long-run competitiveness.

The remainder of this paper is organized as follows: Section 2 reviews relevant literature. Section 3 describes our methodology, including data sources, variables, and baseline model. Section 4 presents main findings, Section 5 addresses endogeneity concerns, and Section 6 explores mechanisms linking NIS performance to investment. Section 7 concludes.

2 Related literature

2.1 National innovation systems and N-tuple helices: conceptual foundations

NISs are the country-level constellation of institutions, policies, incentive regimes, and competencies that organize technological learning and industrial transformation and, in doing so, shape development and competitiveness (Freeman, 1987). Contemporary scholarship emphasizes systemic interdependencies, path-dependent specialization, and the diffusion and use of knowledge across firms, universities, training systems, and public agencies (Kashani & Roshani, 2019; Patel & Pavitt, 1994). These system features shape what firms can feasibly do. They affect investment horizons, influence the payoffs to upgrading, and condition the timing of irreversible capital commitments, providing a direct conceptual bridge to our research question on fixed-capital investment decisions.

An actor-centered "helix" operationalization aligns with this view. Innovation involves not only knowledge generation but also learning and dissemination, motivating policies that enhance knowledge transfer and absorptive capacity, especially among SMEs (Acs et al., 2017). Beyond formal institutions (universities, research organizations), contemporary NISs incorporate informal networks, civil society, and end-users (Carayannis et al., 2018). Financial systems, e.g., banks, venture capitalists, markets, supply risk capital for R&D, commercialization, and scaling (Wonglimpiyarat, 2011). The effectiveness of innovation policy thus hinges on coherent mixes that align system functions with financial architecture. Institutional complementarities among instruments, intermediaries, and capabilities govern access to finance, risk sharing, and knowledge diffusion, crowding in private resources and expanding firms' feasible investment sets, while misalignment yields coordination failures and underinvestment (Kapetaniou et al., 2018).

We formalize NISs as an actor-centered N-tuple helices architecture in which system performance aggregates across society, finance, industry, government, and academia. Whereas the Quintuple Helix expands the Triple/Quadruple models by incorporating civil society and framing the natural environment as an orienting influence (Carayannis et al., 2012), we treat the environment as an external driver, to avoid anthropomorphism and reification (Cai & Etzkowitz, 2020), and elevate finance as a core structural subsystem. Finance shapes appropriability under uncertainty and mobilizes capital formation from early-stage risk finance through scaling via equity and credit markets (Samara et al., 2012; Tylecote, 2007; Wonglimpiyarat, 2011). Our N-tuple approach is grounded in the Triple Helix tradition (Etzkowitz & Leydesdorff, 2000) and is purpose-built to address firms' fixed-asset commitments, not only R&D.

Because technology adoption depends on competences, the "learning economy" stresses skill formation and continuous learning as system attributes that underwrite firms' ability to implement new capital productively (Lam & Lundvall, 2006). Inclusive NIS perspectives further widen participation and access to innovation, reinforcing the policy salience of education and skills systems (Casadella & Tahi, 2025).

Prior NIS research has established that NIS quality and institutional complementarities shape national innovation performance and, in turn, productivity and growth outcomes (Lee et al.,2021). However, three limitations remain salient for understanding firm investment behavior. First, much comparative evidence relies on either narrow innovation proxies or highly aggregated indices. These approaches can benchmark countries but they provide limited actor-level diagnosis and make it difficult to connect empirical relationships to concrete system mechanisms and policy levers. Second, the firm-level outcomes most often examined are innovation outputs or productivity, while the fixed-capital investment decision remains less directly studied, despite being a key behavioral margin linking innovation capacity to production upgrading and structural change. Third, cross-country micro evidence remains uneven and less is known about when NIS effects are stronger or weaker across different system configurations, firm capabilities, and sectoral contexts. These gaps matter because NISs may expand technological opportunities without translating into realized investment when key complements such as finance, skills, and diffusion channels are missing. We address this by adopting an actor-centered, helix-based diagnostic and focusing explicitly on firms' fixed-capital investment propensity in a large cross-country sample.

In sum, our refinement of the NIS concept is twofold: (i) an actor-centered architecture where finance is key and the natural environment remains an external orienting force; and (ii) an emphasis on cross-helix complementarities and coherence as the system property that governs investment under Knightian uncertainty. This framing motivates our empirical question: do stronger, more coherent NISs raise firms' propensity to undertake fixed-capital investment? We operationalize NIS strength with the helix-resolved SFIGA index and test the corporate investment margin directly.

2.2 National innovation systems and corporate investment decisions

NISs shape whether firms commit to irreversible investment by affecting expected returns, financing conditions, and uncertainty. During the European crisis, structural NIS features, e.g., human resources, knowledge stocks, industrial specialization, financial development, helped buffer contractions and sustain innovation investment (Filippetti & Archibugi, 2011). More broadly, shifts in core system functions, such as knowledge creation and diffusion, appropriability and standards, risk intermediation, skills formation, and market creation, can turn latent opportunities into bankable projects and reduce information gaps that raise perceived risk (Bozeman et al., 2015; Kapetaniou et al., 2018; Watkins et al., 2015; Yan et al., 2024). Public incentives and funding mechanisms further reduce risk and catalyze commitments (Lee, 2019), while tax incentives and grants reduce the financing burden of costly projects (Guan & Yam, 2015).

Human capital and networks are especially important for investment in new equipment and technologies. By strengthening VET and skill pipelines, NISs increase firms' ability and confidence to adopt advanced technologies and undertake innovation-intensive activities (Prokop et al., 2021; Sarpong et al., 2023). Dense networks also matter because they facilitate collaboration, spillovers, and cost or risk sharing that can make investment feasible (Schøtt & Jensen, 2016). In the "new industrial policy" era, direction-setting policies in areas such as clean energy and digitalization provide regulatory certainty and more durable demand signals, helping firms justify large, long-horizon commitments (Aiginger & Rodrik, 2020; Malerba & McKelvey, 2020).

Within an actor-centered N-tuple architecture, each helix supports investment through a distinct lever. Finance improves screening and intermediation, extends maturities, relaxes collateral and information constraints, and shares risk, reducing firms' sensitivity to cash flow volatility (Chowdhury et al., 2016; Dahiya & Ray, 2012). Government secures property rights, maintains policy certainty, and uses tools such as procurement, tax credits, and accelerated depreciation to raise after-tax returns to asset acquisition and lower installation frictions (Drobetz et al., 2018; Fan & Liu, 2020; Yang & Li, 2024).

Academia supplies technicians and engineers and diffuses applied know-how through collaboration, standards, and testing infrastructures, reducing integration risk and technology uncertainty (Steinmo, 2015; Galán-Muros & Plewa, 2016). Industry dynamics, including competition, clustering, and supplier networks, raise the marginal product of capital, and when equipment upgrades are paired with organizational change, the payoff from tangible investment can be larger (Huggins & Johnston, 2010; Kong et al., 2022). Society shapes demand sophistication and digital adoption in commerce and payments, which can thicken markets, reduce transactional frictions, and support investment scale and timing (Fonseka et al., 2021; Islam et al., 2018). When these levers reinforce each other, firms are more likely to move from intention to commitment.

This helix perspective helps explain why similar technological opportunities can yield heterogeneous investment responses across countries and over the cycle and clarifies conditions under which system upgrades push firms from hesitation to decisive fixed-asset purchases. Well-functioning NISs can also improve firms' ability to attract external capital by reducing perceived risk (Elia & Santangelo, 2017). These theoretical links directly motivate our empirical tests: we examine whether higher NIS scores are associated with a greater probability of corporate capital investment, and whether helix-consistent channels, e.g., technology adoption, ICT export orientation, and workforce training, amplify this relationship.

2.3 Other determinants of corporate investment

Corporate fixed-asset purchase decisions reflect firms' willingness and ability to commit resources to partly irreversible projects under uncertainty. In this paper, these determinants are not merely controls; they help clarify when and for whom NIS conditions translate into a higher likelihood of undertaking fixed-capital formation. Even when a NIS provides supportive complements, firms differ in their capacity to mobilize resources, coordinate inputs, and execute upgrades.

A first conditioning factor is *scale and internal capacity*. Larger firms are generally better positioned to absorb fixed costs and long payback periods because they can mobilize internal funds, access external finance more easily, and spread adjustment costs, which supports capital-intensive investment and lowers perceived risk (Cenni et al., 2015; Panagiotidis & Printzis, 2021; Zubair et al., 2020). A second factor is *lifecycle position*. Older firms may undertake renewal and upgrading based on accumulated routines and capabilities (Adelino et al., 2017; Czarnitzki & Hottenrott, 2011), while younger firms may pursue more innovation-oriented projects but face tighter constraints (Coad et al., 2016). A third factor concerns *access to finance and market orientation*, which shape whether perceived opportunities become action. When upfront outlays are large, credit constraints can delay or prevent investment (Kahle & Stulz, 2013). In contrast, exporting can increase the returns to upgrading through competitive pressure and standards and can diversify revenues that support reinvestment (Bernard et al., 2007; Krammer et al., 2018). Finally, *governance and formality* affect both risk tolerance and execution quality: ownership structures shape investment horizons (Zhao et al., 2023), managerial efficiency improves project selection and implementation (Goodman et al., 2014), and legal status conditions institutional access, with informal firms facing higher frictions and investing more cautiously (Degryse et al., 2012; Mertzanis, 2017; Robb & Robinson, 2014) (Hypothesis 2 in Sect. 2.4).

These firm-level characteristics operate within a broader *macro-financial environment* that influences the cost of capital and the predictability of returns. Economies with stronger investment momentum and higher confidence tend to provide more supportive conditions for corporate upgrading (Sun et al., 2023; Tawiah et al., 2023). Deeper and more effective financial systems expand access to external funding and support long-horizon projects (Berger et al., 2020). These conditions can amplify or dampen how NIS quality translates into firm behavior, implying systematic cross-country variation in the NIS–investment association (Hypothesis 3 in Sect. 2.4).

These arguments motivate the moderating hypotheses developed next.

2.4 Research hypotheses

Directionality runs from the NIS to firm behavior because system attributes are institutionally sticky, evolve with temporal precedence, and shape resources and rules well before individual investment choices are made (Acs et al., 2014).

Endowments in finance, skills, intellectual property enforcement, and research linkages shape "innovation spaces" by structuring opportunity sets and knowledge flows, thereby attenuating Knightian uncertainty and the irreversibility that deters lumpy capital outlays (McKelvey, 2016). In line with foundational NIS scholarship, stronger and more coherent systems should be positively associated with firms' propensity to undertake fixed-capital formation (Filippetti & Archibugi, 2011; Kapetaniou et al., 2018; Patel & Pavitt, 1994). Mapped onto the helix pathways, finance lowers the cost of capital and relaxes financing constraints. Government provides credible rules, incentives, procurement, and infrastructure. Academia develops skills and firms' absorptive capacity. Industry strengthens competition and cluster externalities that raise the marginal product of capital. Society enhances demand sophistication and trust. Together, these functions reduce uncertainty and coordination failures and increase the likelihood that firms undertake fixed-asset purchases. Building on the reviewed literature, we propose three research hypotheses:

H1: Stronger NISs positively influence corporate fixed-capital investment decisions.

Robust NISs expand access to knowledge, skilled labor, and financial incentives and reduce uncertainty around high-risk projects. Freeman (1987) and Lundvall (1992) highlight that firms in robust NISs can better pursue innovation through institutional support, university partnerships, and public–private collaboration. These systems reduce uncertainty around high-risk investments, enable strategic resource allocation, and support long-term innovation (Wang et al., 2012).

H2: Firm-specific characteristics moderate the effect of the NIS on corporate fixed-capital investment.

The gains from a high-quality system are mediated by firm capabilities: scale, R&D intensity, and absorptive capacity determine how effectively external knowledge and policy instruments are leveraged (Cohen & Levinthal, 1990). Smaller or low-R&D firms may struggle to engage dense innovation networks (Pavitt, 1984), while ownership can tilt access to system support, e.g., state-owned enterprises may benefit from preferential ties (Nemlioglu & Mallick, 2021).

H3: Country-level factors moderate the effect of the NIS on corporate fixed-capital investment.

Regulatory quality, macroeconomic stability, and financial development condition how system channels transmit to firm investment; uncertainty deters innovation outlays (Narula & Dunning, 2000), and underdeveloped finance or weak regulation can choke off access to NIS support (Chaminade et al., 2018).

In a nutshell, we conceive a robust NIS as a meso-level coordination architecture that organizes interactions among the N-tuple helices into routines of resource allocation and knowledge exchange. The hypotheses concern the propensity to undertake fixed-capital formation, with firm attributes conceptualized as micro-level endowments and country conditions as macro context, both distinct from the system itself. System effects propagate through financial intermediation, skills formation, intellectual property enforcement, and research linkages. These channels reduce Knightian uncertainty and coordination failures and enlarge feasible investment sets, so H1 posits a positive association under stronger systems, while H2 and H3 posit moderation by firm capabilities and by the macro context, respectively, without circularity.

3 Empirical strategy

3.1 Data

Our study combines firm-level data from the World Bank's Enterprise Surveys (WBES) with country-level indicators from the World Development Indicators (WDI), Worldwide Governance Indicators (WGI), World Economic Forum (WEF), SCIMAGO, and Global Economy. WBES provides detailed, cross-country comparable data on firm size, ownership, performance, and challenges. Despite limitations such as sampling bias and self-reporting errors, it remains a vital source for analyzing private sector behavior (Bertrand et al., 2024). The WEF Global Competitiveness Report (WEFGCR) offers innovation-related indicators rated on a 1–7 scale. Though partly subjective, WEFGCR metrics are widely cited in innovation studies (Thore & Tarverdyan, 2016). WDI contributed data on trade, investment, and patents, while WGI captured institutional quality (Álvarez et al., 2018). To assess research productivity within the NIS framework, we used SCIMAGO's journal and citation metrics while data on "brain drain" came from the Global Economy.

After matching all data, the final dataset spans 93 countries from 2008 to 2020, covering 119,190 firm-year observations. Winsorizing data at the 1% and 99% levels and taking logarithms of some variables minimized biases and heterogeneity.

3.2 Key variables

Corporate investment decisions are operationalized as the likelihood of undertaking fixed-capital formation. Our dependent variable, FCAPINV, is a binary indicator (0/1) from WBES that records whether a firm purchased fixed-assets in the last fiscal year, including machinery, vehicles, equipment, land, and buildings. It captures the investment decision rather than the amount invested and excludes R&D and other intangible outlays unless capitalized as fixed assets. The indicator supports probit estimation and offers broad, comparable coverage across industries and firm sizes. Prior studies validate this measure in cross-country settings (Farooq et al., 2021; Islam et al., 2018). Accordingly, throughout, we interpret effects as changes in the likelihood of undertaking a fixed-asset purchase, not the amount invested. Since the WBES does not provide harmonized firm-level investment amounts for this measure across countries and years, we instead focus on the investment decision (the extensive margin).

Our primary independent variable is the SFIGA index, a helix-based composite indicator that measures overall innovation performance across countries. Building on Vetsikas (2024), who focuses on 24 OECD European countries, we extend SFIGA to cover a broader sample of 112 countries over the period 2008–2020, utilizing 42 innovation-related indicators (see Electronic Supplementary Material for details). These indicators are classified based on the N-tuple helices approach (Leydesdorff & Smith, 2022), capturing the performance of five key helices, namely Society, Finance, Industry, Government, and Academia. This approach allows us to assess individual helix performance as well as the overall NIS's performance. We relied on the selected indicators for their conceptual relevance and data availability (Cirillo et al., 2019; Maruccia et al., 2020). We employ the min–max normalization method, widely used in studies on technology upgrading (Radosevic & Yoruk, 2018), entrepreneurial ecosystems (Perugini, 2023) and green technology innovation development (Feng et al., 2022), to standardize the indicators between 0 (worst performance) and 1 (best performance). The normalized value for each country is computed as: $\mathrm{I_C} = \frac{\mathrm{V_c - V_{min}}}{\mathrm{V_{max} - V_{min}}}$, where I is the normalized indicator, V is the initial value of indicator, and subscript c is the country. Next, we build five indices representing each helix's performance. The general formula for a helix indicator is: $\mathrm{H} = \sum_{i=1}^{n} \mathrm{w_i I_i}$, where H is the composite index of each helix; $\mathrm{w_i}$ is the weight of the $\mathrm{I_i}$ and $\sum_{i=1}^{n} \mathrm{w_i} = 1(0 \leq w \leq 1$; I: 1, …, n). We assign equal weight to each indicator within the helix. Finally, the overall SFIGA index is calculated by equally weighting[1] the five helices,[2] expressed as: $SFIGA_{index} = \sum_{i=1}^{5} \lambda_i H_i$, where H_{i} represents the helices for each country and λ_{i} indicates the weights of helices).

We reconstruct SFIGA as a helix-based composite designed for global coverage, including countries with nascent or fragmented NISs. Unlike Vetsikas (2024), who applies helix weights in the final aggregation, we adopt equal helix weights to preserve interpretability and cross-country comparability rather than importing covariance-driven weights calibrated on advanced-economy samples. The resulting helix profiles provide diagnostics to identify bottlenecks and prioritize helix-specific policy interventions. SFIGA is designed as a transparent diagnostic summary of how different innovation actors and complements (finance, skills, government capacity, industry linkages, academia, and society) are configured, rather than as a precise structural measure of a

[1] Equal weighting is frequently used when all indicators are conceived equally important or when there is no statistical or empirical basis to justify an alternative weighting scheme (Nardo et al., 2005).

[2] We estimated the Cronbach's Alpha (C-alpha) coefficient for each of the five latent constructs, with all values exceeding the 0.70 threshold for adequate reliability (Nunnally, 1978). C-alpha values for the latent constructs are as follows: Industry (0.963), Academia (0.844), Government (0.830), Society (0.888), and Finance (0.871). These results indicate a high likelihood of shared common factors, consistent with our outlined approach. Further, the SFIGA index exhibits a strong correlation (r=0.81***) with the GII, a widely recognized international benchmark. This alignment affirms the external validity of the SFIGA index and supports its application in tracking systemic performance over time and across countries.

single "innovation mechanism". This matters because any composite index inevitably reflects judgment calls about which ingredients to include and how to combine them. In our case, indicators were selected for conceptual fit and for comparable global coverage across many countries and years. Several inputs are based on expert or population surveys, so they capture perceived conditions rather than direct quantities. Importantly, indicators are not selected based on their statistical association with firm investment. We therefore treat SFIGA as an interpretable profile of system conditions—useful for comparing helix bottlenecks and discussing policy constraints—rather than as a definitive causal "score" of national innovation quality. Because the index is linearly aggregated, it can also embed implicit substitutability across components and may include inputs plausibly correlated with firms' investment decisions; accordingly, SFIGA should not be interpreted as identifying a single causal mechanism. Instead, we use it as a benchmarking device that motivates mechanism-consistent tests and robustness checks.

This actor-resolved measure links system quality—overall and by helix—to the probability that firms undertake fixed-asset investment (FCAPINV).

3.3 Controls

While NIS performance is expected to influence firms' fixed-capital investment, the effect is not directly observable. Therefore, we include firm-specific and country-level control variables that may mediate this relationship. At the firm-level, investment behavior is shaped by internal characteristics (Ding et al., 2013; Mertzanis & Houcine, 2024). We control for firm size (SIZE), which relates to resource access; firm age (AGE), reflecting experience and stability; and access to finance (ACCFIN), which directly impacts investment capacity. Ownership structure is considered via foreign (FOWNPRV) and domestic (DOWNPRV) ownership, while top manager experience (MANAGEXP) may influence strategic decision-making. Corporate legal status (LEGAL) and export performance (EXPRT) are also included, as both can affect firms' investment behavior and international orientation. At the country-level, we control for gross fixed-capital formation (GFCF) and domestic credit to the private sector (DCREDIT) to reflect macroeconomic investment conditions (He et al., 2024). GFCF indicates national investment levels, while DCREDIT captures financial development and credit availability—both essential for firms' capital investment decisions. By integrating firm- and country-level controls, our model provides a more accurate and comprehensive analysis of how NIS performance influences corporate investment behavior. The Appendix contains the description of all variables used in our analysis.

Table 1 presents the distribution of key variables, highlighting the relationship between NIS performance and firms' fixed-capital investment decisions. FCAPINV has a mean of 0.41, showing notable firm-level variation. The SFIGA index (mean = 0.42, SD = 0.15) reflects cross-country differences in NISs. Other variables, such as firm size, finance access, and legal status, also vary widely, allowing the analysis to account for economic and institutional heterogeneity in shaping investment behavior. Multicollinearity risk is generally low, as indicated by a low overall VIF value (1.53) (see Electronic Supplementary Material for details).

3.4 Estimation model

Since FCAPINV is a binary variable, we use a probit model with maximum likelihood estimation (Greene, 2012). To address omitted variable bias in cross-country analysis, we include country and year fixed effects and add country-level control variables in groups to assess economic and institutional influences. Our key predictor, SFIGA, is measured at the country-level, while FCAPINV is at the firm-level. Estimating macro-level variables on micro-units may introduce statistical bias (Moulton, 1990), so we cluster standard errors at the country-level to correct for this. The empirical baseline estimation model takes the following form.

$$FCAPINV_{ijt} = a + SFIGA_{jt}\beta_1 + X2_{ijt}\beta_2 + X3_{jt}\beta_3 + \mu_{ijt} \quad (1)$$

The outcome variable $FCAPINV_{ijt}$ represents the likelihood that firm i, in country j, during year t, undertakes a capital investment. $SFIGA_{jt}$ denotes the helix-based composite index for country j and year t. $X2_{ijt}$ is a vector of firm-specific control variables, while $X3_{jt}$ represents a vector of country-level control factors. The error term μ_{ijt} comprises η_j, λ_t, and ϵ_{ijt}, where η_j captures unobservable country-specific

Table 1 Summary statistics

	Count	Mean	SD	Min	P25	P50	P75	Max
FCAPINV	119,190	0.41	0.49	0.00	0.00	0.00	1.00	1.00
SFIGA	119,190	0.42	0.15	0.09	0.32	0.40	0.48	0.99
AGE	119,190	3.19	0.53	0.69	2.89	3.18	3.47	5.86
SIZE	119,190	1.78	0.77	1.00	1.00	2.00	2.00	3.00
ACCFIN	119,190	0.40	0.49	0.00	0.00	0.00	1.00	1.00
DOWNPRV	119,190	88.61	29.70	0.00	100.00	100.00	100.00	100.00
FOWNPRV	119,190	7.31	24.18	0.00	0.00	0.00	0.00	100.00
MANAGEXP	119,190	18.69	11.35	1.00	10.00	17.00	25.00	75.00
LEGAL	119,190	0.52	0.50	0.00	0.00	1.00	1.00	1.00
EXPRT	119,190	0.07	0.26	0.00	0.00	0.00	0.00	1.00
GFCF	119,190	23.12	6.71	9.81	18.92	22.23	27.01	44.25
DCREDIT	119,190	51.26	32.25	3.93	27.10	43.91	64.53	163.33

effects, λ_t accounts for time-specific effects, and ϵ_{ijt} is a disturbance term assumed to vary across firms, countries, and years, following a normal distribution.

4 Results

Empirically, we estimate how NIS conditions are associated with the likelihood that firms undertake fixed-asset purchases in a large cross-country firm sample. Our focus is on providing an interpretable, policy-relevant diagnosis of how system conditions relate to firms' fixed-asset purchase decisions. We first establish the baseline relationship, then show that it varies across system maturity and firm capacity and finally examine patterns consistent with key channels such as technology adoption, workforce training, and ICT-oriented market exposure.

Table 2 shows a clear baseline pattern: firms located in stronger NIS environments, as captured by SFIGA, are more likely to undertake fixed-asset purchases across all model variants, with coefficients ranging from 0.383 to 2.128 ($p<0.01$) across all models. The direction and strength of the association remain stable as we add firm- and country-level covariates, suggesting that SFIGA captures system conditions that matter for firms' upgrading decisions beyond standard controls. Interpreted substantively, this pattern is consistent with the idea that more coherent systems reduce frictions around upgrading by facilitating access to complements such as finance, skills, and reliable rules. These findings align with prior research emphasizing that well-functioning NISs lower barriers to investment, especially in R&D-intensive sectors (Wang et al., 2012).

The results also indicate that firms differ in how strongly they translate supportive system conditions into investment decisions. In Model 5, larger firms benefit more from strong NIS conditions ($\beta=0.331$, $p<0.01$), consistent with greater internal capacity and easier access to finance. Likewise, firms that are globally engaged, such as exporters ($\beta=0.053$, $p<0.05$) and those with foreign ownership ($\beta=0.002$, $p<0.01$) show a higher likelihood of undertaking fixed-asset purchases, consistent with broader market opportunities and global integration. Governance and managerial capacity are also associated with a higher likelihood of fixed-asset purchases: joint-stock firms ($\beta=0.073$, $p<0.01$) and firms led by more experienced managers ($\beta=0.003$, $p<0.01$) appear better equipped to leverage NIS opportunities. Access to credit further amplifies the likelihood of fixed-asset purchases ($\beta=0.388$, $p<0.01$), that financial constraints remain a key margin even in supportive environments. Interestingly, younger firms display a higher likelihood of undertaking fixed-asset purchases ($\beta=-0.083$, $p<0.01$), consistent with a more active upgrading posture, although this pattern should be interpreted as heterogeneity in investment decisions rather than as a causal lifecycle effect.

Country-level conditions matter as well. A stronger aggregate investment environment, proxied by gross fixed-capital formation (GFCF), is associated with a higher likelihood of firm fixed-asset purchases ($\beta=0.016$, $p<0.05$). Conversely, domestic credit to the private sector (DCREDIT) shows a weak negative

Table 2 Baseline effects

	(1)	(2)	(3)	(4)	(5)
SFIGA	0.383***	1.245***	2.117***	1.269***	2.128***
	(0.034)	(0.418)	(0.794)	(0.417)	(0.789)
AGE	0.016**	−0.065***	−0.082***	−0.060***	−0.083***
	(0.008)	(0.023)	(0.012)	(0.022)	(0.012)
SIZE	0.248***	0.271***	0.341***	0.269***	0.331***
	(0.005)	(0.019)	(0.013)	(0.018)	(0.013)
ACCFIN	0.512***	0.457***	0.388***	0.459***	0.388***
	(0.008)	(0.024)	(0.017)	(0.024)	(0.017)
DOWNPRV	−0.001**	−0.000	0.001	−0.000	0.001
	(0.000)	(0.001)	(0.000)	(0.001)	(0.000)
FOWNPRV	0.003***	0.002***	0.002***	0.002***	0.002***
	(0.000)	(0.001)	(0.000)	(0.001)	(0.000)
MANAGEXP	0.005***	0.005***	0.004***	0.005***	0.003***
	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)
LEGAL	0.259***	0.181***	0.079***	0.179***	0.073***
	(0.008)	(0.043)	(0.020)	(0.042)	(0.019)
EXPRT	0.098***	0.124***	0.070***	0.126***	0.053**
	(0.015)	(0.034)	(0.026)	(0.033)	(0.024)
GFCF	0.012***	0.010*	0.016**	0.009	0.016**
	(0.001)	(0.006)	(0.007)	(0.006)	(0.007)
DCREDIT	−0.001***	−0.002	−0.004*	−0.002	−0.004*
	(0.000)	(0.002)	(0.002)	(0.002)	(0.002)
pseudo R^2	0.082	0.100	0.142	0.103	0.145
Chi2	12,388.230	1,999.808		2,317.907	
Sector FE	No	No	No	Yes	Yes
Year FE	No	Yes	Yes	Yes	Yes
Country FE	No	No	Yes	No	Yes
N	119,190	119,190	119,190	119,190	119,190

The table reports the baseline results using a probit model with distinct types of fixed effects. The parentheses report country-clustered standard errors. The outcome variable is whether the firm has incurred fixed capital investment (FCAPINV). The key independent variable is the helix-based national innovation index (SFIGA). Control variables include firm-specific and country-level characteristics. The pool sample period is 2008–2020. Definition of variables is provided in the Appendix

$^*p<0.1$, $^{**}p<0.05$, $^{***}p<0.01$

effect ($\beta = -0.004$, $p<0.10$), which may reflect cross-country differences in credit allocation and efficiency. Overall, these patterns suggest that system-level innovation conditions and broader macro-financial environments jointly shape firms' fixed-asset purchase decisions.[3]

We also group countries into system maturity archetypes to make heterogeneity interpretable, because similar aggregate innovation standings can reflect different helix bottlenecks and therefore different investment responses. Countries are classified by the SFIGA distribution, with the top decile coded mature and the bottom decile coded fragmented. Results show a clear pattern across system types. In fragmented NISs, the SFIGA coefficient is negative and statistically significant, consistent with missing complementary assets and weak coherence. In intermediate and mature systems, effects are positive and salient, consistent with complementarities among finance, skills, research linkages, government and industry (Electronic Supplementary Material, Appendix Table A7). In a "horse-race" model that includes all five helices simultaneously, dominance analysis shows that government and industry are the most influential for firms' fixed-asset investment, with finance and society smaller and academia modest (Electronic Supplementary Material, Appendix Table A9).

3 We further confirmed this relationship through multiple robustness checks and dominance analysis. Additionally, we identified differential effects across firm sizes and industry sectors. Full details are provided in the Electronic Supplementary Material.

5 Endogeneity

The observed relationship between the SFIGA index and firm-level fixed-capital investment (FCAPINV) may reflect endogeneity rather than a purely causal effect. First, causality could run in the opposite direction: firms that invest more often in fixed-assets may contribute to stronger NISs, making the direction of influence unclear. Second, omitted variable bias may arise from unobserved factors, such as macroeconomic conditions, government policy changes, or broader societal attitudes toward innovation that affect both NIS performance and firms' investment decisions. Third, measurement error in SFIGA, if it does not fully capture the multidimensional nature of innovation systems, may distort the estimated association. These concerns motivate robustness and identification strategies to assess whether the pattern is consistent with a causal interpretation (Wooldridge, 2010). A related concern is that composite indices may partly reflect inputs plausibly correlated with investment by construction, so we interpret SFIGA diagnostically and emphasize the helix decomposition and channel-consistent evidence (Sect. 4) alongside the identification checks below, rather than treating the index coefficient as a structural parameter.

To address these challenges, we employ a combination of instrumental variable (IV) methods, coefficient stability testing, and propensity score matching (PSM). First, we use the logarithm of historical patent applications (LOGPATENTS), including both resident and non-resident filings, as an external instrument for SFIGA. The variable is correlated with SFIGA ($r = 0.16$), consistent with the view that patenting reflects innovation output and the strength of innovation systems (Antonelli et al., 2022; Bottazzi & Peri, 2007). Compared to R&D expenditure, which captures inputs, patents represent realized innovation outcomes and offer broader sectoral coverage (Hottenrott et al., 2016). Moreover, the low correlation between LOGPATENTS and FCAPINV ($r = -0.09$) is consistent with the exclusion restriction that the instrument should not directly affect firms' propensity to invest (Spescha & Woerter, 2021).

Table 3 presents the IV results. Using the Two-Stage Least Squares (2SLS) approach, the first-stage regression shows that LOGPATENTS significantly predicts SFIGA ($\beta = 0.0369$, $p < 0.01$), and the Kleibergen-Paap F-statistic (13.294) supports instrument strength. In the second stage, the estimated effect of SFIGA on FCAPINV remains positive and statistically significant ($\beta = 1.460$, $p < 0.10$). Using a Conditional Mixed Process (CMP) specification (Roodman, 2011), the SFIGA coefficient is again positive and significant ($\beta = 0.399$, $p < 0.01$), consistent with the baseline pattern.

To assess coefficient stability and the potential role of omitted variables, we apply Oster's (2019) test. The adjusted beta for SFIGA is 0.224 ($p < 0.05$), with $\delta = 0.239$, indicating that unobserved selection would need to be substantial to eliminate the estimated relationship.

Additionally, to address selection concerns, we implement propensity score matching (PSM) using nearest-neighbor matching (Rosenbaum & Rubin, 1983). Countries above the global median in SFIGA form the treatment group, while those below form the control group. Post-matching results show a statistically significant treatment effect ($\beta = 0.028$, $p < 0.01$) and a reduction in mean covariate bias to 6.76%, below the 10% threshold.

Together, these complementary approaches—IV estimation, Oster's test, and PSM—indicate that the positive relationship between NIS performance and firms' propensity to invest in fixed-assets is not easily explained by reverse causality or omitted factors. While no single method is definitive, the results point in the same direction across approaches.

We next ask through which firm capabilities this system-level association is most likely to translate into realized investment decisions.

6 Channels of influence

Understanding the mechanisms through which SFIGA is associated with firms' fixed-asset purchase decisions is important for translating NIS performance into actionable insights. We examine three complementary channels through which the SFIGA–investment association is stronger: technological adoption, ICT exports, and workforce training. Results are provided in Table 4.

First, technological adoption (TECHADOPT) can accelerate diffusion by helping firms integrate advanced technologies and improve productivity in ways that align with national innovation goals (Valdez-Juárez & Castillo-Vergara, 2021).

Table 3 Endogeneity analysis

	(1)	(2)	(3)	(4)
SFIGA	1.460*	0.399***	0.745***	
	(0.825)	(0.111)	(0.261)	
AGE	−0.027***	−0.028***	−0.027***	
	(0.004)	(0.003)	(0.004)	
SIZE	0.116***	0.116***	0.116***	
	(0.007)	(0.002)	(0.006)	
ACCFIN	0.136***	0.138***	0.138***	
	(0.006)	(0.003)	(0.006)	
DOWNPRV	0.000	0.000***	0.000	
	(0.000)	(0.000)	(0.000)	
FOWNPRV	0.001***	0.001***	0.001***	
	(0.000)	(0.000)	(0.000)	
MANAGEXP	0.001***	0.001***	0.001***	
	(0.000)	(0.000)	(0.000)	
LEGAL	0.022***	0.026***	0.026***	
	(0.007)	(0.004)	(0.007)	
EXPRT	0.026***	0.024***	0.024***	
	(0.009)	(0.005)	(0.009)	
GFCF	0.008**	0.007***	0.007***	
	(0.004)	(0.001)	(0.002)	
DCREDIT	−0.003**	−0.002***	−0.002**	
	(0.001)	(0.000)	(0.001)	
TREATED				0.028***
				(0.003)
First-stage (SFIGA)				
LOGPATENTS	0.0369***	0.011***		
	(0.0101)	(0.000)		
Kleibergen-Paap F stat	13.294			
Second stage				
F-stat	238.409			118.570
Kleibergen-Paap LM stat (pv)	6.334 (0.012)			
Wald Chi^2		25,673.880		
Atanhrho		0.139 (0.033)		
Delta			0.239	
Beta			0.224**	
Mean bias (%)				6.755
Dummies	Yes	Yes	Yes	Yes
N	111,767	122,574	119,190	148,229

The table reports the results of the endogeneity analysis. The outcome variable is FCAPINV. The key independent variable is SFIGA. Additional control variables include firm-specific and macroeconomic characteristics. The pool sample period is 2008–2020. Model (1) uses an IV model with the 2SLS estimator. Model (2) uses an IV model with the CMP estimator. The external IV instrument used is the annual logarithmic value of patent applications (residents as well as nonresidents) in a country (LOGPATENTS). Model (3) presents the results of the Oster test of coefficient stability. Model (4) presents the results of propensity score matching (treatment variable only)

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

In Model 1, the SFIGA index shows a significant effect ($\beta=1.528$, $p<0.05$), while the interaction term SFIGA * TECHADOPT is also significant ($\beta=0.430$, $p<0.01$), indicating that technology-adopting firms display a stronger SFIGA–investment association (Qalati et al., 2021).

Second, export-oriented ICT sectors (ICTEXP) can connect firms to global markets and enhance competitiveness (Niebel, 2018). Consistent with this view, Model 2 reports a strong positive SFIGA association ($\beta=2.395$, $p<0.01$) and a positive interaction SFIGA * ICTEXP ($\beta=0.040$, $p<0.05$), suggesting that ICT-exporting firms translate supportive system

Table 4 Economic channels

	(1)	(2)	(3)
SFIGA	1.528**	2.395***	1.980**
	(0.753)	(0.774)	(0.875)
SFIGA*TECHADOPT	0.430***		
	(0.034)		
SFIGA*ICTEXP		0.040**	
		(0.020)	
SFIGA*TRAINING			0.763***
			(0.072)
pseudo R^2	0.162	0.144	0.151
Controls	Yes	Yes	Yes
Country FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
Dummies	Yes	Yes	Yes
N	119,190	117,666	112,394

The table presents the impact of economic and non-economic factors through which the NIS influences corporate fixed capital investment. The dataset spans from 2008 to 2020, and a probit model with fixed effects is used for estimation. Standard errors, clustered by country, are reported in parentheses. Model (1) examines the mediating effect of technological adoption by firms (TECHADOPT), Model (2) analyzes the mediating effect of a country's ICT goods exports as a percentage of total goods exports (ICTEXP), and Model (3) explores the mediating effect of firms providing training to full-time permanent workers (TRAINING)

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

conditions into fixed-asset purchase decisions more strongly than otherwise similar firms.

Third, workforce training (TRAINING) equips employees with the skills to adopt and manage new technologies (Nicolas, 2022; Radosevic & Yoruk, 2018). The institutional architecture of VET can condition this channel by shaping skill formation, employer coordination and governance arrangements (Carstensen & Ibsen, 2021), thereby linking NIS design to investment behavior. Vocational education institutions also function as core actors within regional innovation systems through co-designed curricula with firms, equipment upgrading, and the production of synthetic knowledge and technician skills that enable implementation of new manufacturing technologies (Lund & Karlsen, 2020). In Model 3, SFIGA remains positively associated ($\beta = 1.980$, $p < 0.05$), and the interaction SFIGA * TRAINING is the largest and highly significant ($\beta = 0.763$, $p < 0.01$), consistent with training reducing implementation frictions and increasing the likelihood that firms undertake fixed-asset purchases when system complements are supportive.

These findings indicate that SFIGA is not only associated with firms' fixed-asset purchase decisions in the aggregate but that the association is systematically stronger where firm-level enablers are present, namely technology adoption, ICT-oriented market exposure, and workforce training, which helps inform targeted policy support.

7 Conclusions

7.1 Summary of main findings

We investigated how NISs influence firms' decisions to purchase fixed assets across 93 countries during 2008–2020. By developing a helix-based index (SFIGA), we found a robust positive association between stronger NIS performance and the likelihood that firms undertake fixed-asset purchases.

Additional analyses reported in the Electronic Supplementary Material reveal that this relationship is not uniform, reinforcing a central insight in the NIS literature: NISs are heterogeneous and "one size does not fit all". In more coherent and mature systems, stronger NIS performance is more consistently associated with a higher likelihood of fixed-asset purchases. In more fragmented systems, the association is weaker—and can even become negative—consistent with missing complements and coordination failures that make it harder for firms to translate opportunities into realized upgrading decisions.

We also observed heterogeneity across firms. Larger firms more readily convert favorable system conditions into fixed-asset purchase decisions, while smaller firms face tighter constraints. Finally, the overall pattern is consistent with amplification through technology adoption, workforce training, and ICT-oriented export activity, and the helix decomposition points especially to government- and industry-related components as particularly important for firms' investment propensity.

7.2 Theoretical and practical implications

From a theoretical standpoint, this study extends NIS theory by conceptualizing fixed-capital investment as the behavioral channel through which system coordination translates into tangible production upgrading. This perspective treats NISs as coordination architectures that structure firms' capacity to commit to irreversible investment under uncertainty, rather than focusing only on innovation outputs. NIS quality therefore matters not only for invention and R&D but also for the complements that make investment feasible and attractive, including finance, skills, and diffusion channels. Our actor-centered indicator (SFIGA), grounded in the N-tuple helices framework, helps interpret these relationships by linking outcomes to identifiable subsystems and by reducing the risk of "measurement without theory". It also highlights that similar aggregate innovation standings may conceal different binding constraints. Consistent with the helix decomposition, the most policy-relevant levers cluster around government and industry subsystems, which appear comparatively more salient for firms' investment propensity, while finance and skills shape whether SMEs can act on these opportunities.

Practically, this implies targeting the constraints that most often bind for SMEs. Where finance is limiting, improving credit information, collateral frameworks, guarantees, and equipment leasing can reduce financing frictions. Where implementation capacity is limiting, vocational training linked to new equipment, short-cycle digital upskilling, and extension-type support can help firms adopt and use new technologies effectively. Where diffusion and market access are weak, standards and certification support, export-readiness services, and cluster or supplier-development programs can lower adoption costs and strengthen learning through links with universities, technology providers, and lead firms. Such targeted measures matter beyond firm performance because capital upgrading supports technology diffusion, productivity growth, and digital and cleaner production improvements, with implications for job quality and long-run competitiveness.

7.3 Limitations and future research directions

This study has limitations. First, we analyzed the decision to invest, not the size of the investment, so future work should examine investment volumes where data allow. Second, SFIGA is conceived as a transparent diagnostic summary rather than a structural parameter. This is especially relevant given that some components rely on perception-based measures and that indicator inclusion is constrained by global data coverage. SFIGA also implicitly assumes a "laissez-faire" configuration where the helices function independently, which may oversimplify interdependencies and feedback across actors. Future research could test sensitivity to alternative weighting, aggregation, and validation approaches (e.g., principal component analysis, expert-based Delphi weighting across helices) and assess robustness to different indicator sets or aggregation rules that penalize weak components more strongly. This index-construction challenge is also central in the broader measurement debate on entrepreneurial ecosystems, where recent work emphasizes that composite indicators can be useful diagnostically but require caution because aggregation choices may embed substitutability assumptions and conceal vulnerabilities (Hess et al., 2025). Related evidence further suggests that ecosystem elements differ in their relative importance, implying that composite scores may hide which components are most consequential for firm outcomes (Queissner et al., 2025). Third, cross-country observational evidence raises identification concerns, including reverse causality and selection. For instance, stronger NISs may both encourage investment and support firm survival, which could influence patterns by firm age. Finally, survey coverage and the omission of informal institutions and networks may limit generalization, motivating richer longitudinal data and designs that exploit policy shocks to sharpen causal interpretation and deepen understanding of system-level mechanisms.

Appendix

Definition of variables

Variable	Description	Source
FCAPINV	A binary variable that takes the value of 1 if the firm purchased fixed assets, and 0 otherwise. It reflects the firm's decision to invest in fixed capital	WBES
SFIGA	The helix-based indicator captures the overall performance of a NIS. It takes values from 0 (worst) to 1 (best)	Composite indicator based on data from WEF, WDI, SCIMAGO, WGI, Global Economy
AGE	The logarithm of the number of years since the firm's initial establishment	WBES
SIZE	Ordinal variable that takes the value of 1 if the firm is small (5–19 employees), 2 if it is medium (20–99 employees) and 3 if it is large (over 99 employees)	WBES
ACCFIN	A binary variable that takes the value of 1 if the firm has a loan/credit line from a bank, and 0 otherwise	WBES
DOWNPRV	The percentage of the firm's ownership by domestic private individuals, firms, or organizations	WBES
FOWNPRV	The percentage of the firm's ownership by foreign private individuals, firms, or organizations	WBES
MANAGEXP	The number of years of experience of being the top manager	WBES
LEGAL	A binary variable that takes the value of 1 if the firm is joint stock company, and 0 otherwise	WBES
EXPRT	Percent of a firm's total sales that are directly exported	WBES
GFCF	Gross fixed capital formation (% of GDP)	WDI
DCREDIT	Domestic credit to private sector (% of GDP)	WDI
LOGPATENTS	The logarithm of the number of patent applications (residents as well as nonresidents)	WDI
TECHADOPT	A composite indicator capturing firm-level technology adoption based on whether the firm has: (a) a quality certification (ISO); (b) its own website; (c) high-speed internet; (d) introduced new products/services (last 3 years); (e) introduced new processes (last 3 years); and (f) spent on R&D (excluding market research)	WBES
TRAINING	A binary variable that takes the value of 1 if the firm has provided training to its permanent FT workers	WBES
ICTEXP	ICT goods exports (% of total goods exports)	WDI

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Data availability The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval The present paper did not require any interaction or experimentation that demands ethical compliance.

Conflict of interest The authors declare no competing interests.

References

Acs, Z. J., Audretsch, D. B., Lehmann, E. E., & Licht, G. (2017). National systems of innovation. *Journal of Technology Transfer, 42*, 997–1008. https://doi.org/10.1007/s10961-016-9481-8

Acs, Z. J., Autio, E., & Szerb, L. (2014). National systems of entrepreneurship: Measurement issues and policy implications. *Research Policy, 43*(3), 476–494. https://doi.org/10.1016/j.respol.2013.08.016

Adelino, M., Ma, S., & Robinson, D. (2017). Firm age, investment opportunities, and job creation. *Journal of Finance, 72*(3), 999–1038. https://doi.org/10.1111/jofi.12495

Aiginger, K., & Rodrik, D. (2020). Rebirth of industrial policy and an agenda for the twenty-first century. *Journal of Industry, Competition and Trade, 20*, 189–207. https://doi.org/10.1007/s10842-019-00322-3

Allard, G., Martinez, C. A., & Williams, C. (2012). Political instability, pro-business market reforms and their impacts on national systems of innovation. *Research Policy, 41*(3), 638–651. https://doi.org/10.1016/j.respol.2011.12.005

Álvarez, I. C., Barbero, J., Rodríguez-Pose, A., & Zofío, J. L. (2018). Does institutional quality matter for trade? Institutional conditions in a sectoral trade framework. *World Development, 103*, 72–87. https://doi.org/10.1016/j.worlddev.2017.10.010

Andreoni, A., & Tregenna, F. (2020). Escaping the middle-income technology trap: A comparative analysis of industrial policies in China, Brazil and South Africa. *Structural Change and Economic Dynamics, 54*, 324–340. https://doi.org/10.1016/j.strueco.2020.05.008

Antonelli, C., Crespi, F., & Quatraro, F. (2022). Knowledge complexity and the mechanisms of knowledge generation and exploitation: The European evidence. *Research Policy, 51*(8), Article 104081. https://doi.org/10.1016/j.respol.2020.104081

Berger, A. N., Molyneux, P., & Wilson, J. O. (2020). Banks and the real economy: An assessment of the research. *Journal of Corporate Finance, 62*, 101513. https://doi.org/10.1016/j.jcorpfin.2019.101513

Bernard, A. B., Jensen, J. B., Redding, S. J., & Schott, P. K. (2007). Firms in international trade. *Journal of Economic Perspectives, 21*(3), 105–130. https://doi.org/10.1257/jep.21.3.105

Bertrand, J., Klein, P. O., & Pasiouras, F. (2024). National culture of secrecy and firms' access to credit. *Journal of Banking & Finance, 168*, Article 107277. https://doi.org/10.1016/j.jbankfin.2024.107277

Bottazzi, L., & Peri, G. (2007). The international dynamics of R&D and innovation in the long run and in the short run. *The Economic Journal, 117*(518), 486–511. https://doi.org/10.1111/j.1468-0297.2007.02027.x

Bozeman, B., Rimes, H., & Youtie, J. (2015). The evolving state-of-the-art in technology transfer research: Revisiting the contingent effectiveness model. *Research Policy, 44*(1), 34–49. https://doi.org/10.1016/j.respol.2014.06.008

Cai, Y., & Etzkowitz, H. (2020). Theorizing the triple helix model: Past, present, and future. *Triple Helix, 7*(2–3), 189–226. https://doi.org/10.1163/21971927-bja10003

Carayannis, E. G., Barth, T. D., & Campbell, D. F. (2012). The Quintuple Helix innovation model: Global warming as a challenge and driver for innovation. *Journal of Innovation and Entrepreneurship, 1*(1), Article 2. https://doi.org/10.1186/2192-5372-1-2

Carayannis, E. G., Goletsis, Y., & Grigoroudis, E. (2018). Composite innovation metrics: MCDA and the Quadruple Innovation Helix framework. *Technological Forecasting and Social Change, 131*, 4–17. https://doi.org/10.1016/j.techfore.2017.03.008

Carstensen, M. B., & Ibsen, C. L. (2021). Three dimensions of institutional contention: Efficiency, equality and governance in Danish vocational education and training reform. *Socio-Economic Review, 19*(3), 1037–1063. https://doi.org/10.1093/ser/mwz012

Casadella, V., & Tahi, S. (2025). Inclusive national innovation systems: Rethinking institutions in the light of inclusion imperatives. *Journal of Institutional Economics, 21*, Article e2. https://doi.org/10.1017/S1744137425000025

Cenni, S., Monferrà, S., Salotti, V., Sangiorgi, M., & Torluccio, G. (2015). Credit rationing and relationship lending. Does firm size matter? *Journal of Banking & Finance, 53*, 249–265. https://doi.org/10.1016/j.jbankfin.2014.12.010

Chaminade, C., Lundvall, B. Å., & Haneef, S. (2018). *Advanced introduction to national innovation systems*. Edward Elgar Publishing.

Chowdhury, J., Kumar, R., & Shome, D. (2016). Investment–cash flow sensitivity under changing information asymmetry. *Journal of Banking & Finance, 62*, 28–40. https://doi.org/10.1016/j.jbankfin.2015.07.003

Chundakkadan, R., & Sasidharan, S. (2020). Financial constraints, government support, and firm innovation: Empirical evidence from developing economies. *Innovation and Development, 10*(3), 279–301. https://doi.org/10.1080/2157930X.2019.1594680

Cirillo, V., Martinelli, A., Nuvolari, A., & Tranchero, M. (2019). Only one way to skin a cat? Heterogeneity and equifinality in European national innovation systems. *Research Policy, 48*(4), 905–922. https://doi.org/10.1016/j.respol.2018.10.012

Coad, A., Segarra, A., & Teruel, M. (2016). Innovation and firm growth: Does firm age play a role? *Research Policy,*

45(2), 387–400. https://doi.org/10.1016/j.respol.2015.10.015
Cohen, W. M., & Levinthal, D. A. (1990). Absorptive capacity: A new perspective on learning and innovation. *Administrative Science Quarterly, 35*(1), 128–152. https://doi.org/10.2307/2393553
Crotti, R., Potter, J., Shah, P., & Stam, E. (2025). Data and methods for entrepreneurial ecosystem diagnostics. OECD SME and Entrepreneurship Papers, No. 69, OECD Publishing, Paris. https://doi.org/10.1787/5173f4a2-en
Czarnitzki, D., & Hottenrott, H. (2011). R&D investment and financing constraints of small and medium-sized firms. *Small Business Economics, 36*, 65–83. https://doi.org/10.1007/s11187-009-9189-3
Dahiya, S., & Ray, K. (2012). Staged investments in entrepreneurial financing. *Journal of Corporate Finance, 18*(5), 1193–1216. https://doi.org/10.1016/j.jcorpfin.2012.07.002
Degryse, H., De Goeij, P., & Kappert, P. (2012). The impact of firm and industry characteristics on small firms' capital structure. *Small Business Economics, 38*, 431–447. https://doi.org/10.1007/s11187-010-9281-8
Ding, S., Guariglia, A., & Knight, J. (2013). Investment and financing constraints in China: Does working capital management make a difference? *Journal of Banking & Finance, 37*(5), 1490–1507. https://doi.org/10.1016/j.jbankfin.2012.03.025
Drobetz, W., El Ghoul, S., Guedhami, O., & Janzen, M. (2018). Policy uncertainty, investment, and the cost of capital. *Journal of Financial Stability, 39*, 28–45. https://doi.org/10.1016/j.jfs.2018.08.005
Elia, S., & Santangelo, G. D. (2017). The evolution of strategic asset-seeking acquisitions by emerging market multinationals. *International Business Review, 26*(5), 855–866. https://doi.org/10.1016/j.ibusrev.2017.02.004
Erzurumlu, S. S., Erzurumlu, Y. O., & Yoon, Y. (2022). National innovation systems and dynamic impact of institutional structures on national innovation capability: A configurational approach with the OKID method. *Technovation, 114*, Article 102552. https://doi.org/10.1016/j.technovation.2022.102552
Etzkowitz, H., & Leydesdorff, L. (2000). The dynamics of innovation: From National Systems and "Mode 2" to a Triple Helix of university–industry–government relations. *Research Policy, 29*(2), 109–123. https://doi.org/10.1016/S0048-7333(99)00055-4
Fan, Z., & Liu, Y. (2020). Tax compliance and investment incentives: Firm responses to accelerated depreciation in China. *Journal of Economic Behavior & Organization, 176*, 1–17. https://doi.org/10.1016/j.jebo.2020.04.024
Farooq, U., Ahmed, J., & Khan, S. (2021). Do the macroeconomic factors influence the firm's investment decisions? A generalized method of moments (GMM) approach. *International Journal of Finance & Economics, 26*(1), 790–801. https://doi.org/10.1002/ijfe.1820
Feng, S., Zhang, R., & Li, G. (2022). Environmental decentralization, digital finance and green technology innovation. *Structural Change and Economic Dynamics, 61*, 70–83. https://doi.org/10.1016/j.strueco.2022.02.008
Filippetti, A., & Archibugi, D. (2011). Innovation in times of crisis: National Systems of Innovation, structure, and demand. *Research Policy, 40*(2), 179–192. https://doi.org/10.1016/j.respol.2010.09.001
Fonseka, M., Samarakoon, L. P., Tian, G. L., & Seng, R. (2021). The impact of social trust and state ownership on investment efficiency of Chinese firms. *Journal of International Financial Markets, Institutions and Money, 74*, Article 101394. https://doi.org/10.1016/j.intfin.2021.101394
Freeman, C. (1987). *Technology and economic performance: Lessons from Japan*. Pinter.
Galán-Muros, V., & Plewa, C. (2016). What drives and inhibits university-business cooperation in Europe? A comprehensive assessement. *R & D ManagemeNt, 46*(2), 369–382. https://doi.org/10.1111/radm.12180
Goodman, T. H., Neamtiu, M., Shroff, N., & White, H. D. (2014). Management forecast quality and capital investment decisions. *The Accounting Review, 89*(1), 331–365. https://doi.org/10.2308/accr-50575
Greene, W. H. (2012). *Econometric Analysis* (7th ed.). Pearson.
Guan, J., & Yam, R. C. (2015). Effects of government financial incentives on firms' innovation performance in China: Evidences from Beijing in the 1990s. *Research Policy, 44*(1), 273–282. https://doi.org/10.1016/j.respol.2014.09.001
He, X., Xu, R., Sun, K., & Wang, J. (2024). Population intensity, location choice, and investment portfolio selection: A case of emerging economies. *International Review of Financial Analysis, 94*, Article 103271. https://doi.org/10.1016/j.irfa.2024.103271
Herrendorf, B., Rogerson, R., & Valentinyi, A. (2014). *Growth and structural transformation*. Handbook of Economic Growth, Elsevier.
Hess, S., Wahl, A., & Johnson, A. R. (2025). Measuring entrepreneurial ecosystems across levels: A district approach. *Small Business Economics, 65*, 1617–1649. https://doi.org/10.1007/s11187-025-01041-2
Hottenrott, H., Hall, B. H., & Czarnitzki, D. (2016). Patents as quality signals? The implications for financing constraints on R&d. *Economics of Innovation and New Technology, 25*(3), 197–217. https://doi.org/10.1080/10438599.2015.1076200
Huggins, R., & Johnston, A. (2010). Knowledge flow and inter-firm networks: The influence of network resources, spatial proximity and firm size. *Entrepreneurship & Regional Development, 22*(5), 457–484. https://doi.org/10.1080/08985620903171350
Islam, A., Muzi, S., & Rodriguez Meza, J. L. (2018). Does mobile money use increase firms' investment? Evidence from Enterprise Surveys in Kenya, Uganda, and Tanzania. *Small Business Economics, 51*, 687–708. https://doi.org/10.1007/s11187-017-9951-x
Kahle, K. M., & Stulz, R. M. (2013). Access to capital, investment, and the financial crisis. *Journal of Financial*

Economics, 110(2), 280–299. https://doi.org/10.1016/j.jfineco.2013.02.014

Kapetaniou, C., Samdanis, M., & Lee, S. H. (2018). Innovation policies of Cyprus during the global economic crisis: Aligning financial institutions with National Innovation System. *Technological Forecasting and Social Change, 133*, 29–40. https://doi.org/10.1016/j.techfore.2018.02.019

Kashani, E. S., & Roshani, S. (2019). Evolution of innovation system literature: Intellectual bases and emerging trends. *Technological Forecasting and Social Change, 146*, 68–80. https://doi.org/10.1016/j.techfore.2019.05.010

Kergroach, S. (2019). National innovation policies for technology upgrading through GVCs: A cross-country comparison. *Technological Forecasting and Social Change, 145*, 258–272. https://doi.org/10.1016/j.techfore.2018.04.033

Kong, X., Xu, J., & Zhang, Y. (2022). Industry competition and firm productivity: Evidence from the antitrust policy in China. *Finance Research Letters, 47*, Article 103001. https://doi.org/10.1016/j.frl.2022.103001

Krammer, S. M., Strange, R., & Lashitew, A. (2018). The export performance of emerging economy firms: The influence of firm capabilities and institutional environments. *International Business Review, 27*(1), 218–230. https://doi.org/10.1016/j.ibusrev.2017.07.003

Lakitan, B. (2013). Connecting all the dots: Identifying the "actor level" challenges in establishing effective innovation system in Indonesia. *Technology in Society, 35*(1), 41–54. https://doi.org/10.1016/j.techsoc.2013.03.002

Lam, A., & Lundvall, B. -Å. (2006). The learning organization and national systems of competence building and innovation. In E. Lorenz & B. -Å. Lundvall (Eds.), *How Europe's economies learn: Coordinating competing models* (pp. 109–139). Oxford University Press.

Lee, C. C., Qin, S., & Li, Y. (2022). Does industrial robot application promote green technology innovation in the manufacturing industry? *Technological Forecasting and Social Change, 183*, Article 121893. https://doi.org/10.1016/j.techfore.2022.121893

Lee, K. (2019). *The art of economic catch-up: Barriers, detours and leapfrogging in innovation systems*. Cambridge University Press.

Lee, K., Lee, J., & Lee, J. (2021). Variety of national innovation systems (NIS) and alternative pathways to growth beyond the middle-income stage: Balanced, imbalanced, catching-up, and trapped NIS. *World Development, 144*, Article 105472. https://doi.org/10.1016/j.worlddev.2021.105472

Leydesdorff, L., & Smith, H. L. (2022). Triple, quadruple, and higher-order helices: Historical phenomena and (neo-) evolutionary models. *Triple Helix, 9*(1), 6–31. https://doi.org/10.1163/21971927-bja10022

Lund, H. B., & Karlsen, A. (2020). The importance of vocational education institutions in manufacturing regions: Adding content to a broad definition of regional innovation systems. *Industry and Innovation, 27*(6), 660–679. https://doi.org/10.1080/13662716.2019.1616534

Lundvall, B. Å. (1992). *National systems of innovation: Towards a theory of innovation and interactive learning*. Pinter Publishers.

Malerba, F., & McKelvey, M. (2020). Knowledge-intensive innovative entrepreneurship integrating Schumpeter, evolutionary economics, and innovation systems. *Small Business Economics, 54*(2), 503–522. https://doi.org/10.1007/s11187-018-0060-2

Maruccia, Y., Solazzo, G., Del Vecchio, P., & Passiante, G. (2020). Evidence from network analysis application to innovation systems and quintuple helix. *Technological Forecasting and Social Change, 161*, Article 120306. https://doi.org/10.1016/j.techfore.2020.120306

McKelvey, M. (2016). Firms navigating through innovation spaces: A conceptualization of how firms search and perceive technological, market and productive opportunities globally. *Journal of Evolutionary Economics, 26*(4), 785–802. https://doi.org/10.1007/s00191-016-0478-0

Mertzanis, C. (2017). Ownership structure and access to finance in developing countries. *Applied Economics, 49*(32), 3195–3213. https://doi.org/10.1080/00036846.2016.1257106

Mertzanis, C., & Houcine, A. (2024). The impact of the knowledge economy on the financing constraints of firms: Within and between country effects. *International Journal of Managerial Finance, 20*(5), 1170–1199. https://doi.org/10.1108/IJMF-09-2023-0436

Moulton, B. R. (1990). An illustration of a pitfall in estimating the effects of aggregate variables on micro units. *Review of Economics and Statistics*. https://doi.org/10.2307/2109724

Nardo, M., Saisana, M., Saltelli, A., & Tarantola, S. (2005). *Tools for composite indicators building*. Joint Research Centre.

Narula, R., & Dunning, J. H. (2000). Industrial development, globalization and multinational enterprises: New realities for developing countries. *Oxford Development Studies, 28*(2), 141–167. https://doi.org/10.1080/713688313

Nemlioglu, I., & Mallick, S. (2021). Effective innovation via better management of firms: The role of leverage in times of crisis. *Research Policy, 50*(7), Article 104259. https://doi.org/10.1016/j.respol.2021.104259

Nicolas, T. (2022). Short-term financial constraints and SMEs' investment decision: Evidence from the working capital channel. *Small Business Economics, 58*(4), 1885–1914. https://doi.org/10.1007/s11187-021-00488-3

Niebel, T. (2018). ICT and economic growth–Comparing developing, emerging and developed countries. *World Development, 104*, 197–211. https://doi.org/10.1016/j.worlddev.2017.11.024

Nunnally, J. C. (1978). *Psychometric theory*. McGraw-Hill.

Oster, E. (2019). Unobservable selection and coefficient stability: Theory and evidence. *Journal of Business & Economic Statistics, 37*(2), 187–204. https://doi.org/10.1080/07350015.2016.1227711

Panagiotidis, T., & Printzis, P. (2021). Investment and uncertainty: Are large firms different from small ones? *Journal* *of Economic Behavior & Organization, 184*, 302–317. https://doi.org/10.1016/j.jebo.2021.01.011

Patel, P., & Pavitt, K. (1994). National innovation systems: Why they are important, and how they might be measured and compared. *Economics of Innovation and New Technology, 3*(1), 77–95. https://doi.org/10.1080/10438599400000004

Pavitt, K. (1984). Sectoral patterns of technical change: Towards a taxonomy and a theory. *Research Policy, 13*(6), 343–373. https://doi.org/10.1016/0048-7333(84)90018-0

Perkmann, M., Tartari, V., McKelvey, M., Autio, E., Broström, A., D'este, P., & Sobrero, M. (2013). Academic engagement and commercialisation: A review of the literature on university–industry relations. *Research Policy, 42*(2), 423–442. https://doi.org/10.1016/j.respol.2012.09.007

Perugini, F. (2023). Space–time analysis of entrepreneurial ecosystems. *The Journal of Technology Transfer, 48*(1), 240–291. https://doi.org/10.1007/s10961-021-09906-w

Petraite, M., Mubarak, M. F., Rimantas, R., & Von Zedtwitz, M. (2022). The role of international networks in upgrading national innovation systems. *Technological Forecasting and Social Change, 184*, Article 121873. https://doi.org/10.1016/j.techfore.2022.121873

Prokop, V., Hajek, P., & Stejskal, J. (2021). Configuration paths to efficient national innovation ecosystems. *Technological Forecasting and Social Change, 168*, Article 120787. https://doi.org/10.1016/j.techfore.2021.120787

Qalati, S. A., Yuan, L. W., Khan, M. A. S., & Anwar, F. (2021). A mediated model on the adoption of social media and SMEs' performance in developing countries. *Technology in Society, 64*, Article 101513. https://doi.org/10.1016/j.techsoc.2020.101513

Queissner, M., Stolz, L., & Weiss, M. (2025). A meta-analysis of entrepreneurial ecosystem elements and entrepreneurial activity. *Small Business Economics, 64*(4), 1817–1847. https://doi.org/10.1007/s11187-024-00953-9

Radosevic, S. (2022). Techno-economic transformation in Eastern Europe and the former Soviet Union–A neo-Schumpeterian perspective. *Research Policy, 51*(1), Article 104397. https://doi.org/10.1016/j.respol.2021.104397

Radosevic, S., & Yoruk, E. (2018). Technology upgrading of middle income economies: A new approach and results. *Technological Forecasting and Social Change, 129*, 56–75. https://doi.org/10.1016/j.techfore.2017.12.002

Robb, A. M., & Robinson, D. T. (2014). The capital structure decisions of new firms. *Review of Financial Studies, 27*(1), 153–179. https://doi.org/10.1093/rfs/hhs072

Roodman, D. (2011). Fitting fully observed recursive mixed-process models with cmp. *The Stata Journal, 11*(2), 159–206. https://doi.org/10.1177/1536867X1101100202

Rosenbaum, P. R., & Rubin, D. B. (1983). The central role of the propensity score in observational studies for causal effects. *Biometrika, 70*(1), 41–55. https://doi.org/10.1093/biomet/70.1.41

Samara, E., Georgiadis, P., & Bakouros, I. (2012). The impact of innovation policies on the performance of national innovation systems: A system dynamics analysis. *Technovation, 32*(11), 624–638. https://doi.org/10.1016/j.technovation.2012.06.002

Sarpong, D., Boakye, D., Ofosu, G., & Botchie, D. (2023). The three pointers of research and development (R&D) for growth-boosting sustainable innovation system. *Technovation, 122*, Article 102581. https://doi.org/10.1016/j.technovation.2022.102581

Schøtt, T., & Jensen, K. W. (2016). Firms' innovation benefiting from networking and institutional support: A global analysis of national and firm effects. *Research Policy, 45*(6), 1233–1246. https://doi.org/10.1016/j.respol.2016.03.006

Spescha, A., & Woerter, M. (2021). Research and development as an initiator of fixed capital investment. *Journal of Evolutionary Economics, 31*, 117–145. https://doi.org/10.1007/s00191-020-00681-9

Steinmo, M. (2015). Collaboration for innovation: A case study on how social capital mitigates collaborative challenges in university–industry research alliances. *Industry and Innovation, 22*(7), 597–624. https://doi.org/10.1080/13662716.2015.1105127

Sun, C., Abbas, H. S. M., Xu, X., Gillani, S., Ullah, S., & Raza, M. A. A. (2023). Role of capital investment, investment risks, and globalization in economic growth. *International Journal of Finance & Economics, 28*(2), 1883–1898. https://doi.org/10.1002/ijfe.2514

Tawiah, V., Zakari, A., & Xede, J. (2023). Who benefits from corruption; The private individual or the public purse? *International Journal of Finance & Economics, 28*(3), 2900–2914. https://doi.org/10.1002/ijfe.2570

Thore, S., & Tarverdyan, R. (2016). The sustainable competitiveness of nations. *Technological Forecasting and Social Change, 106*, 108–114. https://doi.org/10.1016/j.techfore.2016.02.017

Tylecote, A. (2007). The role of finance and corporate governance in national systems of innovation. *Organization Studies, 28*(10), 1461–1481. https://doi.org/10.1177/0170840607075676

Valdez-Juárez, L. E., & Castillo-Vergara, M. (2021). Technological capabilities, open innovation, and eco-innovation: Dynamic capabilities to increase corporate performance of SMEs. *Journal of Open Innovation: Technology, Market, and Complexity, 7*(1), Article 8. https://doi.org/10.3390/joitmc7010008

Vetsikas, A. (2024). Assessing the performance of national innovation systems with a helix-based composite indicator: Evidence from 24 European countries. *Eastern European Economics, 62*(1), 18–49. https://doi.org/10.1080/00128775.2023.2167722

Vetsikas, A., & Stamboulis, Y. (2023). A conceptual framework for modeling heterogeneous actors' behavior in national innovation systems. *Journal of Evolutionary Economics, 33*(3), 773–796. https://doi.org/10.1007/s00191-023-00829-3

Wang, Y., Vanhaverbeke, W., & Roijakkers, N. (2012). Exploring the impact of open innovation on national systems of innovation—A theoretical analysis. *Technological Forecasting and Social Change, 79*(3), 419–428. https://doi.org/10.1016/j.techfore.2011.08.009

Watkins, A., Papaioannou, T., Mugwagwa, J., & Kale, D. (2015). National innovation systems and the intermediary role of industry associations in building institutional capacities for innovation in developing countries: A critical review of the literature. *Research Policy, 44*(8), 1407–1418. https://doi.org/10.1016/j.respol.2015.05.004

Wonglimpiyarat, J. (2011). The dynamics of financial innovation system. *The Journal of High Technology Management Research, 22*(1), 36–46. https://doi.org/10.1016/j.hitech.2011.03.003

Wooldridge, J. (2010). *Econometric analysis of cross-section and panel data*. MIT Press.

Yan, K., Zhang, Z., Yang, L., Cao, Y., & Shan, Y. (2024). Capital generates green: Evidence from China's national innovation system policy. *International Review of Financial Analysis, 91*, 103033. https://doi.org/10.1016/j.irfa.2023.103033

Yang, L., & Li, R. (2024). Government procurement and corporate investment efficiency: Evidence from China. *Finance Research Letters, 67*, Article 105934. https://doi.org/10.1016/j.frl.2024.105934

Zhao, X., Chen, Q. A., & Zhang, H. (2023). Firm investment and financial autonomy: A transaction cost economics and firm lifecycle approach. *Managerial and Decision Economics, 44*(5), 2540–2567. https://doi.org/10.1002/mde.3832

Zubair, S., Kabir, R., & Huang, X. (2020). Does the financial crisis change the effect of financing on investment? Evidence from private SMEs. *Journal of Business Research, 110*, 456–463. https://doi.org/10.1016/j.jbusres.2020.01.063