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Innovation systems and evolutionary economics: honoring Richard Nelson through evolutionary plasticity and insights from China

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Abstract
This article first reviews the theoretical foundations of evolutionary economics, its main critiques, and intersections with other intellectual traditions, highlighting the diffusion of this perspective into the National Innovation System (NIS) framework and Richard Nelson's seminal contributions. It then applies this evolutionary lens to analyze China's NIS from two complementary perspectives—historical and open-system—offering a more integrative understanding of its development. Drawing on extensive industrial- and firm-level evidence, the study introduces the concept of Evolutionary Plasticity of Innovation Systems, inspired by biological evolution, to explain how similar institutional architectures can generate divergent innovation trajectories across sectors, regions, and countries. This framework contributes to evolutionary economics by extending beyond the prevailing static, discrete categorical epistemology and essentially correlational analysis in nature by providing a generative lens for understanding how innovation systems evolve, persist, and co-adapt under varying conditions, building on Nelson's vision of the economy as an adaptive system. Together, the study advances the evolutionary approach by emphasizing institutional expression and adaptive reconfiguration over replacement, reaffirms the explanatory power of national-level analysis in an increasingly interconnected world, and calls for more analytically sophisticated and theoretically informed examination of innovation dynamics at this level.

Keywords: Innovation System · Evolutionary Economics · Economic Development · Richard Nelson · Globalization · State · China

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1 Introduction

Modern Evolutionary Economics took shape in the 1970 s and 1980 s as both a critique of, and a complement to, neoclassical economics, yet its intellectual roots run far deeper. In The Wealth of Nations (1776), Adam Smith—the founding father of Economics—analyzed the dynamic transformation of industrial organization through his account of pin-making, framing it within the broader, non-static trajectory of economic development in the United Kingdom (Nelson & Winter, 1985; Nelson, 2020). Smith foregrounded self-interested behaviour without presuming perfect rationality and highlighted the constitutive role of institutions in structuring economic activity and shaping development trajectories. Classical economics subsequently retained this long-term, historically embedded orientation (Nelson & Winter, 1985; Nelson, 2020). Karl Marx further advanced a dynamic and evolutionary understanding through his historical materialist framework, in which economic and social development is propelled by dialectical tensions among forces of production, relations of production, and the superstructure (Lundvall, 2007; Khachaturian, 2024).

Richard Nelson is widely recognised as a central figure in modern Evolutionary Economics. Building on his conception of the economy as an evolving system, this paper revisits and extends his intellectual legacy through the analytical lens of National Innovation Systems (NIS), drawing on new empirical evidence from and beyond China. The paper proceeds in three parts. The first synthesises the theoretical foundations of evolutionary economics, addresses major critiques, and traces its diffusion into the NIS tradition. The second applies this evolutionary perspective to China's NIS, integrating two complementary analytical approaches to generate a more comprehensive account of its developmental trajectories. Building on these theoretical insights and empirical observations, the paper proposes Evolutionary Plasticity of Innovation Systems—a system-level property inspired by biological evolution. This concept captures the meta-mechanisms through which innovation systems adapt and diverge across contexts despite sharing similar institutional "genotypes." It moves beyond static, discrete categorical epistemology and essentially correlational analysis in nature by offering a generative lens for understanding how innovation systems evolve, persist, and co-adapt under different conditions. It also reaffirms the continuing necessity and explanatory value of national-level analysis in an era of intensified globalization, while underscoring the need for more comprehensive data, refined observation, greater analytical rigor and caution in its articulation.

2 The economy as an evolving system: theoretical foundations

2.1 Four conceptual pillars for evolutionary economics

Evolutionary Economics has long been advanced as a theoretical critique of the prevailing neoclassical paradigm. Contrary to the neoclassical assumption that economic actors behave with full rationality and that the economic system tends toward a theoretical equilibrium, evolutionary economists contend that the economy should be understood as a dynamic, evolving system in which actors operate with bounded rationality, and whose behavior is shaped by a complex interplay of cultural norms and socioeconomic institutions (Nelson & Winter, 1985; Nelson, 2020).

Drawing on analogies from biological evolution, four foundational concepts underpin evolutionary economics. The first is *routines*, defined as “a wide range of relatively mechanically employed ways of doing things” that economize on various resources, such as time and budget (Nelson, 2020, p. 1104). These routinized practices function analogously to genes in biological organisms, shaping a firm’s behavior and performance. They encompass a broad spectrum of activities—from decision rules and procedures for price setting, recruiting and selecting personnel, to determining the R&D budget—serving as the organizational memory and operational DNA of firms.

Do organizational routines fully resemble genes in biology? Not entirely. Unlike genes—fixed within organisms and transmitted only to offspring—routines, the “genes” of firms, can be deliberately modified through *dynamic capabilities* (Fusco & Minelli, 2010; Nelson, 2020), the second pillar of evolutionary economics. Introduced by Teece et al. (1997) and later central to innovation and management research, dynamic capabilities enable firms to reshape their organizational “DNA” in response to changing environments. They are central to latecomer economies’ “catching-up” processes, where indigenous firms must acquire new competencies (Nelson, 2020). Unlike the static operational efficiency emphasized in neoclassical theory—where firms employ existing technologies to meet established market demands in stable environments—dynamic capabilities involve the ability to sense opportunities and imperatives for innovation, and to implement them effectively (Nelson, 2020). This often (though not always) requires strong R&D capacity, as well as the ability to produce and market new products—capabilities absent from the standard neoclassical theory of the firm (Nelson & Winter, 1985; Nelson, 2020). Taken together, routines and dynamic capabilities—rooted in accumulated organizational experience yet extending it—shape firms’ adaptive success, enabling boundedly rational actors to rely on established patterns while experimenting in unfamiliar contexts.

How do environment-fitting traits emerge and prevail? *Selection* plays a key role in both biological evolution and economic change. In evolutionary biology, phenotypes are bound by the genes they inherit, so selection operates on gene packages via differences in phenotypic performance (Fusco & Minelli, 2010; Nelson, 2020). In evolutionary economics, however, individual economic entities—firms—are not constrained to fixed “genetic” routines; they can actively modify them through dynamic capabilities. Consequently, the selection of routines within an industry reflects not only competition among firms employing different routines but also deliberate adaptation within firms (Nelson, 2020). This adaptive selection has system-wide implications: the widespread adoption of more productive routines across firms contributes far more to industry-wide productivity growth than the mere positive selection of high-performing firms and the negative selection of less productive ones (Nelson, 2020).

Why do selection mechanisms exert such broad influence on industrial growth and beyond? The answer lies in the fourth pillar of evolutionary economics: the *co-evolution* of technology and institutions. Institutional structures shape and sustain the trajectory of technological progress, while major technological shifts often necessitate—and drive—corresponding institutional change (Nelson & Winter, 1985; Nelson, 2020). For example, the rise of biotechnology transformed the pharmaceutical industry, altered university–industry relations, and spurred new government policies; conversely, institutional innovations such as the post–World War II expansion of the U.S. National Institutes of Health reshaped biomedical research priorities (Nelson, 2020). Freeman and Louca (2001) argue that technological leadership depends on the capacity of national institutions to respond to paradigm shifts. Historical cases support this view: Britain's early economic leadership reflected institutions well aligned with emerging technological opportunities (Freeman, 2019; Nelson, 2020). In short, technological and institutional change are mutually reinforcing, and those who adapt most rapidly to this interplay secure lasting competitive advantage.

Positioned against biological evolution, a central distinction lies in firms' ability to intentionally modify their routines through dynamic capabilities—whereas biological phenotypes remain constrained by fixed genotypes (Nelson & Winter, 1985; Nelson, 2020). Supported by conscious policymaking and by an ever-expanding stock of collective knowledge—both lacking clear analogues in biology—firms can therefore actively influence the direction of their own evolution. This perspective aligns evolutionary economics with behavioural critiques of neoclassical assumptions, particularly the neglect of empirically grounded accounts of behaviour. Yet the two approaches diverge in analytical focus: whereas Behavioural Economics centres on individual-level anomalies and decision processes, evolutionary economics emphasises that most economic activity, especially innovation, is undertaken within organizations. Consequently, it foregrounds organizational routines, capabilities, and learning processes as essential units of analysis for understanding economic change (Nelson & Winter, 1985; Powell et al., 2005; Nelson, 2020).

2.2 The National innovation system framework

The National Innovation System (NIS) framework is one of the major contributions of the evolutionary economics tradition. An NIS comprises diverse actors—firms, universities, research institutes, and government agencies—embedded in formal institutions and informal practices, such as information-sharing networks, that shape innovation processes and facilitate the diffusion of knowledge. These interactions generate country-specific innovation trajectories reflecting differences in culture, institutional arrangements, and policy regimes (Nelson & Winter, 1985; Powell et al., 2005; Nelson, 2020). Among these actors, firms remain the primary engines of innovation, continually building and accumulating technological capabilities, while the developmental experiences of latecomer economies underscore the particularly significant role of the state in structuring and steering these systems (Nelson, 1993; Fagerberg & Srholec, 2008; Filippetti & Archibugi, 2011). Within this framework, "the most fundamental resource is knowledge and accordingly, the most important process is learning", and such emphasis on interactions reflects strong taste of Evolutionary Economics (Lundvall, 2007, p.18).

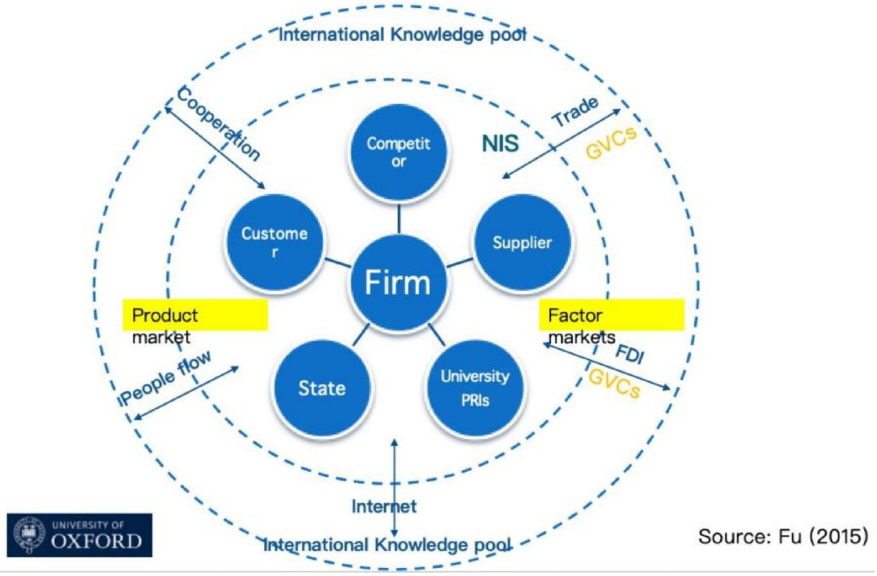
Contrary to critiques that portray the NIS perspective as theoretically loose, its strength lies precisely in embracing the inherent complexity of real-world economic activity, rather than relying on the oversimplified assumptions of full rationality, natural market equilibria, or easily quantifiable indicators embedded in standard economics (Lundvall, 2007; Nelson, 2008). Far beyond a descriptive mapping tool, the NIS remains one of the few economic frameworks with enduring analytical relevance and practical value for innovation analysis and policy design.

Summarized by Lundvall (2007), Freeman (1987) first articulated the modern concept of the national innovation system through his analysis of Japan's innovation and technology policy. While the notion of nationally embedded innovation processes was already implicit in the work of economists such as Richard Nelson and other U.S. scholars who compared technology policies and institutional arrangements across the United States, Japan, and Europe (Nelson, 1984), Freeman's contribution provided the first coherent conceptualization and terminology for this systemic perspective (Lundvall, 2007). Building upon this foundation, Nelson and Winter's (1985) evolutionary framework offered the theoretical underpinnings that linked innovation to institutional learning and path-dependent change. Subsequent contributions by Freeman, Lundvall, and Nelson collectively advanced the NIS approach by emphasizing innovation as an interactive, cumulative, and institutionally embedded process—thus transforming an empirical observation into a robust analytical paradigm for studying national development and technological capability (Lundvall, 2007).

Nelson (1993) defined the *national innovation system* by clarifying and problematizing each of its terms. *Innovation* was understood broadly as something new to the firm, rather than only to the nation or the world, shifting attention from the forefront of world's technology to the wider determinants of national technological capability. The term *system* did not imply a deliberately designed or internally coherent structure, but rather a constellation of institutions whose interactions shape firms' innovative performance. As innovation is defined so broadly, Nelson acknowledged the analytical difficulty to just "what should be included in the innovation system, and what can be left out" (Nelson, 1993, p.13).

Nelson (1993) also acknowledged that the national dimension of an innovation system is both analytically indispensable and conceptually problematic. Institutional arrangements that support innovation vary markedly across sectors, for instance, pharmaceuticals and aerospace, while many core actors and processes increasingly operate across national borders. Yet, Nelson's (1993) comparative analysis of fifteen countries demonstrated that, even in an era of deepening globalization, national differences in innovation performance remain pronounced. These divergences reflect enduring factors defined within national boundaries, such as policy regimes, industrial structures, educational systems, and historical development paths. Such findings call for a more cautious and reflexive use of the term national, while recognizing that

Table 1 ONIS



innovation systems in the contemporary context must evolve toward greater openness and transnational integration.

Fu (2015) helpfully extends the traditional NIS framework to capture the realities of globalised innovation, conceptualising the Open National Innovation System (ONIS) and illustrating its diverse interaction patterns (Table 1). An ONIS is essentially a NIS that is integrated into international knowledge networks, resource flows, and markets (Fu, 2015).

This model has four defining characteristics: First, an ONIS relies on dual knowledge sources, combining foreign and indigenous innovation in a dynamic, evolving manner; Second, an ONIS features multiple driving forces—the state, domestically private owned firms, and multinational enterprises—leveraging a combination of market mechanisms and state coordination to guide innovation priorities and allocate resources; Third, ONIS integrates both the outside-in and inside-out branches of the open innovation model, with the latter gaining greater prominence in the advanced stages of technological development; Finally, ONIS employs multiple channels of knowledge diffusion, as shown in Table 1, adopting a dynamic, multi-channel and multi-layer knowledge sourcing strategy that evolves with different stages of technological development (Fu, 2015). China's experience, as examined in the next section, clearly illustrates this developmental model and pathway.

3 From a National to an open National innovation system: the evolving trajectory of China's NIS

While the original NIS concept was developed with reference to advanced economies, its application to latecomer contexts—such as the "Asian Tigers"—has also yielded valuable insights. However, China's trajectory of NIS development remains relatively underexplored, partly because of the temporal recency of its transformation and the disciplinary and regional backgrounds of the framework's early proponents. This section depicts the evolution of China's NIS through both a historical and an open-system lens, revealing a trajectory characterized by endogenous institutional recombination and adaptive learning from global practices.

From a historical lens, the development of China's NIS can be divided into three major phases, with 2005 marking the gradual emergence of a "textbook-style" NIS (He et al., 2023). The first phase, the foundation period (mid-20th century–late 1970 s), began with an almost non-existent innovation base at the founding of the People's Republic of China (He et al., 2023). Within a few years, China had established a research system led by the Chinese Academy of Sciences, industrial R&D institutes, and universities, underpinned by land reform, education reform, and the socialist transformation of industry (Yu, 2022; He et al., 2023). By 1955, the country had 842 research institutes, 425,000 science and technology personnel (Cheng, 2019), and a centralised, closed innovation model directed by state planning along the lines of the former Soviet Union (Xue, 1997). Guided by the 1956–1967 Science and Technology Development Plan, this system mobilised science to serve national construction and defence, producing landmark achievements such as the "Two Bombs, One Satellite," crystalline bovine insulin, and artemisinin (Hu, 2006)—laying the institutional and technological foundations of China's future NIS.

During this period, scientific research institutes carried out the majority of R&D, while enterprises focused primarily on production (He et al., 2023). Major technological breakthroughs were achieved through state-organised, "campaign-style" joint efforts involving ministries, enterprises, universities, and the Chinese Academy of Sciences (He et al., 2023, p246). While this system delivered notable advances in defence and heavy industry, its weak incentive mechanisms and the disconnection between research and production limited civilian innovation, rendering the system relatively inefficient (He et al., 2023). Nevertheless, it provided essential groundwork for a future NIS by consolidating state leadership in innovation and introducing early elements of systemic coordination.

The second phase, the transition period (late 1970s–early 2000 s), began with the Reform and Opening Up of 1978 and the "market-for-technology" strategy, which triggered major changes in China's industrial, scientific, and enterprise management systems (He et al., 2023). China's 1985 S&T reform redirected technological development toward economic and social needs through measures such as loosening control over research institutes, reforming funding, launching national S&T programs, and promoting market participation, while the mid-1990s "Revitalizing the Nation through Science and Education" strategy reinforced these changes via the Education Revitalization Action Plan, the Knowledge Innovation Program, and the National Key Basic Research Program ("973 Program") (He et al., 2023). The dismantling of specialised industrial ministries led to the market-oriented restructuring of their subordinate R&D institutes—by 2005, nearly 60% scientific research institutes had been converted into enterprises and about 30% absorbed by large firms or conglomerates (He & Tao, 2019). These reforms deconstructed core features of the planned economy, enabling China's industrial sector to integrate into the global economy and achieve sustained growth by leveraging its advantages in labor- and engineering-intensive industries (Feng, 2022).

However, a coherent national innovation system had yet to emerge. R&D remained dominated by research institutes and universities, and although foreign technology transfer boosted manufacturing capacity, especially in joint ventures, domestic firms' technological capabilities lagged (Lu, 2019). Importantly, the growing scale and role of private enterprises during this period laid the institutional foundation for the later "textbook-style" NIS, in which private firms became central actors.

The third phase, the take-off period (2005–present), began with the State Council's 2005 Medium- to Long-Term Science and Technology Development Plan Outline (2006–2020), which for the first time articulated the policy concept of a NIS with five subsystems—technological, knowledge, regional, defence, and intermediary innovation systems—marking the start of using NIS theory to guide national innovation policy (He et al., 2023). In 2006, the CCP Central Committee and the State Council elevated "enhancing indigenous innovation capacity" to a national development strategy, signaling a strategic shift from reliance on foreign technology to indigenous innovation (He et al., 2023). Following the 18th Party Congress in 2012, the National Innovation-Driven Development Strategy Outline shifted the national S&T strategy from catching up to achieving leadership, with innovative reforms across multiple domains such as the Science and Technology Innovation Board (STAR Market) and expanded tax incentives for enterprise R&D (He et al., 2022).

By this stage, China's NIS had acquired a robust institutional framework and a diversified actor base, encompassing not only firms, universities, and research institutes but also new entities such as industrial technology research institutes, industry associations, and alliances (He et al., 2023). Innovation capacity indicators—R&D expenditure, research personnel, publications, and patent filings—rose sharply, propelling China from 38th in global innovation rankings in 2000 to 20th in 2011 and 10th by 2025, alongside the emergence of globally competitive innovation leaders (WIPO, 2025).

From another perspective, China has pursued an open national innovation system (ONIS) path since the launch of the Reform and Opening-Up initiative in the late 1970 s (Fu, 2015). To remind the model introduced in last section, this model has four defining characteristics and key interactive channels between NIS and global innovation resources, all of which are strongly reflected in China's experience.

First, dual knowledge sources, namely, the dynamic and evolving integration of foreign and indigenous innovation, play a key role (Fu, 2015). As previously discussed, China's trajectory from the "market for technology" strategy during the early Reform era to the post-2006 emphasis on indigenous innovation exemplifies this evolving integration of foreign and domestic innovation.

Second, an ONIS involves diverse drivers—including the state, domestic private enterprises, and multinational corporations—that jointly utilize market dynamics and governmental coordination to steer innovation agendas and distribute resources (Fu, 2015). It is evident that the state's role evolved substantially throughout the Foundation and Transition periods, shifting from a position of dominant leadership to a more diversified configuration. Băzăvan (2019) proposes a more nuanced typology of the state's roles within China's NIS. First, as "principal or sole funder, manager, and executor", the state leads in strategic technologies and priority sectors beyond private-sector capacity, providing substantial subsidies, making large-scale public investments, and erecting strong market barriers to protect domestic firms from foreign competition (Băzăvan, 2019, p2). Second, as "facilitator, coordinator, stimulator, and business partner", the state intervenes in sectors that are commercially viable but require additional support to achieve desired technological upgrades within strategic timelines (Băzăvan, 2019, p2). In this role, it mobilizes diverse actors across the innovation chain, stimulates private investment, fosters an incentive-rich environment, and encourages domestic firms to expand internationally. Third, as "distant observer", the state allows certain technology areas to evolve organically, delaying regulation and granting private firms wide latitude—even over critical public infrastructure and data—if this accelerates technological advancement (Băzăvan, 2019, p2).

Domestic private enterprises are also active actors in pushing China's innovation and development. Contrary to common assumptions, R&D funding in China is predominantly driven by the business sector (Fu, 2015zăvan, 2019)—more so than in the United States, the European Union, or South Korea (Băzăvan, 2019). OECD data show that in 2016, business expenditure on R&D (BERD) accounted for 76.1% of China's gross domestic expenditure on R&D (GERD), second only to Japan (78.1%) among the world's major R&D spenders (Băzăvan, 2019). In contrast, the government's share of GERD fell to 20% in 2016—lower than in the EU (31.7%), the U.S. (25.1%), South Korea (22.7%), and far below Russia (68.2%) (Băzăvan, 2019).

Additionally, despite state-owned enterprises (SOEs) have long been central to the Chinese economy—particularly before and during the early stages of reform—foreign-invested and domestically owned private firms now not only invest more in R&D than SOEs but also achieve higher innovation efficiency, producing greater outputs in high-technology and low- to medium-technology sectors, respectively (Fu, 2015). Taken together, these findings underscore the diverse drivers and their concerted efforts in shaping the openness of China's contemporary NIS.

Third, an ONIS encompasses both the outside-in and inside-out dimensions of the open innovation model, with the latter becoming increasingly prominent as technological capabilities advance (Fu, 2015). China's high-speed railway industry exemplifies the outside-in-to-inside-out shift. In 2004, with no high-speed trains, China signed technology transfer and joint venture agreements with Alstom, Siemens, Bombardier, and Kawasaki through China Northern Locomotive (CNR) and China South Locomotive & Rolling Stock Corp. (CSR) (Prud'homme et, al., 2018; Băzăvan, 2019). The first line opened in 2007, and within a decade, Chinese firms assimilated and improved the imported technology, expanding the network to 24,000 km—two-thirds of the global total—and becoming major exporters, now holding a larger global market share than their former partners (Băzăvan, 2019).

Huawei, one of China's most prominent technology firms, has followed a similar trajectory. Initially, it pursued an outside-in approach, relying on foreign technologies, joint ventures, and international partnerships to acquire advanced capabilities through technology importation, reverse engineering, and learning from global leaders (Fu & Sun, 2015). As its absorptive capacity, R&D infrastructure, and talent base expanded, Huawei transitioned to an inside-out model, leveraging proprietary technologies to drive indigenous innovation, export advanced solutions, and shape global standards, most notably in 5G technologies, thus transforming from a technology recipient into a global innovation leader and rule-setter (Fu & Sun, 2015).

Finally, ONIS employs multiple channels of knowledge diffusion, as shown in Table 1, adopting a dynamic, multi-channel and multi-layer knowledge sourcing strategy that evolves with different stages of technological development (Fu, 2015). In China's case, beyond substantial trade and investment flows, diverse forms of international cooperation, and a well-developed digital infrastructure, people-to-people exchanges, particularly with leading innovative economies, have been pivotal. Between 1978 and 2022, over eight million Chinese students studied abroad, and by 2021, approximately six million had returned (Peng, 2025). These returnees, many with experience in top universities and enterprises, have brought back not only technical knowledge but also tacit expertise, strategic insights, and global perspectives, significantly strengthening China's indigenous innovation and developmental capacity.

Notably, although China has adopted an ONIS strategy, its openness has been selectively applied (Fu, 2015, Băzăvan, 2019). The government has deliberately maintained barriers and restrictions on multinational corporations (MNCs) in sectors where domestic firms had yet to reach competitive maturity, and such markets were opened, or are opened, only once domestic enterprises had developed sufficient strength to withstand, or even dominate, international competition (Băzăvan, 2019). A prominent example is the internet sector. The "Great Firewall of China", a censorship mechanism blocking platforms such as Google, YouTube, Facebook, and Twitter, has been officially justified on political, security, and ideological grounds. However, it also created a protected environment in which Baidu, Alibaba, and Tencent could grow in an uncontested market, ultimately emerging as global-scale competitors to U.S. internet giants (Băzăvan, 2019). Similarly, the financial sector stayed largely closed to foreign banks until domestic institutions had become resilient and among the world's largest, leaving little room for foreign entrants after liberalization—a pattern also seen in foreign third-party payment platforms, fintech providers, and online retail businesses, whose market access was long restricted or denied (Shim & Shin, 2016; Băzăvan, 2019).

4 The evolutionary plasticity of innovation system

Latecomer economies such as China have developed their distinctive ways of constructing NIS, often combining strong state involvement with varying degrees of openness. Even within a same analytical group, usually labeled as large high-income countries, small high-income countries, and low-income countries, national-level differences stand out concerning the developmental trajectories, characteristics, and bottlenecks of each NIS (Nelson, 1993). This raises a fundamental question that motivates the further discussion of this paper: how is divergence generated under institutional similarity?

A substantial body of literature has addressed differences in innovation outcomes by linking them to contextual factors such as culture, policy regimes, or historical legacies. This paper does not dispute these findings, but providing alternative perspective and logic of explaining them. Much of the existing quantitative literature remains correlational in nature, treating contextual factors as explanatory variables rather than theorizing how they operate on institutional architectures. This paper instead contributes a generative perspective, explaining how similar institutional "DNA", namely, major actors, institutions, mechanisms in modern economies can be differentially expressed across contexts, thereby producing divergent innovation system attributes without institutional rupture. Importantly, this perspective is complementary rather than substitutive to quantitative approaches, as generative analysis addresses an explanatory level that cannot be fully captured by variable-based correlations alone.

To advance this perspective, the paper introduces the concept of Evolutionary Plasticity of Innovation Systems. Evolutionary plasticity denotes a system-level property through which a given institutional architecture can generate diverse innovation trajectories in response to heterogeneous environmental conditions. The concept draws inspiration from phenotypic plasticity in biological evolution—the capacity of a stable genotype to produce distinct phenotypes as environmental pressures shape the expression of underlying genetic material (Vogt et al., 2008; Fusco & Minelli, 2010; Jones, 2012; Figueiró, 2017). A classic example is the jaguar (Panthera onca): forest- and wetland-dwelling populations exhibit adaptive variation in bite force and skull morphology, optimizing predation efficiency for soft-tissue versus hard-shelled prey (Jones, 2012; Figueiró, 2017). By analogy, the core components and functions of innovation systems in both theory and practices, namely, major actors, institutions, and governance mechanisms, are broadly shared across countries and industries, much like a common genetic code. Yet their concrete configurations, interaction intensities, and operational mechanisms—comparable to phenotypic expression—are developmentally contingent and inherently plastic, responding to sectoral structures, policy regimes, socioeconomic contexts, and historical opportunities. Evolutionary plasticity thus shifts analytical attention from institutional replacement to institutional expression, recombination, and scaling under varying structural and policy environments.

This generative logic helps explain why innovation systems within a single national context can exhibit pronounced sectoral and regional divergence. In China, for instance, the high-speed rail industry is asset-intensive, production-concentrated, and thus dominated by large SOEs—conditions that enable the state to exercise direct coordination and control over technological development. Production activities within this industry mainly cluster in provinces such as Jilin, Hebei, and Shandong, where resource endowments, a heavy-industrial foundation, and geographic proximity to Beijing historically reinforced state-led production. By contrast, the artificial intelligence sector, exemplified by recent breakthroughs such as DeepSeek, is relatively asset-light, knowledge-intensive, and populated primarily by private small- and medium-sized enterprises. High-tech private firms thrive in regions such as Hangzhou, Shanghai, and Shenzhen, where business environments are historically more flexible, market-oriented, and innovation-friendly. In these contexts, the state's influence operates less through direct command and more through ecosystem-building, standard-setting, and indirect support, illustrating the differentiated state roles discussed earlier. Such variations, such as in configuration and spatial distribution of key actors, do not represent distinct institutional "genotypes," but rather context-specific expressions of a shared institutional architecture shaped by sectoral, regional, and organizational environments.

A similar generative logic underpins the cross-national diversity of innovation systems documented in Nelson's (1993) comparative study of fifteen countries. At the national level, variations such as in historical development trajectories, positions within the global division of labor, and patterns of institutional coupling among the state, firms, and research organizations shape how shared innovation-system components are recombined and expressed over time. In the United States, for instance, the profound legacy of the Second World War contributed to the emergence of a science- and defense-driven innovation system centered on universities and public research, enabling sustained frontier scientific and technological leadership (Nelson, 1993). By contrast, Germany—as a nineteenth-century latecomer—and Japan and Korea as twentieth-century catch-up economies placed greater emphasis on engineering capabilities and applied innovation, thereby generating strong manufacturing competitiveness (Nelson, 1993). These divergent trajectories reflect not distinct institutional "types" of innovation systems, but context-dependent expressions of shared institutional foundations.

Taken together, these patterns speak directly to longstanding debates on the necessity of "national" within the NIS framework. Despite wide variation in developmental trajectories, industrial specialization, and current adaptive bottlenecks, modern innovation systems share core structural features: firms as the primary locus of innovation, public provision of education and basic research, and sustained government involvement in shaping knowledge production. National differences, therefore, resemble phenotypic variation—context-specific expressions of a shared institutional "genotype"—rather than fundamentally distinct institutional forms. From an evolutionary perspective, corporate, sectoral, regional, national, and global innovation systems should not be viewed as discrete analytical categories mechanically but as interrelated levels of an evolving whole, analogous to cells, tissues, organs, and systems within a living organism —and no trends will ever deny the existence and importance of these analytical and operational levels. Intensified international interactions may blur these boundaries and complicate national-level analysis, yet they do not negate the national level as a real and consequential site of coordination, governance, and policy intervention. Especially under conditions of heightened geopolitical tension, the NIS remains an indispensable analytical and policy framework for understanding how innovation systems adapt, differentiate, and persist through evolutionary plasticity. In short, globalization does not diminish the necessity and explanatory power of national-level analysis; rather, it demands more comprehensive data, refined observation, and greater analytical sophistication and caution in articulation.

5 Conclusion

This study first reviews the theoretical stance of evolutionary economics, which conceptualizes the economy as a dynamic, evolving system in which actors' behavior is continuously shaped by the complex interplay of cultural norms and socioeconomic institutions (Nelson & Winter, 1985; Nelson, 2020). This perspective challenges the neoclassical assumption of fully rational actors and equilibrium-based systems (Nelson & Winter, 1985; Nelson, 2020). Evolutionary economists emphasize that firms—the primary actors in innovation—operate with bounded rationality, relying on established routines that have yielded satisfactory results, while also developing dynamic capabilities to experiment new ways in unfamiliar or changing contexts (Nelson & Winter, 1985; Nelson, 2020). The selection of routines within an industry reflects both inter-firm competition and intra-firm adaptation (Nelson & Winter, 1985; Nelson, 2020). Such selection generates broader system-level benefits by fostering the co-evolution of technology and institutions—effects that go beyond productivity gains from the mere survival of high-performing firms and crowding out of the low-performing firms (Nelson & Winter, 1985; Nelson, 2020).

Adopting this evolutionary lens, the study applies the National Innovation System (NIS) framework—one of the most influential extensions of evolutionary economics—to analyze China's innovation practices with a specific focus on its NIS development, revealing a trajectory characterized by endogenous institutional recombination and adaptive learning from global practices. From a historical perspective, China's NIS has progressed through three stages: the foundation period (mid-20th century–late 1970 s), characterized by strong state planning; the transition period (late 1970s–early 2000 s), marked by a surge in firms following market reforms but with limited capabilities and networks; and the take-off period (2006–present), during which a textbook-style NIS emerged. In 2005–2006, NIS building became a national strategy, with increasing emphasis on indigenous innovation (He et al., 2023). Alternatively, China's NIS trajectory can be seen as following an Open National Innovation System path, integrating foreign and domestic knowledge sources, engaging multiple public and private drivers, combining outside-in and inside-out open innovation models, and facilitating diverse channels of knowledge diffusion (Fu, 2015). This openness, however, remains strategically selective to shield domestic firms from excessive competition and enable their growth (Fu, 2015, Băzăvan 2019).

Finally, this paper advances the concept of Evolutionary Plasticity of Innovation Systems to reinterpret the dynamics of institutional adaptation and diversity within and across national contexts. Drawing on an analogy from biological evolution, evolutionary plasticity describes how a stable institutional "genotype" can generate multiple developmental "phenotypes" as innovation systems respond to shifting technological, industrial, and policy environments. This perspective extends the evolutionary economics tradition by shifting analytical focus from institutional replacement to institutional expression, recombination, and scaling. Empirical evidence from China illustrates how similar institutional foundations give rise to divergent innovation dynamics—such as the contrast between state-dominated, asset-intensive sectors like high-speed rail and entrepreneurial, knowledge-intensive sectors such as artificial intelligence—while cross-country comparisons confirm that systemic variety emerges from context-specific recombination and learning rather than categorical difference. By foregrounding expression and reconfiguration over rupture and replacement, this concept extends Nelson's vision of the economy as an adaptive system, offering a generative lens for understanding how innovation systems evolve, persist, and co-adapt under changing global and geopolitical conditions. Rather than diminishing the relevance of the national level, the notion of evolutionary plasticity reasserts its analytical and policy importance as a key site of coordination, directionality, and adaptive learning in shaping technological and socioeconomic change, while calling for more comprehensive evidence and methodological precision in its analysis.

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