# Effects and Mechanisms of Innovation Spillovers in Global Value Chains: Evidence from OEM and Buyer-Supplier Relationships in Advanced Manufacturing

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***Abstract:*** *Innovation spillovers from multinational corporations to domestic firms are increasingly prominent in global value chain (GVC) evolution, yet prior work has largely focused on technology transfer, leaving the distinct nature of innovation spillovers underexplored. Existing GVC literature also remains divided between intra-product and inter-product perspectives, overlooking GVC heterogeneity. This study examines two governance structures: OEM relationships (process-based, intra-product) and buyer-supplier relationships (modular-based, inter-product), and investigates their divergent innovation spillover effects, along with the moderating role of inter-organizational relationship (IOR) characteristics. Using an unbalanced panel of 2,150 transaction observations from 597 dyads across nine advanced manufacturing industries (2012-2022), we integrate annual transaction volumes with patent citations and subsequent innovation outcomes. Empirically, we find that innovation spillovers are significantly stronger in OEM relationships than in buyer-supplier relationships, with a positive interaction between the two chains. Furthermore, multidimensional IOR traits substantially affect both spillover magnitudes and the variance across GVC types. This study advances GVC research by shifting the focus from technology transfer to innovation spillovers and bridging intra-product and inter-product specialization divides. It offers exploratory theoretical insights and provides strategic implications for Chinese firms regarding GVC embeddedness and innovation decisions.*

***Keywords:*** *Global value chains; Innovation spillover effects; OEM relationships; Buyer-supplier relationships; Inter-organizational relationship characteristics*

JEL Classification Codes: F14, O33

DOI: 10.19602/j.chinaeconomist.2026.07.06

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Funding: This study was supported by the General Program of National Natural Science Foundation of China (NSFC) (Grant No. 71973129) for the project "Mechanisms of Knowledge Spillover in Heterogeneous Global Innovation Chains: A Cross-level Empirical Study based on the mvQCA Method from a Dyadic Perspective"; the Young Scientists Program of NSFC (Grant No. 72204222) for the project "The Impact Mechanism of Technological Heterogeneity on University Technology Transfer from a Knowledge Recombination Perspective"; and the Science and Technology Planning Project of Zhejiang Province (Grant No. 2023C35015) for the project "Research on the Asymmetric Participation of Zhejiang Manufacturing Enterprises in Global Innovation Chain Governance".

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## 1. Introduction

For domestic firms, building technological and innovative capabilities is strategically important, and the process is increasingly driven by global value chains (GVCs) that can enable them to leverage technology transfer and innovation spillover from multinational corporations (MNCs). Global value chain theory posits that manufacturing enterprises in developing countries can acquire technology transfers from MNCs through "learning by embedding", from which they can develop their own technological capabilities (Figueiredo et al., 2020; Duan et al., 2021; Anzolin et al., 2022) and achieve four distinct types of upgrades: product, process, functional, and inter-chain. MNCs employ a variety of channels to transfer technology to manufacturing firms in developing countries, including patent licensing, technology transfer agreements, technical documentation, expert training, and exploratory technological learning. The effectiveness of such technology transfer is influenced by multiple factors, including value chain dependence (Deng et al., 2022; Soontornthum et al., 2020), relationship duration (Isaksson et al., 2016; Ito et al., 2023), regional differences (Pasquali, 2021; Ito et al., 2023), institutional distance (Song & Yang, 2022; Wang et al., 2023), technological distance (Palit et al., 2022), and firm-specific characteristics (Duan et al., 2021). However, recent empirical studies on Chinese original equipment manufacturer (OEM) firms suggest that improvements in technological capabilities do not necessarily lead to genuine upgrades. In certain contexts, the asset specificity of technological capabilities may instead intensify external dependence, weaken bargaining power, and place firms in a more disadvantageous position in terms of rent distribution, resulting in a "pseudo-upgrading" dilemma (Fan et al., 2023; Zhou et al., 2024). In effect, capability enhancement by OEM firms may merely result in them becoming "a cog in someone else's machine" (Yu & Wen, 2011; Hu et al., 2021), a scenario in which their efforts primarily serve to bolster the MNC's dominant market position rather than their own strategic autonomy. As President Xi Jinping emphasized: "Key and core technologies cannot be secured through begging, buying, or pleading." The phenomenon of 'pseudo-upgrading' suggests that reliance solely on technology transfer may be insufficient for achieving genuine improvements in innovation capability. Accordingly, this study shifts the analytical focus from technology transfer to innovation spillovers, with the aim of exploring how substantive innovation capabilities can be developed within GVCs.

In the strategic context of innovation-driven development, innovation spillovers within GVCs have emerged as a new research focus. Lema et al. (2015), through case studies of the electronics and information technology industries in Brazil and India, have found that MNCs not only transfer technical knowledge but also diffuse innovation-related knowledge on a significant scale, generating substantial innovation spillover effects. Innovation spillovers from MNCs to manufacturing firms in developing countries thus represent a frontier phenomenon in the evolution of GVCs. Here, a distinction can be drawn between "fish" and "fishing": technical knowledge refers to applied knowledge related to production processes and product development (akin to being given a "fish"), while innovation knowledge emphasizes R&D capabilities and sustained innovation in processes and new product development (akin to mastering the skill of "fishing"). As Chinese manufacturing firms transition from building technological capabilities to developing innovation capabilities, the question how to leverage innovation spillovers from MNCs to construct

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such capabilities has become a critical issue for acquiring innovation resources on a global scale. Although, existing studies have examined the necessary conditions and forms of innovation spillovers in GVCs (Isaksson et al., 2016; Palit et al., 2022), as well as their influencing factors (Chu et al., 2019; Hsu et al., 2022), the literature remains largely focused on technology transfer. Research on the mechanisms of innovation spillovers from MNCs to local firms within GVCs specifically, which key factors drive these spillovers, and how they operate, remains notably limited.

The innovation spillover effects within GVCs are shaped by a confluence of factors, including the intrinsic characteristics of the GVCs themselves, cross-national institutional divergence, the nature of innovation activities, and firms' innovation and learning capabilities. As the primary structural conduits for innovation spillovers, the inherent heterogeneity of GVCs is undeniably a critical determinant of innovation spillover. What distinct innovation spillover effects arise across different types of GVCs? Although GVCs exhibit heterogeneity across industries, nations, and firms, the most theoretically salient distinction lies in their fundamental structural architectures.

The first type is the process-deconstructed GVC formed through intra-product specialization and organizational decomposition along the value-creation sequence of "R&D and design, manufacturing, branding, and marketing" (Lu, 2004). This corresponds to the configuration popularized by the "smiling curve". A prototypical example is the transnational OEM relationship in the semiconductor industry between a chip design firm (e.g. Qualcomm) and a wafer foundry (e.g. SMIC). The second type is the modular-deconstructed GVC that arises from inter-product specialization and organizational decomposition based on the sequence of "components, modules/process equipment, and final products" (Grossman & Rossi-Hansberg, 2008). A typical example is the transnational buyer-supplier relationship between a component provider (e.g. Japan's Sumitomo Chemical, which supplies wafer materials) and a foundry (e.g. SMIC). Research on these two modes of division of labor has largely remained bifurcated. Studies on intra-product specialization primarily focus on embedding, low-end lock-in, and upgrading (Lee et al., 2015; Yang et al., 2017; Zhen & Wang, 2020), with "transnational subcontracting" (OEM) serving as the representative context. Additionally, research on inter-product specialization concentrates on supplier selection and buyer-supplier governance (Hennart, 2020; Sharma et al., 2022), with "transnational procurement" as the main setting. GVC research has yet to incorporate these two distinct types into a unified analytical framework. By taking innovation spillover effects as an entry point, this study seeks to bridge the divide between intra-product and inter-product perspectives and in doing so explore a new paradigm for GVC research and contributing to the theoretical development of the field.

The dyadic inter-organizational relationships (IORs) formed between multinational corporations (MNCs) and manufacturing firms in developing countries constitute the essential channels for innovation spillovers. What impact do IOR characteristics have on the innovation spillover effects within different types of GVCs? Drawing on the literature on (transnational) IORs, the key theoretical dimensions of IOR characteristics include inter-organizational dependence structures (Soontornthum et al., 2020; Deng et al., 2022), relationship duration (Dyer & Nobeoka, 2000; Potter & Paulraj, 2021), and the partner country origin of the transaction partner (Zhang et al., 2019; Wang, 2011). From the perspective of Resource Dependence Theory (RDT),

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"dependence structures" are the specific pattern of balanced or asymmetric mutual dependence between organizations (Pfeffer & Salancik, 2003; Lv et al., 2017). In the GVC context, how do the dependence structures between MNCs and domestic firms influence innovation spillovers? How does the duration of these relationships affect such outcomes? Furthermore, MNCs from different countries serve as conduits for the political, institutional, and cultural attributes of their home nations, which significantly influence their spillover effects. As Chinese manufacturing firms embed themselves in GVCs, what differentiated innovation spillover effects do transaction partners from different countries or regions generate?

A key factor perpetuating the divide between research on intra-product and inter-product specialization is that most manufacturing firms in developing countries are typically embedded in only one type of global value chain (GVC). They either participate as suppliers or clients in transnational procurement networks (inter-product), or they are integrated into a specific segment of a multinational corporation's (MNC) value-creation process as partners in particular value-adding activities (intra-product). A critical methodological breakthrough for bridging these two strands of research lies in the strategic use of OEM samples. The OEM model is most mature in industries such as semiconductors, smartphones, and consumer automobiles, with the semiconductor sector being especially representative. Taking the semiconductor industry as an example, wafer foundries such as TSMC and SMIC not only undertake production for fabless design firms such as Qualcomm, thereby forming OEM relationships based on intra-product specialization and constituting process-deconstructed GVCs but also procure raw materials and components globally. For instance, the relationship between material giants such as Japan's Sumitomo Chemical and a foundry such as SMIC constitutes a buyer-supplier relationship based on inter-product specialization and forms a modular-deconstructed GVC. Accordingly, by synthesizing data on the OEM relationships between these firms and their clients with data on the buyer-supplier relationships between the same firms and their suppliers, it becomes possible at a methodological level to integrate intra-product and inter-product specialization into a unified analytical framework. This enables a systematic analysis of innovation spillover effects in GVCs and an empirical examination of how different types of GVCs and their inter-organizational relationship (IOR) characteristics influence the mechanisms of innovation spillovers. To this end, we rigorously selected nine prominent Chinese advanced manufacturing firms primarily engaged in OEM operations. Based on the Bloomberg Supply Chain Database (2012-2022), three types of GVC samples were constructed: 245 OEM dyads between OEM firms and their clients, yielding 883 observations of process-deconstructed GVCs based on intra-product specialization; 300 buyer-supplier dyads between OEM firms and their suppliers, yielding 1,016 observations of modular-deconstructed GVCs based on inter-product specialization; and 251 observations involving 52 dual-role dyads (where transaction partners simultaneously act as both OEM clients and suppliers), which were used to explore the interaction effects between different GVC modalities. Annual transaction values were used to measure IOR characteristics, and invention patent citations and subsequent innovation outcomes were employed to capture the innovation spillover effects of MNCs on OEM firms.

This paper makes several theoretical contributions. First, it advances the frontier of GVC

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research from a focus on "technology transfer" to the broader domain of "innovation spillovers". Second, it bridges the divide between research on intra-product and inter-product specialization by first incorporating these two GVC types into a unified framework and then identifying significant differences in their spillover effects, offering important paradigm-level implications for the field. Third, from the perspective of IORs, it explains the mechanisms that underlie the variance in innovation spillover efficacy across GVC types. The remainder of the paper is organized as follows. Section 2 develops the theoretical framework and research hypotheses; Section 3 describes the empirical research design; Section 4 analyzes the empirical results; Section 5 provides further analysis; Section 6 discusses the findings; and Section 7 concludes with policy implications.

## 2. Theoretical Analysis and Research Hypotheses

### 2.1 Knowledge Flows in GVCs: from Technology Transfer to Innovation Spillovers

The transfer of technology from MNCs to manufacturing firms in developing countries has long served as a strategic pillar for enhancing supplier capabilities and strengthening the collective competitiveness of GVCs. Consequently, technology transfer remains a seminal theme in the GVC literature. However, contemporary observations indicate that MNCs are generating increasingly potent innovation spillover effects for firms in developing countries. This phenomenon, characterized by the unintentional diffusion of innovation-related knowledge and its acquisition by domestic firms through exploratory learning to bolster innovation capabilities, has emerged as a distinctive new frontier in GVC evolution. Innovation spillovers and technology transfer represent two fundamentally different paradigms that diverge significantly across two primary dimensions.

First, they differ in the nature of the knowledge involved. Technical knowledge refers to the application of existing skills, tools, and resources to solve practical problems or achieve specific functional objectives. In contrast, innovation knowledge involves the synthesis of new ideas and methods to create novel technologies or business models. Although interrelated, innovation knowledge serves as the generative source of technical knowledge. Within GVCs, MNCs maintain a decisive advantage in both domains. OEM firms typically possess substantial technical proficiency, but the intrinsic nature of the OEM model, coupled with the strategic containment strategies employed by MNCs, often stifles the accumulation of core innovation knowledge, particularly in proprietary technologies and brand equity.

Second, they differ in the modality of knowledge flow. Technology transfer is an intentional process wherein a source deliberately transmits technical knowledge to a recipient through formal mechanisms such as patent licensing, technical documentation, and expert training, facilitating exploitative learning. Conversely, innovation spillovers refer to the unintentional diffusion of innovation knowledge (Duan et al., 2021; Hsu et al., 2022). Recipient firms capture this knowledge through exploratory mechanisms, including patent citations, benchmarking, and reverse engineering. In their study of innovation quality, Duan et al. (2021) explicitly distinguish between this deliberate transfer and the serendipitous spillover of knowledge. Although early GVC research primarily focused on unidirectional technology transfer from developed to developing economies (Pietrobelli & Rabellotti, 2011), subsequent scholarship has expanded to examine bidirectional and multidirectional flows between MNCs, supply chain partners, and regions (Alcacer & Oxley, 2014;

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Lee et al., 2018). Further studies have also highlighted dynamic factors such as knowledge sharing and organizational learning (Poddar et al., 2021; Wang et al., 2023; Clayton et al., 2022; Büttner et al. 2022). However, empirical evidence from Chinese OEM firms shows that improvements in technical capabilities do not inherently catalyze strategic upgrading. In certain contexts, the asset specificity of these capabilities can exacerbate dependence on MNCs and erode bargaining power (Yu & Wen, 2011; Hu et al., 2021). The practice of Chinese enterprises demonstrates that achieving technological self-reliance ultimately depends on independent innovation. To this end, it is imperative to build upon the continued learning of technology from MNCs by placing greater emphasis on leveraging the innovation spillover effects within GVCs. This involves proactively exploring and acquiring innovation knowledge on a global scale, subsequently internalizing and integrating it to foster the creation of autonomous technological capabilities. Currently, robust theoretical frameworks and empirical evidence regarding the mechanisms of GVC innovation spillovers remain sparse. Therefore, investigating these effects is of strategic significance for Chinese firms in their pursuit of innovation-driven development and represents a vital direction for advancing GVC theory.

### 2.2 Two Types of GVC: OEM Relationships and Buyer-Supplier Relationships

MNCs simultaneously pursue both comparative and competitive advantages, which drives the specialized deconstruction and networked reconfiguration of value-creating activities on a global scale (Gereffi et al., 2005) and ultimately gives rise to GVCs. Therefore, the essence of a GVC lies in the division of labor, and its organizational form represents a restructuring based on that division. The level of the division of labor is fundamentally driven by market thickness, which in turn determines the degree of specialization. Under specific conditions of market thickness, value-creation activities undergo specialized deconstruction and networked reconfiguration based on dimensions such as technical decomposability, the equilibrium between comparative and competitive advantages, and supply capacity. As illustrated in Figure 1, the division of labor unfolds along two distinct trajectories. The first is inter-product specialization, where production entities with relative advantages undertake specific subdivided value modules. For example, personal computers, as products with complex architectures, achieve extensive modular deconstruction and division across value modules such as chips, displays, and various components, forming modular-deconstructed GVCs based on inter-product specialization. The second trajectory is intra-product specialization, where production entities with comparative advantages undertake specific stages of the value-creation process. In the semiconductor industry, for instance, activities such as chip design, wafer fabrication, and packaging/testing achieve comprehensive process deconstruction and division according to the value-creation sequence, forming process-deconstructed GVCs based on intra-product specialization.

#### *2.2.1 OEM relationships: process-deconstructed gvcs based on intra-product specialization*

In process-deconstructed GVCs, firms that specialize in different stages of value creation are interconnected through intra-product specialization. Within the global semiconductor GVC, the three core stages of R&D/Design, Manufacturing, and Packaging/Testing are highly subdivided, giving rise to multiple interfaces such as Design-Manufacturing, Manufacturing-Packaging/

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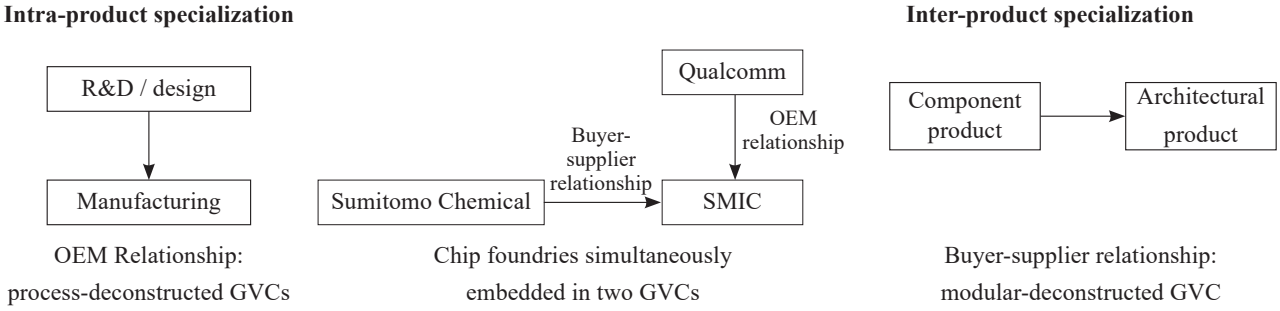


**Fig. 1. Chip Foundries Simultaneously Embedded in two GVCs**

Testing, and Design-Packaging/Testing. Among these, the Design-Manufacturing interface constitutes the OEM (foundry) relationship. In this study, OEM relationships refer specifically to the subcontracting model in advanced manufacturing industries (e.g. semiconductors) and represent an inter-firm transactional relationship characterized by high transaction complexity, deep technological collaboration, and a high degree of specialization. These relationships involve sophisticated proprietary technologies and complex, well-integrated production processes. OEM firms provide specialized design or manufacturing services in accordance with clients' technical specifications and ensure product quality through continuous process innovation and stringent process control. For example, in the semiconductor industry, foundries provide chip manufacturing services strictly based on the technical specifications of their clients' R&D and design. Because both the design stage (highly innovative and complex) and the manufacturing stage (equally innovation-intensive) exhibit extreme technological sophistication, specialization, and differentiation, the interaction between these two stages involves rich dynamics of "coopetition" (cooperation and competition). This interface constitutes a primary arena of global strategic competition within the semiconductor GVC. As such, OEM relationships fully capture the essential features of process-deconstructed GVCs and have long been a focal point in research, particularly regarding the GVC upgrading of OEM firms in developing countries such as China. They therefore serve as a primary empirical context for examining innovation spillover effects. What innovation spillover effects do chip design firms (e.g. Qualcomm) generate for independent foundries (e.g. SMIC)? Furthermore, how do the characteristics of the IORs between design firms and foundries influence these spillover effects?

*2.2.2 Buyer-supplier relationships: modular-deconstructed gvcs based on inter-product specialization*

In modular-deconstructed GVCs, vertical buyer-supplier relationships are formed between modules and architectural products, as well as between technical equipment and final products. In addition, horizontal linkages exist in the form of coupling between different modules within the same stage and competition within individual modules. Among these, vertical buyer-supplier relationships constitute the primary axis of modular-deconstructed GVCs. Buyer-supplier relationships refer to inter-firm transactions based on inter-product specialization. Their defining feature is the achievement of relatively low-complexity coordination enabled by modular product interfaces or standardized technical specifications. These relationships are typically governed by market-based or modular GVC governance structures (Gereffi et al., 2005)

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that emphasize standardization and flexibility in transactions. Interactions between firms are primarily oriented toward meeting product specifications and price requirements, with relatively limited deep technological or knowledge exchange. Typical examples include the "lithium battery (module)-smartphone (architectural product)" linkage in the consumer electronics industry and the "lithography equipment (technical equipment)-semiconductor (product)" linkage in the semiconductor GVC. Within the semiconductor GVC, core manufacturing equipment such as lithography systems embodies innovation capabilities that rival or even exceed those of chip design and represents the technological frontier of modern manufacturing. What innovation spillover effects do multinational equipment manufacturers (e.g. ASML) generate for domestic chip foundries (e.g. SMIC)? Furthermore, how do the characteristics of the IORs between these key equipment providers and foundries shape the resulting innovation spillover effects?

*2.2.3 OEM and buyer-supplier relationships: from bifurcation to integration*

The research on GVCs rooted in intra-product specialization versus those rooted in inter-product specialization, has long remained fragmented. This seeming bifurcation can be attributed to four primary factors. First, GVCs based on intra-product specialization emerged as a prominent phenomenon only after the 1990s, significantly lagging behind the extensive history of inter-product specialization. Second, most firms in developing countries primarily establish linkages with MNCs through cross-border buyer-supplier relationships; mature OEM arrangements are largely confined to a small number of technologically complex, highly modularized advanced manufacturing industries, such as semiconductors. This empirical constraint has naturally limited the integration of these two strands of GVC research. Third, the "smile curve" concept, which gained significant social influence in the early 1990s by focusing on the value distribution of "R&D-Manufacturing-Branding", heavily constrained academic and practical perceptions of GVCs within the intra-product specialization model. Fourth, significant differences in research paradigms exist between disciplines, such as international trade in economics and international business in management, and the dialogue between these fields remains insufficient. Consequently, the majority of GVC studies in China have focused on process-deconstructed GVCs based on intra-product specialization and have centered on GVC governance and the upgrading of firms or industries in developing countries (Liu & Zhang, 2007, 2009; Liu, 2005; Yu & Wen, 2011; Xiang et al., 2014; Lv et al., 2018, 2020; Hu et al., 2021; Luo & Lv, 2022). In contrast, research on inter-product specialization is predominantly situated within the field of international business and focuses on supply chain relationship management and the governance of cross-border buyer-supplier relationships, including supplier selection, contract management, trust building, risk management, and knowledge sharing (Dyer & Hatch, 2006; Alcacer & Oxley, 2014; Isaksson et al., 2016; Um & Ho, 2020).

Advancing GVC theory necessitates integrating these different GVC types into a unified analytical framework. This is essential not only for strategic decision-making regarding GVC embedding, such as how Chinese OEM firms evaluate the value, governance modes, and upgrading strategies of OEM versus buyer-supplier relationships, but also for the theoretical evolution of the field. Such integration allows GVC theory to transcend the limitations of a conceptual focus

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confined to intra-product specialization and facilitates the construction of a more systematic GVC framework. The present study utilizes innovation spillover effects as an analytical entry point. It pursues a dual objective: first, to reveal the mechanisms of innovation spillovers in GVCs and advance research on knowledge governance by addressing the core theoretical question: "How do innovation spillover effects differ across these two GVC types, and how do inter-organizational relationship characteristics influence these effects and their disparities?" Second, it aims to explore a research paradigm that bridges intra-product and inter-product perspectives in an effort to contribute a new lens to and understanding of the further development of GVC theory. Such an integrative approach not only may enrich existing GVC scholarship but may also assist firms, policymakers, and researchers in navigating the complex interactions and challenges of the global economy.

### 2.3 Innovation Spillover Effects in GVCs

We compare the innovation spillover effects across OEM and buyer-supplier GVCs by utilizing OEM and buyer-supplier relationships as empirical contexts. Integrating insights from inter-organizational knowledge governance literature, the comparison is logically structured along four dimensions: (1) the innovation intensity of the spillover source (Hsu et al., 2022; Ito et al., 2023); (2) the learner's baseline innovation capacity and motivation (Figueiredo et al., 2020; Duan et al., 2021); (3) the inter-organizational interaction interface (Isaksson et al., 2016; Potter & Paulraj, 2021); and (4) the scope of innovation spillover (Palit et al., 2022). Regarding the learner's baseline innovation capacity, the foundational capabilities are broadly consistent across both relationship types. However, in terms of the innovation intensity of the spillover source, R&D/design firms, acting as clients in OEM relationships, almost invariably possess formidable R&D or branding capabilities and are prototypical innovation-driven organizations (Su et al., 2020). Although certain suppliers (e.g. ASML) may possess innovation capabilities that rival or exceed those of OEM clients, the majority of suppliers are driven by production capacity rather than innovation. Consequently, as primary subjects of innovation spillover, OEM clients generally exhibit significantly higher innovation intensity than the OEM firms' own suppliers. In terms of learning motivation, an OEM firm acting as the "contracting party" (Party B) has a much stronger incentive to engage in relationship-specific innovation learning in order to sustain the partnership (Yu, 2010) than it does when acting as the "purchasing party" (Party A) in a buyer-supplier relationship.

Regarding the inter-organizational interaction interface, the complexity and intensity of the "Design-Manufacturing" interface are significantly higher than those of the "Supplier-Client" interface. The latter often relies on modular interfaces where suppliers conduct "encapsulated" modular innovation. Interactions that are more complex, intimate, and difficult to codify greatly facilitate the spillover of tacit innovation knowledge (Potter & Paulraj, 2021). In terms of the scope of innovation spillover, the technological distance between OEM clients and OEM firms is significantly smaller than the distance between suppliers and OEM firms in buyer-supplier relationships; a smaller technological distance is positively correlated with stronger spillover effects (Liu et al., 2015; Palit et al., 2022). The scope of spillovers from OEM clients encompasses not only market-driven insights into marketing and services but also core product technological innovation. In contrast, innovation spillovers from modular suppliers are largely restricted by the

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technical standards of modular product/service interfaces. Highly standardized interfaces effectively shield a substantial portion of innovation knowledge, particularly tacit knowledge (Dong et al., 2020; Schott and Schaefer, 2023). Based on this analysis we propose the following hypothesis.

Hypothesis 1: Compared to buyer-supplier relationships, OEM relationships generate more significant innovation spillovers for the focal manufacturing firm.

OEM firms are simultaneously embedded in two distinct GVC modalities, OEM relationships and buyer-supplier relationships, thereby accessing two different sources of innovation spillovers. In contrast to firms embedded solely in a single buyer-supplier chain, OEM firms that occupy both roles gain a significant advantage in the diversity and richness of acquired knowledge. This combination of heterogeneous knowledge generates a catalytic "fermentation effect" (Hao et al., 2014) that provides a superior foundation for both knowledge acquisition and subsequent innovation outcomes. This advantage operates through three specific mechanisms. First, knowledge spillovers from suppliers bolster an OEM firm's foundational supply capacity, which in turn strengthens its absorptive capacity to internalize innovation from OEM clients: the "supply-capability" effect (Potter & Paulraj, 2021; Palit et al., 2022). Second, knowledge acquired from OEM clients provides strategic direction that enables firms to absorb supplier spillovers more efficiently and with greater relevance to OEM-specific requirements: the "OEM-orientation" effect. Third, dual embedding increases the complexity and depth of interactions with both clients and suppliers and thus offers more diversified learning opportunities and a more robust platform for knowledge acquisition: the "scenario-richness" effect (Chae et al., 2020; Um & Ho, 2020). Based on these three effects we propose the following additional hypothesis.

Hypothesis 2: Innovation spillovers from OEM relationships and buyer-supplier relationships exhibit a positive interaction effect. The overall innovation spillover effect for OEM firms simultaneously embedded in both GVC types is significantly stronger than the spillover effects derived from either suppliers or OEM clients in isolated, single-relationship settings.

### 2.4 Inter-Organizational Relationship Characteristics and GVC Innovation Spillovers

Beyond the inherent differences in GVC types, the variation in innovation spillover effects also depends on the specific characteristics of the IORs between transaction partners, such as the "OEM Client (e.g. Qualcomm)-OEM Firm (e.g. TSMC)" dyad and the "Supplier (e.g. ASML)-OEM Firm (e.g. TSMC)" dyad. To clarify the complete logic underlying these different spillover effects, it is essential to examine IORs as the primary conduits of knowledge flow. Drawing on Transaction Cost Economics (TCE), Resource Dependence Theory (RDT), Relational Contract Theory, and organizational interface perspectives, the literature in these fields suggests that IOR characteristics encompass subjective dimensions, such as inter-organizational trust (Dyer & Singh, 1998) and social interaction patterns (Yu & Wen, 2011), and objective dimensions, such as dependence structures, relationship quality, and the broader international context (Chae et al., 2020; Deng et al., 2022; Wang et al., 2023). To facilitate a more structured analysis, we categorize these theoretical elements into three core dimensions. First is the inter-organizational dependence structure, formed by relationship-specific assets and resource dependence (Yu, 2010; Xiang et al., 2014); second is the relationship duration, which reflects the cumulative effects of trust, social

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interaction, and relationship quality over time; and third is the country or region of the transaction partner, which integrates the institutional, cultural, and geopolitical contexts in which the relationship is embedded.

*2.4.1 Inter-organizational dependence structures*

The term Inter-organizational dependence structure refers to the relatively stable configuration shaped by the degree of mutual reliance between two organizations. These structures primarily arise from the bilateral resource dependence between partners (Pfeffer & Salancik, 2003; Yu & Wen, 2011) and constitute the core power mechanism of inter-organizational governance. They not only govern inter-firm interactions (Soontornthum et al., 2020) but also profoundly shape the immediate resource environment in which firms operate (Jiang et al., 2023), thereby exerting a decisive influence on value creation and appropriation (Yu et al., 2023; De Pourcq & Verleye, 2022). Consequently, they dictate the parameters of inter-organizational knowledge governance (Dyer & Singh, 1998), including both technology transfer and innovation spillovers. Within GVCs, these dependence structures are critical in determining the upgrading trajectories of manufacturing firms in developing countries (Liu & Zhang, 2009). The existing literature often discusses knowledge spillover from dominant to subordinate partners in broad terms and frequently fails to distinguish between intentional technology transfer and unintentional innovation spillovers. One perspective suggests that higher levels of asymmetric dependence foster relational stability, which in turn facilitates knowledge sharing (Almeida et al., 2021). Conversely, another view argues that as dependence becomes more unbalanced, the dominant party leverages its power to exert selective control over knowledge flows, facilitating spillovers that are mutually beneficial and suppressing those that pose competitive risks (Hu et al., 2020). Furthermore, the subordinate party's knowledge-search scope may be narrowed by this dependence, directly limiting the diversity of knowledge acquisition and subsequent innovation (Hsu et al., 2022). This perspective emphasizes that asymmetric dependence may lead to opportunistic behavior and the inhibition of innovation.

In the OEM context, how does a dependence structure influence innovation spillovers from clients or suppliers? In OEM relationships, firms typically exhibit a severe dependence on a few key clients. Observations show that many OEM firms derive over 70% of their annual revenue from their top five clients. Although this typical dependence structure may generate a relationship-building effect that aids spillovers, the stark power imbalance allows OEM clients to manipulate the knowledge governance of the relationship. Clients seek this control to shape the OEM firm's technical capabilities through technology transfer and simultaneous restriction of innovation spillovers to preempt potential risks, a competitive constraint effect. Given the narrow technological distance between the two parties, an OEM firm acquiring innovation knowledge might enter the customer's domain as a direct competitor. A classic example is Google's entrustment of Pixel smartphone production to HTC, and HTC simultaneously producing its own competing smartphones. In contrast, within buyer-supplier relationships, the technological distance between OEM firms and suppliers is greater and the knowledge bases are more heterogeneous. In this setting, the relationship-building effect that results from the OEM firm's higher relative dependence on its suppliers is likely to outweigh the competitive constraint effect, potentially leading to

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more robust innovation spillovers. Based on this we propose the following additional hypothesis.

Hypothesis 3: In OEM relationships, the innovation spillover from OEM clients to OEM firms is negatively correlated with the OEM firm's relative dependence on its clients; however, in buyer-supplier relationships, the innovation spillover from suppliers to OEM firms is positively correlated with the OEM firm's relative dependence on its suppliers.

*2.4.2 Relationship duration*

The duration of the inter-organizational relationship between an OEM firm and its clients or suppliers serves as a comprehensive proxy for inter-organizational trust and relationship quality. According to inter-organizational relationship theory, social factors along the relational continuum, such as long-term orientation, mutual trust, and relationship quality, function alongside power structures as decisive determinants of knowledge governance (Liu & Bi, 2009; Yu & Wen, 2011). These factors mitigate opportunistic risks, reduce future uncertainty, and solidify mutual commitment (Dyer & Singh, 1998). This, in turn, facilitates investment in relationship-specific assets and joint R&D, particularly the sharing of proprietary and tacit knowledge (Dyer & Nobeoka, 2000; Isaksson et al., 2016; Potter & Paulraj, 2021). Consequently, relationship duration exerts a reinforcing effect on the innovation spillovers from transaction partners to OEM firms in both GVC modalities.

Compared to buyer-supplier relationships, the technological distance between OEM clients and OEM firms is relatively narrow, allowing innovation spillovers to peak more rapidly. By contrast, in buyer-supplier relationships, the greater technological distance and more significant knowledge heterogeneity provide a longer temporal window for the absorption of innovation. From a medium- to long-term perspective, the reinforcing effect of relationship duration on innovation spillovers in OEM relationships is relatively weaker than in buyer-supplier relationships. As relationships persist, the cumulative innovation spillover effects from suppliers are expected to intensify progressively. Based on this we propose the following additional hypothesis.

Hypothesis 4: Relationship duration reinforces innovation spillovers from transaction partners to OEM firms in both OEM and buyer-supplier relationships, and this reinforcing effect is more significant in buyer-supplier relationships than in OEM relationships.

*2.4.3 Transaction partner country or region*

Given the intricacies of the international landscape and escalating global competition, the country or region of a transaction partner serves as a proxy for the international context in which IORs are embedded. For empirical purposes, transaction partners are classified as either domestic or foreign. In the specific context of GVC participation, many domestic partners have achieved significant technical parity with global frontiers; foreign OEM clients generally possess superior R&D, design, and innovation capabilities (Zhang et al., 2019; Wang, 2011). In international OEM operations, a substantial portion of key component and equipment suppliers are foreign entities that are directly designated by the clients through contractual mandates. Furthermore, even when OEM firms independently select suppliers, the rigorous technical specifications of high-end manufacturing lead them to prioritize globally leading firms. Consequently, both foreign OEM

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clients and foreign suppliers are expected to generate more robust innovation spillover effects than their domestic counterparts. Moreover, greater institutional and geographical distance may hinder formal technology transfer, and the resulting contextual heterogeneity is highly conducive to exploratory learning (Zhou et al., 2022), thereby amplifying the overall innovation spillover effect. Based on this reasoning we propose our final hypothesis.

Hypothesis 5: Both foreign OEM clients and foreign suppliers exert stronger innovation spillover effects on OEM firms than their domestic transaction partners, respectively.

## 3. Empirical Research Design

### 3.1 Sample Selection, Data Sources, and Processing

This study focuses on listed OEM firms within advanced manufacturing sectors, such as semiconductors, personal computers (PCs), and smartphones. Based on corporate annual reports and other public disclosures, we selected listed OEM firms that are simultaneously embedded in two distinct GVC modalities: OEM relationships and buyer-supplier relationships. To ensure a sufficient volume of OEM-specific observations and to measure the associated innovation spillover effects more precisely, firms where OEM operations do not constitute the primary business (e.g. Samsung and Intel) were excluded. Although such firms are global leaders in semiconductor manufacturing, their diversified business models mean their inter-firm linkages often resemble buyer-supplier arrangements rather than specialized OEM relationships. The final sample comprises nine prominent Chinese OEM-centric firms and 442 transaction partners that together constitute 597 distinct dyads.

Using the Bloomberg Supply Chain Database, we retrieved longitudinal inter-firm transaction data for these 597 dyads over an 11-year period (2012-2022). This dataset includes critical metrics such as annual transaction values, the proportion of these values relative to each party's total revenue or cost, and transaction timelines. Transaction partners were categorized into three types: (1) OEM clients; (2) suppliers in buyer-supplier relationships; and (3) dual-role partners that function simultaneously as both an OEM client and a supplier to the focal firm. To ensure rigorous classification, we manually verified the business nature of each transaction by cross-referencing Bloomberg's source documentation (e.g. annual report disclosures and transaction filings). This meticulous screening identified: 191 OEM clients that formed 245 OEM dyads with 883 transaction-year observations spanning the period from 2012- to 2022. Two hundred fifty-four suppliers formed 300 buyer-supplier dyads with 1,016 observations, and 26 dual-role enterprises formed 52 dual-transaction dyads with 251 observations (comprising 124 OEM and 127 buyer-supplier records).

Financial data for the focal OEM firms and their partners were synchronized from the Wind Database and corporate filings. Patent and citation data, including the count and frequency of patents cited by OEM firms from their partners, as well as subsequent innovation outcomes, were extracted from the Incopat database. To resolve inconsistencies in firm nomenclature across databases, we implemented a code-matching procedure that accounted for abbreviations and typographical variations. For instance, entries such as "GM", "General Motors", and "G. Motors"

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were standardized and mapped to unique identifiers (e.g. stock tickers). All algorithmically generated matches subsequently underwent manual auditing to ensure data integrity.

**3.2 Variable Measurement**

The following describes our estimation of GVC Innovation Spillover Effect as a function of various key variables. Following the research of Corsino et al. (2019) and Clayton et al. (2022) on knowledge diffusion and innovation spillovers, the measurement of the innovation spillover effect incorporated three components. Each dyadic pair *i* was formed between an OEM firm *f* and its partner, either a supplier *s* or a customer *c*. *n* is the number of new patents generated by OEM firm *f* in year *t* that result from citing the patents of supplier *s* (or customer *c*). *p* is the total number of unique patents belonging to supplier *s* (or customer *c*) cited by OEM firm *f* in year *t*. *q* is the total frequency (number of times) that OEM firm *f* cited the patents of supplier *s* (or customer *c*) in year *t*. By combining these three variables, we constructed the dependent variable Innovation-Spillover$_{it}$, which represents the innovation spillover effect produced within the dyadic relationship *i* in year *t*. To mitigate the impact of outliers, a logarithmic transformation was applied. The specific calculation formula is as follows: $lnins_{it}=ln\ (n_{it}+p_{it}+q_{it})$.

The explanatory variables consisted of variables at two levels: GVC modality and inter-organizational relationship (IOR) characteristics. GVC modality includes types based on dyadic relationships (OEM relationships and buyer-supplier relationships) as well as the dual-relationship type (where a transaction partner is simultaneously an OEM customer and a supplier to a focal OEM firm). IOR characteristics were structured into three dimensions: inter-organizational dependence structure, relationship duration, and the transaction partner's country or region. The specific definitions are as follows:

GVC Modality measures whether the relationship between the OEM firm and the transaction partner is an OEM relationship or a buyer-supplier relationship. We selected listed firms in China's advanced manufacturing sector whose primary business is contract manufacturing as the sample. Due to the unique position of OEM firms in GVCs, their transaction relationships with clients were identified as OEM relationships, signifying the OEM firm's embedding in process-deconstructed GVCs. Their transactions with suppliers were identified as buyer-supplier relationships, signifying embedding in modular-deconstructed GVCs. When a transaction partner serves as both an OEM customer (forming an OEM relationship) and a supplier (forming a buyer-supplier relationship) to the OEM firm, the relationship between the transaction partner and the OEM firm is considered a dual-transaction relationship.

Inter-organizational dependence structure refers to the relative dependence of the OEM firm on its transaction partner. Taking OEM relationships as an example, the relative dependence of an OEM firm on its customer was defined as the ratio between the percentage of revenue the OEM firm derives from the customer and the percentage of procurement costs the customer pays to the OEM firm. This ratio represents the disparity in dependence between the two parties (Lv et al., 2017). When the ratio is close to 1, it reflects an equilibrium of mutual dependence between the firms, whereas the degree of deviation from this value reveals the asymmetry of the interdependence. A ratio above 1 indicates that the OEM firm's dependence on the customer is

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higher than the reverse dependence. That is, the OEM firm's revenue share is higher than the customer's cost share. Referencing Yu (2010) on the measurement of OEM power structures[1] and Yeniyurt et al. (2014) on the measurement of inter-organizational dependence, and comprehensively considering the bilateral dependence structure, the dependence of both transaction parties was incorporated. Accordingly, the calculation formula for the inter-organizational dependence structure is as follows:

$$\text{Supplier Dependence Structure}=\frac{\text{Transaction value / OEM firm's total costs}}{\text{Transaction value / Supplier's total revenue}} \quad (1)$$

$$\text{Customer Dependence Structure}=\frac{\text{Transaction value / OEM firm's total revenue}}{\text{Transaction value / Customer's total costs}} \quad (2)$$

Transaction values, as well as the corresponding cost and revenue shares for OEM firms, suppliers, and clients, were obtained directly from Bloomberg, which synthesizes public information such as corporate annual reports. When the transaction partner is a supplier, the database provides the ratio of the transaction value to the OEM firm's total costs and the ratio of the transaction value to the supplier's total revenue. When the partner is a client, it provides the ratio of the transaction to the OEM firm's total OEM revenue and the ratio of the transaction to the client's total OEM expenditures. The inter-organizational dependence structure integrates these two factors. A ratio greater than 1 indicates that the OEM firm is more dependent on the partner (supplier or client), whereas a ratio less than 1 suggests that the partner is more dependent on the OEM firm.

Relationship duration refers to the number of years a transaction relationship existed between the OEM firm and its partner from 2012 to 2022, compiled from the Bloomberg Supply Chain Database. Following Liu & Bi (2009), we measured the duration of effective dyadic relationships by assigning a value of 1 for the initial year of the relationship and incrementing it for each subsequent year the transaction occurs.

Finally, transaction partner country or region reflects the international context of the relationship in which transaction partners were categorized as either domestic or foreign to signify whether the dyad was embedded in a Chinese value chain (1) or an international one (0).

For control variables we chose to control for the transaction value between the OEM firm and its partner as a key indicator of interaction intensity and economic importance, using the transaction amounts disclosed by Bloomberg. At the firm level, we controlled for characteristics including R&D investment, firm size, and operating profit for both the OEM firm and its partners. In the regression analysis, we included firm fixed effects and year fixed effects to account for individual heterogeneity and temporal shocks. Considering the time-lagged nature of innovation

[1] This study develops a refined measurement of inter-organizational dependence structure. Rather than directly replicating the approach of Yu (2010), we synthesize diverse theoretical insights to innovatively capture power asymmetry. Specifically, we calculate the ratio of directional dependence indicators between the focal firm and its transaction partners. Theoretically, our framework aligns with Yu (2010) by conceptualizing the relative position within a dyad through the lens of dominance and subordination. Operationally, however, we introduce several methodological refinements. We incorporate the dependence ratio perspective proposed by Lv et al. (2017) to quantify power imbalances. Furthermore, we draw on Yeniyurt et al. (2014) to operationalize dependence through the specific metrics of cost and revenue shares. This multi-dimensional, bilaterally grounded framework allows for a more comprehensive and precise characterization of the structural complexity inherent in inter-organizational dependence.

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(Guo et al., 2016; Yao et al., 2024), all explanatory and control variables at the dyadic and firm levels were lagged by one period to improve the accuracy and fit of the model. Detailed definitions for all variables are presented in Table 1.

**TABLE 1. Variable Definitions**

| Variables | | Definition | Source |
|---|---|---|---|
| GVC innovation spillover effect | $Lnins_{it}$ | New Patents from Citations: The number of new patents generated by the focal firm through the citation of a partner's (supplier/client) patents; The number of unique patents from the partner cited by the focal firm; The total frequency with which the focal firm cited the partner's patents. | Compiled from Incopat patent data |
| GVC modality | $Relation_{it-1}$ | GVC Modality: A categorical variable determined by the dyadic relationship type. Modular-deconstructed GVCs (buyer-supplier relationships) are coded as 0 (Relation_MG); Process-deconstructed GVCs (OEM relationships) are coded as 1 (Relation_DG); Dual-transaction relationships (where the firm maintains both OEM and buyer-supplier roles with a partner) are coded as 2 (Relation_Both). | Compiled from cross-industrial chain OEM enterprise data |
| Relative dependence structure | $Rely_{it-1}$ | Relative Dependence (OEM on Customer): Calculated as the ratio of transaction value as a share of the focal firm's total foundry revenue to transaction value as a share of the customer's total foundry expenditures. Relative Dependence (OEM on Supplier): Calculated as the ratio of the focal firm's procurement share from a specific supplier to that supplier's revenue share from the focal firm. | Sourced from Bloomberg Supply Chain Database |
| Relationship duration | $Dura_{it-1}$ | The total number of years during which an active transaction relationship existed between 2012 and 2022. | |
| Partner's country or region | $Coun_{it-1}$ | A dummy variable where 1 represents a domestic partner and 0 represents a foreign one. | |
| Transaction value | $Rv_{it-1}$ | The natural logarithm of the annual transaction volume between the focal firm and its partner. | Compiled from Wind financial data, supplemented by CSMAR and corporate annual reports; patent data from Incopat. |
| OEM firm size | $Fscale_{it}$ | The natural logarithm of the focal OEM firm's total assets. | |
| OEM firm R&D expenditure | $Frd_{it}$ | The natural logarithm of the focal OEM firm's R&D investment. | |
| OEM firm operating profit | $Fprofit_{it}$ | The natural logarithm of the focal OEM firm's operating profit. | |
| Partner's innovation level | $Cpat_{it-1}$ | The natural logarithm of the total number of invention patents held by the transaction partner. | |
| Partner's firm size | $Cscale_{it-1}$ | The natural logarithm of the transaction partner's total assets. | |

### 3.3 Model Construction

The primary objective of this study is to understand the mechanism of innovation spillovers within GVCs, specifically exploring the disparities in GVC innovation spillovers (Hypotheses 1 and 2) and the different mechanisms of these spillovers (Hypotheses 3-5). In the main analysis, the dependent variable, Innovation Spillover, is measured by aggregating three patent-related dimensions. The explanatory variables involve two levels: GVC modality and inter-organizational relationship characteristics. All models in this research share the following basic structure:

$$Lnins_{it}=\beta_0+\beta_1 Relation_{it-1}+\beta_2 Rely_{it-1}+\beta_3 Dura_{it-1}+\beta_4 Coun_{it-1}+\beta_5 Relation_{it-1}\times Rely_{it-1}$$
$$+\beta_6 Relation_{it-1}\times Dura_{it-1}+\beta_7 Relation_{it-1}\times Coun_{it-1}+\gamma X_{it}+F_i+\mu_t+e_{it}.$$

*Relation* represents the different GVC modalities and is a three-category variable determined by the dyadic relationship type: buyer-supplier relationships are identified as modular-deconstructed GVCs *(Relation_MG*), OEM relationships are identified as process-deconstructed

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GVCs (*Relation_DG*), and cases where an OEM firm and its partner simultaneously maintain both relationships are considered dual-transaction relationships (*Relation_Both*). *Rely* represents the inter-organizational dependence structure; *Dura* is the inter-organizational relationship duration; and *Coun* is a 0/1 binary variable representing the international context of the relationship, where 1 indicates embedding in a domestic value chain and 0 indicates embedding in an international value chain. $F_i$ represents individual fixed effects, referring here to the control for focal OEM firms, and $\mu_t$ (year fixed effects) refers to the addition of annual fixed effects to the panel data regression results. Finally, $X_{it}$ represents the matrix of control variables corresponding to dyad *i* in year *t*.

# 4. Empirical Results

## 4.1 Descriptive Statistics and Correlation Analysis

Table 2 presents the descriptive statistics and correlation coefficient matrix for the sample data. The final sample consists of 2,150 observations of transaction data between OEM firms and their partners from 2012 to 2022. This includes 245 OEM dyads with 883 observations, 299 buyer-supplier dyads with 1,016 observations, and 52 dual-role dyads with 251 observations (comprising 124 OEM and 127 buyer-supplier transaction records). Correlation analysis reveals that both inter-organizational dependence and the partner's country or region are negatively correlated with GVC innovation spillover, and relationship duration shows a positive correlation. These preliminary findings are consistent with the theoretical derivations of our research hypotheses.

**TABLE 2. Descriptive Statistics and Correlation Coefficient Matrix**

| Descriptive Statistics | | | | | | | Correlation Matrix | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Variables** | **Obs** | **Mean** | **SE** | **Min** | **Max** | **VIF** | $Lnins_{it}$ | $Relation_{it-1}$ | $Rely_{it-1}$ | $Dura_{it-1}$ | $Coun_{it-1}$ | $Rv_{it-1}$ | $Fscale_{it}$ | $Frd_{it}$ | $Fprofit_{it}$ | $Cpat_{it-1}$ | $Cscale_{it-1}$ |
| $Lnins_{it}$ | 2150 | 1.063 | 1.641 | 0.000 | 7.229 | | 1 | | | | | | | | | | |
| $Relation_{it-1}$ | 2150 | 0.644 | 0.680 | 0.000 | 2.000 | 1.280 | 0.150 | 1 | | | | | | | | | |
| $Rely_{it-1}$ | 2150 | 1.172 | 1.390 | 0.000 | 7.581 | 1.160 | -0.003 | 0.301 | 1 | | | | | | | | |
| $Dura_{it-1}$ | 2150 | 1.299 | 0.490 | 0.693 | 2.398 | 1.140 | 0.171 | 0.082 | -0.002 | 1 | | | | | | | |
| $Coun_{it-1}$ | 2150 | 0.366 | 0.482 | 0.000 | 1.000 | 1.150 | -0.166 | 0.201 | 0.032 | -0.100 | 1 | | | | | | |
| $Rv_{it-1}$ | 2150 | 17.839 | 2.363 | 0.000 | 24.576 | 1.880 | 0.457 | 0.100 | -0.071 | 0.265 | -0.237 | 1 | | | | | |
| $Fscale_{it}$ | 2150 | 25.533 | 2.344 | 21.223 | 29.233 | 3.620 | 0.274 | -0.123 | 0.054 | 0.205 | -0.190 | 0.511 | 1 | | | | |
| $Frd_{it}$ | 2150 | 19.171 | 8.224 | 0.000 | 25.819 | 2.270 | 0.245 | -0.126 | 0.045 | 0.159 | -0.214 | 0.415 | 0.704 | 1 | | | |
| $Fprofit_{it}$ | 2150 | 17.302 | 14.371 | -20.713 | 27.746 | 1.760 | 0.169 | -0.115 | 0.031 | -0.037 | -0.107 | 0.245 | 0.584 | 0.231 | 1 | | |
| $Cpat_{it-1}$ | 2150 | 3.924 | 3.013 | 0.000 | 10.467 | 1.260 | 0.413 | 0.009 | -0.097 | 0.166 | -0.016 | 0.418 | 0.137 | 0.082 | 0.040 | 1 | |
| $Cscale_{it-1}$ | 2150 | 23.398 | 3.520 | 0.000 | 33.496 | 1.010 | 0.088 | 0.035 | -0.017 | 0.077 | -0.059 | 0.058 | 0.018 | 0.023 | -0.012 | 0.057 | 1 |

## 4.2 Comparison of GVC Innovation Spillover Effects and Interaction Effect Test

We constructed regression models to evaluate the relative strength of innovation spillover effects across the two types of GVCs, OEM and buyer-supplier relationships, as well as their interaction effects. To mitigate potential multicollinearity, we conducted a Variance Inflation Factor

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(VIF) diagnostic prior to the regression analysis. The VIF values for all independent variables are below 5 (Table 2), indicating that multicollinearity is not a significant concern. The sample was analyzed using Ordinary Least Squares (OLS) regression, as summarized in Table 3.

**TABLE 3. Comparison of Innovation Spillover Effects across GVCs**

| Variables | $Lnins_{it}$ | | | |
|---|---|---|---|---|
| | OLS | | FE | |
| | (1) | (2) | (3) | (4) |
| *Relation_DG* | 0.512*** | 0.437*** | 0.493*** | 0.426*** |
| | (0.074) | (0.075) | (0.073) | (0.071) |
| $Rely_{it-1}$ | | -0.053** | -0.116*** | -0.072*** |
| | | (0.026) | (0.026) | (0.024) |
| $Dura_{it-1}$ | | 0.141** | 0.548*** | 0.445*** |
| | | (0.066) | (0.077) | (0.073) |
| $Coun_{it-1}$ | | -0.352*** | -0.201*** | -0.196*** |
| | | (0.069) | (0.067) | (0.063) |
| *Relation_Both* | | | | 0.896*** |
| | | | | (0.099) |
| *Constant* | 0.784*** | -1.369** | 10.599*** | 9.541*** |
| | (0.050) | (0.623) | (3.293) | (3.018) |
| Control variables | No | Yes | Yes | Yes |
| Year FE | No | No | Yes | Yes |
| Individual FE | No | No | Yes | Yes |
| Observations | 1,899 | 1,899 | 1,899 | 2,150 |
| Adjusted R-squared | 0.024 | 0.331 | 0.404 | 0.400 |

Note: ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. Values in parentheses represent standard errors. Due to space constraints, coefficients for control variables and fixed effects are not reported; this convention applies to all subsequent tables unless otherwise specified.

Model OLS (1) includes only pure-play OEM and buyer-supplier dyads (where *Relation_MG* = 0 and *Relation_DG* = 1), directly illustrating the spillover disparities across GVC types. Model OLS (2) incorporates control variables into the OLS (1) framework, and these results show that the impact of GVC type on innovation spillover remains significant. The Fixed Effects (3) model further accounts for individual fixed effects of the OEM firms and time (year) fixed effects. Using the buyer-supplier relationship (*Relation_MG*) as the benchmark category, the regression coefficient for the OEM relationship (*Relation_DG*) is 0.493 and is significant at the 1% level. This suggests that OEM relationships generate significantly stronger innovation spillover effects than buyer-supplier relationships, provides empirical support for Hypothesis 1, and indicates that OEM clients may exert a stronger spillover effect on firms than suppliers do.

The Fixed Effects (4) model integrates the dual-role samples (*Relation_Both*) to explore the interaction effects between OEM and buyer-supplier relationships. In this model, the coefficient for OEM relationships remains positive and statistically significant (0.426, $p < 0.01$), consistent with previous research. The coefficient for dual-role relationships (*Relation_Both*) is also positive

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and significant (0.896, $p < 0.01$), indicating that when an OEM firm maintains a dual-transaction relationship with a partner, the resulting innovation spillover is significantly stronger than that of a singular buyer-supplier relationship. Comparing the coefficients of dual-role relationships and OEM relationships further demonstrates that the former yields a stronger spillover effect. This evidence suggests the presence of a positive interaction effect between OEM and buyer-supplier relationships, where embedding in multiple GVC roles simultaneously captures more knowledge than a single configuration, thereby supporting Hypothesis 2.

### 4.3 Mechanism Test of Innovation Spillover in GVCs

To investigate how inter-organizational relationship (IOR) characteristics influence innovation spillover across different GVC configurations, interaction terms between GVC types and IOR dimensions were also incorporated into the model. Applying fixed-effects OLS regression to the sample data yielded five regression models, the results of which are presented in Table 4.

**TABLE 4. Mechanisms of Innovation Spillover in GVCs**

| Variables | $Lnins_{it}$ | | | | |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| *Relation_DG* | 0.493*** | 0.743*** | 0.024 | 0.699*** | 0.592*** |
| | (0.073) | (0.104) | (0.172) | (0.081) | (0.197) |
| $Rely_{it-1}$ | -0.116*** | 0.048 | -0.115*** | -0.088*** | 0.072 |
| | (0.026) | (0.055) | (0.026) | (0.026) | (0.055) |
| $Dura_{it-1}$ | 0.548*** | 0.548*** | 0.386*** | 0.575*** | 0.456*** |
| | (0.077) | (0.077) | (0.094) | (0.076) | (0.093) |
| $Coun_{it-1}$ | -0.201*** | -0.137** | -0.211*** | 0.150* | 0.192** |
| | (0.067) | (0.069) | (0.067) | (0.091) | (0.093) |
| $Relation_DG \times Rely_{it-1}$ | | -0.232*** | | | -0.226*** |
| | | (0.069) | | | (0.068) |
| $Relation_DG \times Dura_{it-1}$ | | | 0.362*** | | 0.264** |
| | | | (0.120) | | (0.120) |
| $Relation_DG \times Coun_{it-1}$ | | | | -0.738*** | -0.709*** |
| | | | | (0.131) | (0.132) |
| *Constant* | 10.599*** | 10.220*** | 10.288*** | 9.928*** | 9.358*** |
| | (3.293) | (3.286) | (3.287) | (3.268) | (3.258) |
| Control variables | Yes | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes | Yes |
| Individual FE | Yes | Yes | Yes | Yes | Yes |
| Observations | 1,899 | 1,899 | 1,899 | 1,899 | 1,899 |
| Adjusted R-squared | 0.404 | 0.407 | 0.407 | 0.414 | 0.418 |

Model (1) serves as the baseline regression since it controls for both year fixed effects and individual fixed effects of the OEM firms. The coefficient for the OEM firm's relative dependence on its transaction partner ($Rely_{it-1}$) is negative (-0.116, $p < 0.01$). This indicates that, without distinguishing between GVC types, a higher relative dependence on a transaction partner directly

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weakens the GVC innovation spillover effect. In Model (2), an interaction term between GVC modality and relative dependence ($Relation_DG \times Rely_{it-1}$) is introduced. This result shows that the coefficient for this interaction term is also negative (-0.232, $p < 0.01$), suggesting that higher relative dependence on an OEM client weakens the innovation spillover effect in OEM relationships. In this model, the coefficient for the dependence structure ($Rely_{it-1}$) becomes positive but is not statistically significant. This implies that in buyer-supplier relationships, the OEM firm's relative dependence on its supplier does not directly influence innovation spillover, which runs contrary to Hypothesis 3.

In Model (1), the regression coefficient for relationship duration ($Dura_{it-1}$) is positive (0.548, $p < 0.01$), indicating that the longer the transaction relationship persists, the more significant the GVC innovation spillover effect becomes. Going further, in Model (3), we introduce the interaction between GVC modality and relationship duration and find that the coefficient for relationship duration is also positive (0.386, $p < 0.01$), showing that innovation spillover in buyer-supplier relationships is directly correlated with duration. The interaction term ($Relation_DG \times Dura_{it-1}$) is also positive (0.362, $p < 0.01$), meaning that each additional unit of relationship duration in an OEM relationship increases the innovation spillover effect by 0.748 units (0.386 + 0.362), ceteris paribus. This finding contradicts Hypothesis 4. We therefore find that relationship duration has a stronger reinforcing effect on OEM relationships than on buyer-supplier relationships and that although relationship duration strengthens spillovers in both GVC types, its impact is significantly more prominent in OEM relationships.

Transaction partner country or region reflects the regional contextual differences within GVCs. In Model (1), the coefficient for the partner's country or region ($Coun_{it-1}$) is negative (-0.201, $p < 0.01$), indicating that international value chains exhibit stronger innovation spillover effects. In Model (4), the interaction term between GVC modality and the partner's country/region ($Relation_DG \times Coun_{it-1}$) is also negative (-0.738, $p < 0.01$), showing that international spillover effects are stronger specifically within OEM relationships, which supports the portion of Hypothesis 5 regarding international OEM relationships. However, the coefficient for the partner's country or region ($Coun_{it-1}$) becomes positive (0.150, $p < 0.1$) in this model, suggesting that domestic value chains actually yield stronger innovation spillovers in buyer-supplier relationships. Consequently, the part of Hypothesis 5 that contends that international buyer-supplier relationships also have stronger spillover effects is not supported.

### 4.4 Robustness Checks

*4.4.1 Lagged variable specifications*

To mitigate the potential impact of measurement bias regarding innovation spillovers on the research findings, we also used global value chain innovation spillover data lagged by two and three years to test the spillover effects and their underlying mechanisms. The lagged data encompass inter-organizational relationship-level variables (including dependence structure, relationship duration, and transaction value) as well as firm-level variables for OEM clients and suppliers (such as firm size, R&D investment, and innovation levels). The results of the corresponding robustness tests are presented in Table 5.

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**TABLE 5. Robustness Checks for Mechanisms of GVC Innovation Spillovers**

| Variables | $Lnins_{it}$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2-Period Lagged ($j$=2) | | | | 3-Period Lagged ($j$=3) | | | |
| | (1) | (2) | (3) | (4) | (1) | (2) | (3) | (4) |
| *Relation_DG* | 0.494*** | 0.820*** | 0.157 | 0.735*** | 0.536*** | 0.844*** | 0.236 | 0.827*** |
| | (0.095) | (0.140) | (0.145) | (0.104) | (0.116) | (0.169) | (0.180) | (0.125) |
| $Rely_{it-j}$ | -0.121*** | 0.066 | -0.122*** | -0.082** | -0.091** | 0.092 | -0.093** | -0.040 |
| | (0.034) | (0.068) | (0.034) | (0.035) | (0.042) | (0.084) | (0.042) | (0.043) |
| $Dura_{it-j}$ | 0.127*** | 0.131*** | 0.072** | 0.139*** | 0.160*** | 0.163*** | 0.106** | 0.179*** |
| | (0.025) | (0.025) | (0.031) | (0.025) | (0.033) | (0.033) | (0.042) | (0.033) |
| $Coun_{it-j}$ | -0.193** | -0.110 | -0.199** | 0.275** | -0.211* | -0.128 | -0.211* | 0.418*** |
| | (0.091) | (0.095) | (0.091) | (0.125) | (0.113) | (0.117) | (0.112) | (0.157) |
| $Relation_DG \times Rely_{it-j}$ | | -0.281*** | | | | -0.270** | | |
| | | (0.088) | | | | (0.108) | | |
| $Relation_DG \times Dura_{it-j}$ | | | 0.116*** | | | | 0.108** | |
| | | | (0.038) | | | | (0.050) | |
| $Relation_DG \times Coun_{it-j}$ | | | | -0.977*** | | | | -1.247*** |
| | | | | (0.180) | | | | (0.221) |
| *Constant* | 14.746*** | 14.094*** | 13.883*** | 14.713*** | 18.039*** | 17.081*** | 16.886*** | 17.380*** |
| | (4.686) | (4.673) | (4.678) | (4.631) | (5.973) | (5.968) | (5.984) | (5.872) |
| Control variables | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Individual FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 1,226 | 1,226 | 1,226 | 1,226 | 894 | 894 | 894 | 894 |
| Adjusted R-squared | 0.436 | 0.440 | 0.440 | 0.449 | 0.441 | 0.444 | 0.443 | 0.460 |

Model (1) illustrates the relationship between GVC innovation spillovers and inter-organizational relationship characteristics. Here the empirical results for OEM relationships (*Relation_DG*) are positive and statistically significant at the 1% level under both the two-period and three-period lagged data tests. This supports the primary hypothesis of this paper that there are disparities in GVC innovation spillover effects, with process-deconstructed GVCs generating more innovation spillovers than modular-deconstructed GVCs. The inter-organizational dependence structure ($Rely_{it-j}$) remains consistently negative as well, indicating that the higher the OEM firm's relative dependence on its transaction partner, the weaker the GVC innovation spillover effect. Relationship duration ($Dura_{it-j}$) is also consistently positive, showing that relationship duration reinforces GVC innovation spillovers. Additionally, the transaction partner's country or region ($Coun_{it-j}$) is negative, indicating that innovation spillover effects are more prominent in international GVCs.

Models (2), (3), and (4) present the robustness tests for how IOR characteristics influence the innovation spillover effects of GVCs. The interaction term between GVC modality and inter-organizational dependence structure remains negative, maintaining consistency with the initial empirical results. In OEM relationships, higher dependence on the client leads to a stronger inhibitory effect on innovation spillovers. Similarly, the interaction term between GVC modality and relationship duration is still positive, which suggests that relationship duration has a reinforcing effect on innovation spillovers in both types of value chains, and this effect is more significant in process-deconstructed GVCs, which aligns with the empirical results. Finally, the interaction term between GVC modality and the transaction partner's country or region remains

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statistically significant at the 1% level with a negative coefficient. These robustness findings are all consistent with the original empirical results, showing that in OEM relationships, foreign clients have a stronger innovation spillover effect on OEM firms, whereas in buyer-supplier relationships, domestic suppliers have a stronger innovation spillover effect.

*4.4.2 Heckman selection model*

This study is based on the transactional relationships between OEM firms and their suppliers and clients. To ensure data representativeness and empirical accuracy, it is crucial to select samples with actual transaction values and clear transaction proportions. However, this selection process may lead to sample selection bias, as the sample may disproportionately include only those dyadic pairs that publicly disclose such details, thereby omitting other types of transactional relationships. To combat this, we employed the Heckman two-stage method for further robustness testing. In the first stage, a Probit model was used to identify the factors influencing a firm's decision to disclose transaction details, from which the Inverse Mills Ratio (IMR) for each observation was estimated. In the second stage, the IMR was incorporated as a control variable into the primary regression model to correct for potential selection bias. This approach addresses, to a certain extent, the statistical errors that were potentially introduced by sample selection bias, ensuring the robustness and reliability of the original research findings.

The results of the Heckman two-stage estimation are presented in Table 6. In Model (1), the dependent variable is the firm's transaction disclosure (*Vdisclosure*), a binary categorical variable (0/1) used to determine whether a firm disclosed its transaction details. Based on the original explanatory and control variables, institutional distance ($Ins_distance_{it}$) and technological distance ($Tech_distance_{it}$) were added to the model to estimate the Inverse Mills Ratio (IMR) for each observation. Models (2) and (3) report the regression results after incorporating the IMR as a control variable, and Models (4) and (5) serve as benchmarks for the Heckman model, illustrating the analysis results without correction for selection bias. First, the IMR coefficient is positive (0.287, $p < 0.01$), indicating the presence of sample selection bias. Specifically, the selectivity of the baseline empirical sample has a positive impact on the dependent variable, highlighting the importance of correcting for selection bias. These empirical results demonstrate that the coefficients for variables such as GVC modality and inter-organizational relationship characteristics in the Heckman models are essentially consistent with those in the OLS models. This suggests that despite the potential influence of sample selection, the coefficients of the explanatory variables remain stable overall, indicating that the predictive or explanatory power of the model remains largely unchanged after accounting for potential sample selection bias.

**TABLE 6. Heckman Robustness Checks for GVC Innovation Spillover**

| Variables | *Vdisclosure* | *Lnins*$_{it}$ | | | |
|---|---|---|---|---|---|
| | Probit | Heckman 2 stage | | OLS | |
| | (1) | (2) | (3) | (4) | (5) |
| *Relation_DG* | | 0.247*** | 0.230*** | 0.493*** | 0.426*** |
| | | (0.025) | (0.026) | (0.073) | (0.071) |
| *Relation_Both* | | | 0.455*** | | 0.896*** |
| | | | (0.039) | | (0.099) |

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TABLE 6 Continued

| Variables | *Vdisclosure* | *Lnins*$_{it}$ | | | |
|---|---|---|---|---|---|
| | Probit | Heckman 2 stage | | OLS | |
| | (1) | (2) | (3) | (4) | (5) |
| *Rely*$_{it-1}$ | 0.902*** | -0.082*** | -0.050*** | -0.116*** | -0.072*** |
| | (0.139) | (0.016) | (0.015) | (0.026) | (0.024) |
| *Dura*$_{it-1}$ | 0.271 | 0.182*** | 0.153*** | 0.548*** | 0.445*** |
| | (0.218) | (0.024) | (0.022) | (0.077) | (0.073) |
| *Coun*$_{it-1}$ | -0.108 | -0.051* | -0.051** | -0.201*** | -0.196*** |
| | (0.154) | (0.027) | (0.025) | (0.067) | (0.063) |
| *Rv*$_{it-1}$ | 0.334*** | 0.150*** | 0.164*** | 0.103*** | 0.108*** |
| | (0.039) | (0.026) | (0.022) | (0.020) | (0.018) |
| *Ins_distance*$_{it}$ | 0.231** | | | | |
| | (0.107) | | | | |
| *Tech_distance*$_{it}$ | -0.335** | | | | |
| | (0.137) | | | | |
| *IMR* | | 0.287*** | 0.322*** | | |
| | | (0.032) | (0.029) | | |
| *Constant* | 2.567 | 6.828*** | 6.847*** | 10.599*** | 9.541*** |
| | (7.950) | (1.131) | (1.077) | (3.293) | (3.018) |
| Control variables | Yes | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes | Yes |
| Individual FE | Yes | Yes | Yes | Yes | Yes |
| Observations | 7483 | 6630 | 7483 | 1,899 | 2,150 |
| pseudo R-squared | 0.948 | | | | |
| Adjusted R-squared | | 0.371 | 0.373 | 0.404 | 0.400 |

*4.4.3 Poisson regression (PPML)*

This study measures the dependent variable, GVC innovation spillover, using patent counts and citations, the statistical distribution of which contains zero values and exhibits over-dispersion. Following Shin et al. (2022), we therefore employed Poisson Pseudo-Maximum Likelihood (PPML) for additional robustness testing. PPML is a regression method designed for count data, making it suitable for handling zero-valued and over-dispersed datasets. It maintains high robustness even under potential model misspecification.

The PPML estimation results are shown in Table 7. Columns (1) and (2) test the heterogeneity of innovation spillovers across GVC types. The coefficients for OEM relationships (*Relation_DG*) and dual-transaction relationships (*Relation_Both*) are both positive and statistically significant at the 1% level. This indicates that OEM relationships yield stronger innovation spillovers than buyer-supplier relationships and that dual-role embedding creates a positive interaction that reinforces these spillovers. Columns (3)-(5) test the mechanisms of IOR characteristics. Here the interaction terms between GVC modality and dependence structure (*Relation_DG*×*Rely*$_{it-1}$) and between GVC modality and partner country/region (*Relation_DG*×*Coun*$_{it-1}$) both remain negative at the 1% level, consistent with the main findings. In Model (4), the interaction between GVC modality and relationship duration (*Relation_DG*×*Dura*$_{it-1}$) is not statistically significant, but the main effect of relationship duration (*Dura*$_{it-1}$) remains positive and statistically significant at the 1% level. This underscores the fact that relationship stability and longevity are critical factors in facilitating knowledge sharing and innovation.

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**TABLE 7. Robustness Checks - Poisson Regression (PPML) Results**

| Variables | $Lnins_{it}$ | | | | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| *Relation_DG* | 0.399*** | 0.371*** | 0.599*** | 0.247 | 0.466*** | 0.680*** |
| | (0.076) | (0.071) | (0.107) | (0.188) | (0.079) | (0.196) |
| $Rely_{it-1}$ | -0.069** | -0.030 | 0.065 | -0.070** | -0.051* | 0.194*** |
| | (0.030) | (0.028) | (0.067) | (0.030) | (0.030) | (0.052) |
| $Dura_{it-1}$ | 0.636*** | 0.572*** | 0.645*** | 0.574*** | 0.645*** | 0.563*** |
| | (0.093) | (0.085) | (0.094) | (0.117) | (0.093) | (0.109) |
| $Coun_{it-1}$ | -0.315*** | -0.275*** | -0.270*** | -0.317*** | 0.007 | 0.096 |
| | (0.076) | (0.063) | (0.077) | (0.076) | (0.119) | (0.098) |
| *Relation_Both* | | 0.942*** | | | | 0.665*** |
| | | (0.091) | | | | (0.070) |
| $Relation_DG \times Rely_{it-1}$ | | | -0.192** | | | -0.332*** |
| | | | (0.083) | | | (0.072) |
| $Relation_DG \times Dura_{it-1}$ | | | | 0.108 | | 0.073 |
| | | | | (0.117) | | (0.107) |
| $Relation_DG \times Coun_{it-1}$ | | | | | -0.526*** | -0.475*** |
| | | | | | (0.152) | (0.121) |
| *Constant* | 17.325*** | 16.411*** | 16.009*** | 17.022*** | 16.882*** | 13.433*** |
| | (4.731) | (4.066) | (4.594) | (4.723) | (4.680) | (3.892) |
| Control variables | Yes | Yes | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Individual FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 1899 | 2150 | 1899 | 1899 | 1899 | 2150 |
| Pseudo R-squared | 0.332 | 0.327 | 0.333 | 0.332 | 0.334 | 0.335 |

*4.4.4 Negative binomial regression*

To address potential over-dispersion in the data, we further introduced a Negative Binomial Regression (NBR) model. By incorporating a dispersion parameter, this type of model more accurately handles cases where the variance exceeds the mean, providing robust estimates when data dispersion exceeds the assumptions of the Poisson distribution. Table 8 presents the NBR estimation results. Columns (1) and (2) provide robustness checks for the innovation spillover effects across different GVC types, with results remaining consistent with the primary findings. Columns (3)-(5) test the mechanisms of inter-organizational relationship (IOR) characteristics. Here the interaction terms between GVC modality and dependence structure ($Relation_DG \times rely_{it-1}$) and between GVC modality and the partner's country or region ($Relation_DG \times coun_{it-1}$) are both negative at the 1% level. Similar to the Poisson regression results, the interaction term for relationship duration ($Relation_DG \times dura_{it-1}$) is not statistically significant. Overall, the NBR results corroborate the robustness of the previous findings.

# 5. Further Research

## 5.1 Innovation Spillover Mechanisms in Process-Deconstructed GVCs

Innovation spillover mechanisms vary significantly across different GVC configurations. Although the preceding analysis employed interaction terms to test these effects, such an approach

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**TABLE 8. Robustness Check - NBR Results**

| Variables | $Lnins_{it}$ | | | | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| *Relation_DG* | 0.402*** | 0.407*** | 0.639*** | 0.159 | 0.489*** | 0.700*** |
| | (0.080) | (0.074) | (0.121) | (0.196) | (0.084) | (0.203) |
| $Rely_{it-1}$ | -0.086*** | -0.051* | 0.063 | -0.087*** | -0.065** | 0.195*** |
| | (0.032) | (0.027) | (0.065) | (0.032) | (0.032) | (0.053) |
| $Dura_{it-1}$ | 0.632*** | 0.585*** | 0.630*** | 0.537*** | 0.643*** | 0.536*** |
| | (0.095) | (0.087) | (0.095) | (0.118) | (0.095) | (0.106) |
| $Coun_{it-1}$ | -0.335*** | -0.326*** | -0.275*** | -0.338*** | -0.055 | 0.032 |
| | (0.084) | (0.074) | (0.087) | (0.084) | (0.121) | (0.104) |
| *Relation_Both* | | 1.013*** | | | | 0.715*** |
| | | (0.105) | | | | (0.094) |
| $Relation_DG \times Rely_{it-1}$ | | | -0.219*** | | | -0.368*** |
| | | | (0.084) | | | (0.072) |
| $Relation_DG \times Dura_{it-1}$ | | | | 0.179 | | 0.121 |
| | | | | (0.132) | | (0.118) |
| $Relation_DG \times Coun_{it-1}$ | | | | | -0.527*** | -0.476*** |
| | | | | | (0.170) | (0.135) |
| *Constant* | 17.153*** | 16.636*** | 15.600*** | 16.592*** | 16.615*** | 13.700*** |
| | (5.225) | (4.363) | (5.242) | (5.240) | (5.178) | (4.307) |
| lnalpha | -0.665*** | -0.709*** | -0.684*** | -0.666*** | -0.709*** | -0.868*** |
| | (0.139) | (0.143) | (0.140) | (0.139) | (0.143) | (0.142) |
| Control variables | Yes | Yes | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Individual FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 1899 | 2150 | 1899 | 1899 | 1899 | 2150 |
| Pseudo R-squared | 0.181 | 0.182 | 0.183 | 0.182 | 0.183 | 0.188 |

Note: lnalpha represents the natural logarithm of the dispersion parameter, which is used to control for the degree of over-dispersion in the data. The fact that lnalpha is statistically different from zero indicates that the data exhibits over-dispersed characteristics, suggesting that the NBR model is more appropriate than the Poisson regression model.

may overlook the specific characteristics of transaction partners and dyadic relationships inherent to each GVC type. To investigate the differential impact of inter-organizational relationship (IOR) characteristics under "process-deconstructed" and "modular-deconstructed" GVC scenarios more precisely, we split the research sample into two distinct sub-samples based on GVC type. By treating IOR characteristics as the primary explanatory variables within these specific contexts, we can further explore the unique innovation spillover mechanisms of each configuration.

Table 9 reports the empirical results for the process-deconstructed GVC sub-sample. The coefficient for the inter-organizational dependence structure ($Rely_{it-1}$) is negative (-0.225, $p < 0.01$), indicating that higher dependence on an OEM client leads to lower innovation spillover, and the positive coefficient for relationship duration ($Dura_{it-1}$) (0.839, $p < 0.01$) indicates that long-term cooperative relationships facilitate innovation spillovers. Furthermore, the coefficient for the partner's country or region ($Coun_{it-1}$) is negative (-0.431, $p < 0.01$), implying that foreign OEM clients are more effective in driving innovation spillovers than their domestic counterparts.

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**TABLE 9. Mechanism Test of Innovation Spillover in Process-Deconstructed GVCs**

| Variables | $Lnins_{it}$ | | |
|---|---|---|---|
| | Baseline regression ($j$=1) | 2-Period Lagged ($j$=2) | 3-Period Lagged ($j$=3) |
| | (1) | (2) | (3) |
| $Rely_{it-j}$ | -0.225*** | -0.233*** | -0.189*** |
| | (0.041) | (0.058) | (0.068) |
| $Dura_{it-j}$ | 0.839*** | 0.237*** | 0.275*** |
| | (0.126) | (0.039) | (0.051) |
| $Coun_{it-j}$ | -0.431*** | -0.564*** | -0.654*** |
| | (0.110) | (0.147) | (0.174) |
| *Constant* | 8.787* | 5.770 | 13.087 |
| | (5.069) | (6.939) | (8.371) |
| Control variables | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes |
| Individual FE | Yes | Yes | Yes |
| Observations | 883 | 567 | 424 |
| Adjusted R-squared | 0.487 | 0.530 | 0.546 |

## 5.2 Innovation Spillover Mechanisms in Modular GVCs

Table 10 reports the empirical results for innovation spillover mechanisms within modular-deconstructed GVCs. These results show that the regression coefficient for relationship duration ($Dura_{it-1}$) is positive (0.364, $p < 0.01$), which is consistent with the findings in process-deconstructed GVCs. Regarding the partner's country or region ($Coun_{it-1}$), the coefficients are positive across multiple lagged periods, which suggests that over a longer time horizon, domestic suppliers facilitate GVC innovation spillovers more effectively than foreign suppliers.

**TABLE 10. Mechanism Test of Innovation Spillover in Modular-Deconstructed GVCs**

| Variables | $Lnins_{it}$ | | |
|---|---|---|---|
| | Baseline regression ($j$=1) | 2-Period Lagged ($j$=2) | 3-Period Lagged ($j$=3) |
| | (1) | (2) | (3) |
| $Rely_{it-j}$ | 0.047 | 0.069 | 0.071 |
| | (0.058) | (0.072) | (0.091) |
| $Dura_{it-j}$ | 0.364*** | 0.072** | 0.107** |
| | (0.096) | (0.033) | (0.045) |
| $Coun_{it-j}$ | 0.095 | 0.223* | 0.361** |
| | (0.094) | (0.130) | (0.167) |
| *Constant* | 13.164*** | 23.575*** | 27.854*** |
| | (4.331) | (6.345) | (8.616) |
| Control variables | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes |
| Individual FE | Yes | Yes | Yes |
| Observations | 1,016 | 659 | 470 |
| Adjusted R-squared | 0.311 | 0.344 | 0.347 |

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Comparing these results to those of process-deconstructed GVCs reveals that the impact of inter-organizational dependence varies across different value chain types. Unlike the significant inhibitory effect observed when an OEM firm depends on an OEM client, the positive impact of depending on a supplier in a modular chain is not statistically significant. However, relationship duration consistently shows a positive influence on innovation spillovers in both GVC types. Additionally, the complex patterns associated with national and regional factors suggest that the partner's location plays distinct roles depending on the specific GVC configuration.

**5.3 Mechanism Analysis: The Role of Technological Distance**

Technological distance is a critical metric for assessing the ease of knowledge transfer and plays a vital role in explaining the disparities in innovation spillover effects between OEM relationships and buyer-supplier relationships. It quantifies the degree of divergence in technological knowledge and innovation trajectories between firms, thus reflecting the similarity and complementarity of their technological foundations, as well as potential barriers to knowledge exchange (Forman & Van Zeebroeck, 2019; Banal-Estañol et al., 2022; Palit et al., 2022). A smaller technological distance implies greater technological proximity, meaning that firms share similar knowledge bases. This similarity makes it easier for partners to understand and absorb each other's technical knowledge, thereby reducing the barriers to learning and knowledge integration (Isaksson et al., 2016).

To test this, we follow the calculation method of Jones et al. (2021) and Palit et al. (2022) to quantify technological distance by the Euclidean distance of patent portfolios across International Patent Classification (IPC) categories. The specific steps are as follows. First, patent application data for OEM firms and their suppliers and clients are collected and categorized according to four-digit IPC codes. Next, the number of patents within each IPC category is calculated. Based on these data, the technological distance between the OEM firm and its supplier or customer in a specific year can be calculated as follows:

$$Tech_distance_{it}=\sqrt{\sum_{j=1}^{N}(P_{ik}-P_{jk})^2} \tag{3}$$

where $i$ and $j$ represent two different firms, $t$ represents the patent application year, and $P_{ik}$ and $P_{jk}$ are the number of patents for company $i$ and company $j$ in the $k^{th}$ IPC category, respectively. This indicator reflects a measure of technical similarity; a smaller technological distance indicates that the two companies are technologically closer, and the opposite implies a larger technical difference.

Table 11 presents the mechanisms of technological distance in the innovation spillover effects of the two types of GVCs. In Model (1), the coefficient for technological distance ($Tech_distance_{it}$) is positive (0.027, $p < 0.01$), which means that when relationship types are not distinguished, technological distance is positively correlated with the GVC innovation spillover effect. That is, the greater the technological distance, the stronger the GVC innovation spillover effect. In Model (2), an interaction term between GVC type and technological distance is introduced. This model shows that after adding the interaction term, the coefficient for technological distance becomes negative (-0.041, $p < 0.01$), and the coefficient for the interaction term ($Relation_DG \times Tech_distance_{it}$) is positive (0.127, $p < 0.01$). These results indicate that technological distance has a

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negative impact on the innovation spillover effect of buyer-supplier relationships. Specifically, in buyer-supplier relationships, a smaller technological distance leads to a stronger innovation spillover effect. In contrast, in OEM relationships, technological distance is positively correlated with the innovation spillover effect of OEM clients. That is, in OEM relationships, a larger technological distance leads to a stronger innovation spillover effect. Models (3)-(6) use different methods to perform robustness checks, and these results show that the research conclusions are relatively robust: technological distance plays different roles in different types of value chains. In modular-deconstructed value chains, a smaller technological distance reduces the technical barriers to the spillover of suppliers' innovative knowledge, thereby strengthening the innovation spillover effect. In process-deconstructed value chains, a larger technological distance reduces the competition effect caused during the knowledge flow process, thereby strengthening the innovation spillover effect.

**TABLE 11. Mechanism Test of Innovation Spillover in GVCs**

| Variables | $Lnins_{it}$ | | | | | |
|---|---|---|---|---|---|---|
| | OLS | | PPML | | NBR | |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| *Relation_DG* | 0.506*** | -0.111 | 0.399*** | -0.120 | 0.403*** | -0.115 |
| | (0.073) | (0.105) | (0.076) | (0.151) | (0.080) | (0.141) |
| $Tech_distance_{it}$ | 0.027*** | -0.041*** | 0.029** | -0.018 | 0.023* | -0.025 |
| | (0.010) | (0.013) | (0.012) | (0.017) | (0.012) | (0.016) |
| $Rely_{it-1}$ | -0.116*** | -0.105*** | -0.067** | -0.057* | -0.085*** | -0.076** |
| | (0.026) | (0.025) | (0.030) | (0.030) | (0.032) | (0.032) |
| $Dura_{it-1}$ | 0.545*** | 0.527*** | 0.634*** | 0.631*** | 0.634*** | 0.611*** |
| | (0.077) | (0.076) | (0.093) | (0.092) | (0.095) | (0.094) |
| $Coun_{it-1}$ | -0.141** | -0.207*** | -0.229*** | -0.282*** | -0.257*** | -0.321*** |
| | (0.070) | (0.070) | (0.075) | (0.076) | (0.093) | (0.094) |
| $Relation_DG \times Tech_distance_{it}$ | | 0.127*** | | 0.076*** | | 0.083*** |
| | | (0.016) | | (0.019) | | (0.019) |
| *Constant* | 10.167*** | 11.066*** | 16.729*** | 17.316*** | 14.378*** | 14.788*** |
| | (3.291) | (3.238) | (4.704) | (4.677) | (4.689) | (4.641) |
| Lnalpha | | | | | -0.690*** | -0.746*** |
| | | | | | (0.142) | (0.146) |
| Control variables | Yes | Yes | Yes | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Individual FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 1899 | 1899 | 1899 | 1899 | 1899 | 1899 |
| Adjusted R-squared | 0.406 | 0.426 | | | | |
| Pseudo R-squared | | | 0.333 | 0.337 | 0.182 | 0.186 |

## 6. Discussion of Findings

### 6.1 Comparative and Interaction Effects of GVC Innovation Spillovers

Previous research on GVC knowledge spillovers has largely been confined to intentional technology transfer from MNCs to local firms (Pasquali, 2021; Deng et al., 2022; Yang et al.,

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2022). Unintentional innovation spillover effects, those occurring without subjective intent, remain underexplored. Furthermore, the long-standing division between inter-product and intra-product specialization has left the innovation spillover effects of different GVCs a theoretical puzzle. By using OEM and buyer-supplier relationships to represent process-deconstructed and modular-deconstructed GVCs, respectively, this study highlights significant disparities in their innovation spillover effects. Specifically, process-deconstructed GVCs generate significantly stronger innovation spillovers than modular-deconstructed GVCs. Additionally, the study identifies a positive interaction effect between these two types of GVCs that validates the existence of inter-organizational innovation spillovers (Rashed et al., 2010; Alcacer & Oxley, 2014) and the heterogeneity of innovation knowledge from different sources (Um & Ho, 2020: Yu, 2021). Most importantly, the study clarifies the internal mechanisms of GVC innovation spillovers. By classifying GVCs into process-deconstructed and modular-deconstructed types and utilizing the context of OEM firms being simultaneously embedded in both, this research integrates the historically separate perspectives of inter-product and intra-product specialization. This integration holds paradigm-expanding significance for key research domains such as GVC governance and the upgrading trajectories of firms in developing countries."

### 6.2 Mechanisms of GVC Innovation Spillovers

This study incorporates inter-organizational relationship (IOR) characteristics into the analysis of GVC innovation spillovers, elucidating the micro-mechanisms of these effects and contributing to the literature on GVC knowledge dynamics. First, the we find that the more an OEM firm depends on its OEM client, the more the innovation spillover in that relationship is inhibited. This aligns with the existing consensus that high dependence on transaction partners weakens a firm's technical upgrading capacity (Yu, 2011, 2014; Deng et al., 2022; Hsu et al., 2022). Our findings indicate that innovation spillovers follow this same logic, and that the impact of dependence structure varies significantly across different relationship types, deepening the research on both inter-organizational dependence and innovation spillovers. Second, since it was established (Alcacer & Oxley, 2014; Isaksson et al., 2016) that relationship duration reinforces knowledge spillover effects, there has been a lack of comparison across different types of organizational relationships. This study attests to the critical role of relationship duration in promoting innovation spillovers and finds that its reinforcing effect is significantly stronger in OEM relationships than in buyer-supplier relationships. Finally, although previous studies have suggested that increased technological distance hinders the cultivation of innovation capabilities (Liu et al., 2015; Banal et al., 2022; Palit et al., 2022), our research finds that the manifestation of this rule varies across value chain types. In buyer-supplier relationships, a large technological distance acts as a barrier to innovation spillover. In contrast, in OEM relationships that same technological distance can become an advantage, fostered by close relational proximity that leads to stronger innovation spillovers.

### 6.3 Moderating Effects of Domestic and International Partners

We incorporated the country or region of transaction partners as a contextual factor to explore the performance disparities in innovation spillovers between domestic and international partners. Within the GVC literature, transaction partners of local firms are traditionally categorized using

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broad descriptors such as “flagship firms”, MNCs, or “international suppliers/clients”, often overlooking the distinction between domestic and international value chains. In reality, the location of a transaction partner encapsulates critical contextual information, including bilateral institutional structures, innovation cultures, and inter-organizational geographic proximity. Our empirical results show that in process-deconstructed GVCs, foreign OEM clients generate stronger innovation spillover effects than domestic ones. In contrast, in modular-deconstructed GVCs, domestic suppliers facilitate innovation spillovers more effectively than foreign suppliers over a longer time horizon.

## 7. Research Conclusions and Policy Implications

This study extends the analytical scope of GVC knowledge research from technology transfer to innovation spillovers. Using OEM firms as the empirical setting, it bridges the long-standing divide between intra-product and inter-product specialization to examine the innovation spillover effects of two GVC types, process-deconstructed (OEM relationships) and modular-deconstructed (buyer-supplier relationships), as well as the influence of inter-organizational relationship characteristics. Our most important findings are as follows. First, systematic differences exist between the two GVC types, with process-deconstructed GVCs generating significantly stronger innovation spillovers than modular-deconstructed GVCs. Moreover, there is a positive interaction effect. When a transaction partner simultaneously serves as both an OEM customer and a supplier, reflecting a state of relational multiplexity, the resulting innovation spillover effect is more robust than under single-chain embeddedness. Second, the impact of inter-organizational relationship characteristics varies across governance structures. Although greater dependence of OEM firms on their customers inhibits innovation spillovers, relationship duration consistently reinforces them. In addition, technological distance exhibits divergent effects. In OEM relationships, greater technological distance facilitates stronger spillovers, but in buyer-supplier relationships, technological proximity (smaller distance) enhances spillover effects. Third, the geographic context of transaction partners plays a differentiated role. In OEM relationships, foreign customers generate stronger innovation spillovers, whereas in buyer-supplier relationships, domestic suppliers exert a more significant spillover effect.

As mentioned above, President Xi Jinping stated that “Key and core technologies cannot be secured through begging, buying or pleading.” This underscores a necessary strategic shift for local firms embedded in GVCs, one that must move from a focus on “technology transfer” to “innovation spillover.” Although seeking intentional technology transfer from multinational corporations, local firms must also leverage the innovation spillover effects inherent in GVCs and engage in exploratory learning to acquire rich knowledge resources. First, firms should deepen their participation in the global innovation landscape. Adopting an open strategic mindset is the micro-foundation of the “dual circulation” development paradigm. By looking outward, local enterprises establish the essential conduits needed to access global innovation resources. This shift in perspective allows firms to transition from passive “absorbers” to active “innovators”, which directly supports China’s strategic goal of independent innovation.

Second, both enterprises and policymakers should engage in rational decision-making

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regarding GVC embeddedness—taking into account factors such as governance type (process-deconstructed vs. modular-deconstructed) and partner origin (domestic vs. international)—to fully leverage the interactive effects between heterogeneous GVCs. A "one-size-fits-all" strategy is ineffective because different GVC types offer distinct innovation resources. For example, process-deconstructed GVCs and modular-deconstructed GVCs provide different learning opportunities. In strategic and high-tech sectors, OEM arrangements remain a vital pathway for acquiring frontier technology. Therefore, the state should implement differentiated policies that encourage traditional industries to move toward own-brand manufacturing (OBM). It should also increase support for OEM activities in high-end, advanced manufacturing. Third, firms and regulators should prioritize building stable and balanced relationships. Relationship duration and dependence are the primary drivers of innovation spillovers. To optimize these effects, firms should focus on long-term, balanced GVC partnerships. On a practical level, this means local enterprises must manage their relationship-specific investments carefully. By diversifying their partner portfolios, firms can reduce excessive concentration on dominant clients and maintain the strategic autonomy necessary for independent growth.

Fourth, the Chinese government should expand high-standard opening-up through precision-oriented policies. As de-globalization risks rise, major economies have incentives to take the lead in stabilizing and restructuring global production networks. Since the geographic and institutional context of a partner moderates spillover effects, policy interventions must be targeted. Specifically, the state should cultivate National Value Chains as the core of the domestic cycle and should also promote the integration of local firms into the global landscape to ensure a resilient and complementary "dual circulation" pattern.

Although the inter-organizational dyad is the fundamental and most vital unit of GVC analysis, it remains only a localized segment of the chain. Consequently, conclusions drawn at the dyadic level regarding the GVC as a whole should be interpreted with caution. Furthermore, because this study utilized OEM and buyer-supplier relationships to represent process-deconstructed and modular-deconstructed GVCs, respectively, and did not incorporate other structurally rich relationship types, such as the "foundry-packaging/testing" interface in the semiconductor GVC, the results may not be generalizable. As an initial exploration into a new paradigm for GVC research using a dyadic lens, future studies should ascend to the "chain level." There is a need to join the perspectives of intra-product and inter-product specialization to develop a more unified and systematic framework. Finally, since our classification into two basic types provides a tractable analytical entry point, future research should adopt a taxonomic perspective to conduct specialized classification studies on the diverse typologies of GVCs.

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