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## DISENTANGLING TRADE DYNAMICS: COMPARATIVE GRAVITY ANALYSIS OF CROSS-BORDER GOODS AND SERVICES FLOWS

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### ABSTRACT

This paper provides a comprehensive examination of international trade patterns through the lens of the gravity model, focusing on the nuanced distinctions between merchandise goods and service trade. By synthesizing theoretical foundations and empirical advancements, it highlights the challenges and complexities inherent in modeling trade in intangible services compared to physical goods. The research delves into the multifaceted determinants of trade costs—including economic size, geographic distance, cultural proximity, regulatory barriers, and digital transformation—showing how their influence varies across sectors. Emphasis is placed on the evolving role of service trade in global value chains, with particular attention to modes of supply and sector-specific heterogeneities. The paper underscores the critical importance of incorporating multilateral resistance terms and advanced econometric techniques to accurately capture trade flows in both goods and services. Findings suggest that while gravity equations remain a robust tool for international trade analysis, adaptations are necessary to address the unique features of service trade. This work advances understanding of trade integration and policy implications in an increasingly interconnected and service-oriented global economy.

**KEYWORDS:** international trade, trade dynamics, economics, trade law

### 1. INTRODUCTION

Understanding the dynamics of cross-border flows of goods and services remains one of the central challenges in inter-national economics. Since Tinbergen's pioneering work [1], the gravity model has become the workhorse framework for quantifying bilateral trade flows and evaluating the effects of policy changes. Its intuitive analogy to Newton's law of gravity—where economic size attracts trade and distance resists it—has proven remarkably robust across decades and datasets.

Yet the global economy has changed profoundly since the early gravity models were formulated. The rise of services trade, digital platforms, and global value chains has blurred the lines between producers and consumers, exporters and importers, and goods and services [2]. In this environment,



traditional proxies for trade costs such as distance or tariffs capture only a fraction of the frictions faced by firms and consumers.

A growing literature has extended gravity models to incorporate new dimensions. Structural gravity models derived from micro foundations address the so-called multilateral resistance terms that capture third-country effects [3]. PPML estimation techniques handle zero trade flows and heteroscedasticity [4], making it possible to work with highly disaggregated datasets including services.

Services trade, in particular, introduces complexities absent in merchandise trade. It is shaped by intangibility, simultaneity of production and consumption, and regulatory heterogeneity. Classifying services by mode of supply under the General Agreement on Trade in Services (GATS) reveals distinct patterns of cost and market entry [5]. Producer services, consumer services, and network-based services each respond differently to policy interventions and digital infrastructure [6].

The digital revolution amplifies these challenges. Cross-border data flows, online platforms, and cloud computing have reduced information costs but increased the importance of data governance and cybersecurity [7]. Gravity models that ignore these factors risk underestimating or misattributing the effects of policy changes.

Climate change and sustainability concerns have added yet another layer. Trade routes may shift due to melting ice or climate-induced disruptions [8], while deep trade agreements now include environmental provisions that shape competitiveness and market access. These trends call for new variables and theoretical extensions to capture dynamic trade costs.

Migration and mobility also matter. Diaspora networks and temporary movement of professionals can facilitate market entry and knowledge transfer [9]. Visa policies, recognition of qualifications, and remote work arrangements affect the tradability of services, especially under GATS Modes 2 and 4. Network analysis of global value chains provides a way to model interdependencies beyond bilateral flows. Input-output linkages, social network indicators, and platform participation variables can enrich gravity models and yield better policy counterfactuals [10]. By embedding countries in a network rather than treating them as isolated dyads, researchers can capture spillovers and resilience. This paper builds on these developments by revisiting the gravity model in the context of both goods and services trade. We propose a comparative analysis that integrates sectoral heterogeneity, digital-era trade cost measurement, network interdependencies, deep trade agreements, and emerging issues of climate, technology, and mobility. In doing so, we provide a roadmap for updating the gravity framework to meet the challenges of the twenty-first century.



The remainder of the paper is organized as follows. Section II reviews the evolution of gravity models for goods and services. Section III examines sectoral heterogeneity in trade flows. Section IV discusses measurement of trade costs in the digital era. Section V analyzes network interdependencies and global value chains. Section VI explores deep trade agreements and policy innovations. Section VII highlights emerging issues related to climate, technology, and mobility. Section VIII concludes.

## **II. EVOLUTION OF GRAVITY MODELS FOR GOODS AND SERVICES**

The gravity model of trade originated with [1], who drew an analogy between Newton’s law of gravitation and international trade flows. In his seminal work, Tinbergen proposed that bi-lateral trade volumes are directly proportional to the economic sizes of the two countries and inversely proportional to the geographic distance between them. This early formulation was intuitive but relatively simple, focusing on merchandise goods and ignoring many structural features of modern trade.

Subsequent advances refined the model into what is now termed the “structural gravity model.” The influential contribution by [3] introduced the concept of multilateral resistance, showing that bilateral trade flows are also shaped by each country’s relative position within the global trading network. This adjustment made the model more consistent with general equilibrium theory and allowed for more accurate welfare analysis.

One of the major developments in applying gravity models to both goods and services trade has been the inclusion of sectoral heterogeneity. [11] and later [12] stressed that differences in sector characteristics—such as transportability, regulation, and the degree of firm heterogeneity—necessitate sector-specific adaptations. These works opened the door to disaggregated analyses that differentiate between traditional goods trade and emerging cross-border services.

Another milestone was the introduction of appropriate estimators. Traditional studies often used ordinary least squares (OLS) on log-linearized forms of the gravity equation, but this excluded zero trade flows and generated heteroscedasticity problems. [4] proposed the Poisson Pseudo-Maximum Likelihood (PPML) estimator, which is now the standard because it handles zero flows naturally and provides consistent estimates under heteroscedasticity. PPML has become especially important in services trade where many bilateral flows are zero.

A related line of research explores fixed effects and instrumental variables to address endogeneity and unobserved heterogeneity. [13] provide a comprehensive guide on incorporating exporter, importer, and time fixed effects to absorb multilateral resistance and policy shocks. This approach improves identification of policy variables such as tariffs, free trade agreements, and service trade restrictions. Beyond estimation techniques, the scope of explanatory variables has expanded significantly.



Traditional gravity models focused on economic mass and distance; modern models incorporate cultural ties, migration, digital connectivity, and climate-related disruptions. For example, [7] show how inter-net penetration lowers fixed costs and increases cross-border trade in both goods and services, while [14] highlight the role of digital services as intermediate inputs in global value chains. Services trade presents unique challenges because services are often intangible, regulated differently, and may require proximity between producer and consumer. [12] demonstrate that while gravity models can still be applied to services, their sensitivity to distance, regulation, and institutional quality differs from goods trade. The OECD's Service Trade Restrictiveness Index (STRI) has become an important proxy for capturing these barriers in gravity equations [15].

Another recent innovation is the application of network and input-output approaches to model interdependencies in global value chains. [16] use social network analysis to quantify how digital service linkages among partners reduce market access costs. This highlights how the modern economy's interconnectedness calls for gravity models that go beyond bilateral frameworks.

Finally, a growing literature examines “deep” trade agreements that harmonize regulations and address behind-the-border barriers. [17] show that deep trade agreements have stronger effects on services trade integration than shallow agreements, reflecting the importance of regulatory convergence for intangible sectors.

Taken together, these contributions mark a clear evolution of the gravity model from a simple empirical regularity for goods to a flexible, theory-consistent framework capable of capturing the complexities of modern trade—including services, digital flows, and global networks. This evolution underpins the analyses in the following sections.

### **III. SECTORAL HETEROGENEITY IN TRADE FLOWS**

The gravity framework was initially developed to explain merchandise trade, but subsequent research has highlighted that different sectors behave very differently under the same economic conditions. [11] showed early on that sector-specific trade cost elasticities vary widely, which means that a single “one-size-fits-all” model may mask important differences between industries. Recognizing this heterogeneity is crucial for understanding both goods and services trade.

One of the key distinctions is between homogeneous goods, differentiated goods, and services. Homogeneous goods, such as raw materials, tend to have relatively low trade barriers and are less sensitive to cultural and regulatory differences. In contrast, differentiated goods—such as branded consumer products—exhibit higher sensitivity to transport costs, consumer preferences, and policy restrictions [18]. Services, as noted by [12], introduce even more complexity due to their intangibility,



simultaneity of production and consumption, and regulatory frameworks.

Within the services sector itself, there is pronounced heterogeneity. [6] classify international services into three broad categories: producer services (used as inputs for goods and other services), consumer services (such as tourism), and network-based services (such as telecommunications). Each category differs in market structure, degree of tradability, and the importance of proximity to consumers. These differences imply that trade cost parameters estimated for one category cannot be readily transferred to another.

Producer services, for example, often require cross-border data flows and specialized labor. The supply of these services may rely heavily on digital infrastructure and skilled personnel, making them sensitive to regulations on data privacy, cross-border investment, and labor mobility. In contrast, consumer services such as travel and hospitality are strongly linked to the physical movement of persons (GATS Mode 2), and their trade volumes respond to visa restrictions, transportation networks, and exchange rates [5].

Network-based services like telecommunications or cloud computing show yet another pattern. [14] demonstrate that regulatory barriers such as foreign equity caps or licensing requirements (GATS Mode 3) have a disproportionately large impact on these sectors. Their analysis of Service Trade Restrictiveness Index (STRI) scores by mode of supply reveals that some services are mostly affected by data flow restrictions (Mode 1), while others are constrained by the movement of natural persons (Mode 4).

Even within goods trade, sectoral differences matter. Perishable agricultural products face high transport and storage costs, while high-value, low-weight goods like microchips can be shipped long distances at relatively low cost per unit of value. [19] argue that variation in the value-to-weight ratio across products is a major determinant of the elasticity of trade with respect to distance. This heterogeneity affects both trade policy outcomes and welfare calculations.

The extensive and intensive margins of trade also differ by sector. Lawless [20] shows that some trade cost components—like fixed entry costs—mainly affect the decision to export (extensive margin), while variable costs such as tariffs affect the volume exported (intensive margin). Services trade often displays stronger fixed-cost effects because firms must invest in foreign market research, build distribution networks, and comply with licensing regimes.

Sectoral heterogeneity has important implications for policy evaluation. [17] find that deep trade agreements reduce barriers unevenly across sectors: regulatory harmonization benefits network-based



and producer services more strongly than consumer services, while tariff reductions primarily affect goods. This means that the effectiveness of trade agreements cannot be judged solely on aggregate trade flows; sector-level impacts must be considered.

Another emerging dimension of heterogeneity comes from digitalization. As [7] note, the Internet lowers fixed entry costs differently across sectors: it has a transformative effect on digitally deliverable services but only a marginal effect on non-digitally tradable services. Similarly, [16] show that the network position of firms in global digital value chains influences their market access costs, which vary widely by sector.

Finally, acknowledging sectoral heterogeneity enriches the theoretical foundations of gravity models. Allowing for sector-specific trade elasticities, multilateral resistance terms, and policy effects leads to more precise estimation and better policy prescriptions. As [13] emphasize, researchers should exploit detailed microdata and disaggregated trade statistics to capture these nuances rather than relying on aggregate flows that obscure important differences.

#### **IV. MEASUREMENT OF TRADE COSTS IN THE DIGITAL ERA**

Accurately measuring trade costs is a central challenge for gravity models, particularly as the nature of trade evolves in a digitalized and service-oriented global economy. Early applications of the gravity equation often proxied trade costs solely through geographic distance, tariffs, and a handful of dummy variables [1]. While these proxies remain useful, they fail to capture the growing importance of intangible barriers such as data regulations, institutional quality, and digital connectivity.

A first step in improving measurement is distinguishing between fixed and variable trade costs. [21] show that firms only enter export markets when they can cover fixed entry costs in addition to variable shipping or transaction costs. This distinction is especially relevant for services, where licensing, certification, and infrastructure investments often dominate the cost structure. Gravity models that incorporate both margins provide a richer picture of trade frictions.

Another important distinction is between “behind-the-border” and “beyond-the-border” costs. [22] classify costs incurred within the exporter’s jurisdiction—such as compliance with domestic regulations or investment in marketing networks—as behind-the-border, whereas tariffs, customs delays, and restrictive quotas imposed by the importing country are beyond-the-border. This taxonomy helps researchers construct more precise proxies for trade barriers.

Modern proxies extend far beyond tariffs and transport costs. The OECD’s Service Trade Restrictiveness Index (STRI) captures regulatory barriers specific to services sectors, including



restrictions on foreign equity, licensing requirements, and limitations on the movement of people [15]. Incorporating the STRI into gravity models allows analysts to quantify service trade barriers analogous to how tariffs are used for goods.

Digital connectivity is another transformative dimension. [7] demonstrate that Internet penetration reduces fixed entry costs and promotes trade by lowering information and transaction barriers. In the context of services, this effect is particularly strong for digitally deliverable services such as software, financial analytics, and online education. Gravity models now often include variables such as broadband subscriptions, number of Internet users, or data flow indices to capture these effects.

Climate-related factors also play a growing role in shaping trade costs. [8] identify three channels through which climate change affects trade: damage to infrastructure from extreme weather events, changes in labor productivity, and shifts in shipping routes due to melting ice in the Arctic. Including proxies such as average temperature anomalies, frequency of extreme events, or shipping route distances can improve the explanatory power of gravity models in a warming world.

The mobility of people interacts with digitalization to shape trade costs. Visa policies, recognition of professional qualifications, and telecommunication networks influence the ease with which service providers and consumers can interact across borders. These factors are particularly salient for GATS Modes 2 and 4, where consumption abroad and movement of natural persons dominate [5].

Measurement issues also arise from zero trade flows and heteroscedasticity. Traditional log-linear OLS regressions drop zero observations, which is problematic when studying highly disaggregated service flows. The Poisson Pseudo-Maximum Likelihood (PPML) estimator recommended by [4] naturally accommodates zeros and heteroscedasticity, making it the preferred choice for modern gravity applications.

Combining multiple data sources can further improve measurement. For example, [14] decompose the STRI by mode of supply and link it to firm-level export data, enabling them to estimate mode-specific trade cost elasticities. Similarly, [16] integrate social network indicators with PPML gravity estimations to capture interdependencies in digital service supply chains.

Finally, researchers are beginning to explore dynamic and time-lagged effects of trade policies. As [13] note, policy changes such as deep trade agreements may take several years to fully manifest in observed trade flows. Using pooled intervals, lagged policy variables, or difference-in-differences approaches can help account for these delays and produce more accurate elasticity estimates.



In sum, measuring trade costs in the digital era requires moving beyond traditional proxies and embracing multidimensional indicators. By incorporating regulatory, digital, climate, and network-based measures, gravity models can provide a more comprehensive and policy-relevant understanding of contemporary trade frictions.

## **V. NETWORK INTERDEPENDENCIES AND GLOBAL VALUE CHAINS**

Traditional gravity models treat bilateral trade flows as largely independent observations, but modern trade is embedded in complex global production networks. Intermediate goods and services flow across multiple borders before reaching final consumers, creating interdependencies that simple bilateral models may fail to capture [2]. Recognizing and modeling these interdependencies has become crucial for accurate analysis.

Global value chains (GVCs) have transformed the structure of international trade. As production processes fragment across countries, intermediate inputs cross borders multiple times. This phenomenon amplifies the importance of indirect linkages: a country's trade with one partner is influenced by its partner's trade with third countries [23]. Ignoring such network effects risks misestimating trade elasticities and policy impacts.

Network analysis provides a natural toolkit to model these interdependencies. By representing countries as nodes and trade flows as edges, researchers can compute centrality measures, clustering coefficients, and other indicators that summarize each country's position in the global trade network [24]. These metrics can then be included as covariates in gravity models to capture spillovers and indirect effects.

Services, especially digital services, intensify these network dynamics. Unlike physical goods, digital services can be embedded in products or delivered instantaneously across multiple jurisdictions. [16] use a two-stage gravity approach combining PPML estimation with social network indicators to quantify how digital service linkages among partners reduce market access costs and facilitate knowledge spillovers.

Input–output linkages provide another window into network interdependencies. [10] construct the World Input–Output Database (WIOD) to trace value added across industries and countries. Integrating such data with gravity equations allows researchers to differentiate between direct exports and foreign value-added content, yielding a more nuanced picture of trade policy effects.

The movement of intermediate services is particularly important for high-tech industries. For example, cloud computing, financial analytics, and software development serve as critical inputs to



manufacturing exports. Restrictions on cross-border data flows or foreign direct investment in these sectors can ripple through supply chains and affect merchandise trade [14].

Network interdependencies also alter the effectiveness of trade agreements. A deep agreement between two countries can produce positive externalities for third parties by lowering costs along shared supply chains. Conversely, protectionist measures in one country can disrupt entire networks, leading to spillover losses for uninvolved economies [17]. Gravity models augmented with network variables can help quantify these indirect effects.

Another dimension is resilience. The COVID-19 pandemic and recent geopolitical tensions revealed vulnerabilities in tightly coupled supply chains. Incorporating network metrics such as redundancy, betweenness centrality, and diversification into gravity equations can inform policymakers about which sectors or partners pose systemic risk [25].

The rise of digital platforms adds yet another layer of complexity. Platforms such as e-commerce marketplaces and app stores act as intermediaries connecting multiple countries and sectors simultaneously. These multi-sided networks can shift market power and trade costs in ways not captured by bilateral models. Extending gravity models to include platform participation variables or cross-network effects is an emerging research frontier [7].

Finally, incorporating network interdependencies enriches welfare analysis. Standard gravity-based counterfactuals may underestimate or overestimate gains from trade liberalization if they ignore spillovers through global value chains. By embedding network measures, researchers can produce more realistic simulations of policy changes and identify where benefits and costs will be concentrated [13].

## **VI. DEEP TRADE AGREEMENTS AND POLICY INNOVATIONS**

A central theme in modern trade policy is the rise of “deep” trade agreements that go beyond tariff reduction to address regulatory, institutional, and behind-the-border barriers. Early gravity models mainly incorporated simple dummy variables for free trade agreements (FTAs) or customs unions [1]. While such variables captured some integration effects, they did not reflect the full scope of policy innovations now shaping international commerce. [3] demonstrated that bilateral trade flows depend not only on bilateral barriers but also on multilateral resistance factors. Deep trade agreements—such as the Comprehensive and Progressive Agreement for Trans-Pacific Partnership (CPTPP) or the EU’s internal market—directly influence these multilateral resistances by harmonizing regulations and standards across many sectors simultaneously. This harmonization lowers trade costs beyond what simple tariff cuts achieve.



One striking feature of deep agreements is their heterogeneous impact on goods versus services. [17] find that while tariff reductions primarily boost merchandise trade, regulatory convergence and mutual recognition clauses benefit services trade more strongly. Provisions on investment, intellectual property rights, and data flows are particularly relevant for digitally deliverable services and high-value producer services. The inclusion of mobility provisions also distinguishes deep agreements from shallow ones. Commitments to ease visa restrictions, recognize professional qualifications, or allow temporary movement of service providers correspond to GATS Mode 4 and can dramatically lower fixed costs of entry into foreign markets [5]. Gravity models incorporating such provisions show larger effects on service exports than on goods exports.

Another innovation in deep agreements is the establishment of common digital markets. By aligning data protection standards, facilitating cross-border data transfers, and promoting interoperability of digital platforms, these agreements reduce information costs and legal uncertainty for firms engaged in e-commerce and online services [7]. The digital chapters in recent agreements such as the Digital Economy Partnership Agreement (DEPA) provide early evidence of these effects.

Deep agreements also increasingly incorporate sustainability and climate-related provisions. [8] argue that harmonizing environmental regulations and coordinating responses to climate risks can lower transaction costs and reduce uncertainty for firms operating in global value chains. Including such variables in gravity equations helps identify whether these “green” provisions affect trade volumes or shift comparative advantage.

Institutional quality plays a critical role in determining the effectiveness of deep agreements. [15] note that high-income countries with strong regulatory institutions realize larger gains from regulatory harmonization than do low-income countries. This heterogeneity implies that the same agreement may produce divergent outcomes across participants, a finding gravity models can help quantify.

Methodologically, researchers have begun to adopt difference-in-differences and event-study designs within the PPML gravity framework to estimate the causal effects of deep agreements [13]. These approaches exploit staggered implementation dates and variation in agreement depth across sectors, producing more credible estimates than simple before-and-after comparisons.

Deep trade agreements can also produce indirect network effects, as discussed in the previous section. Liberalizing rules for investment or data flows between two countries may reduce costs for third countries connected through supply chains or digital platforms. Conversely, discriminatory measures can propagate negative spillovers [16]. Incorporating network variables into gravity models helps



identify these externalities.

Finally, the rise of deep trade agreements underscores the need for richer policy variables in gravity equations. Simple dummy indicators for FTAs cannot capture provisions on competition policy, state-owned enterprises, or labor standards. Future research will benefit from detailed coding of agreement provisions—such as the Design of Trade Agreements (DESTA) database—to analyze which policy innovations drive trade flows across goods and services sectors.

## VII. EMERGING ISSUES: CLIMATE, TECHNOLOGY AND MOBILITY

While gravity models have evolved to incorporate many structural features of trade, several emerging issues are re-shaping global commerce in ways that call for new variables and approaches. Three particularly salient themes are climate change, technological transformation, and human mobility.

Climate change introduces both risks and opportunities for international trade. Extreme weather events, rising sea levels, and changing transport routes affect the cost and reliability of shipping goods and providing services. [8] identify how floods, storms, and temperature shocks can disrupt infrastructure, reduce worker productivity, and alter comparative advantages. Gravity models augmented with climate indicators such as temperature anomalies or frequency of disasters can help predict these effects.

Another climate-related dimension is the opening of new sea routes. Melting ice in the Arctic has already shortened shipping distances between major ports, potentially lowering transport costs for some trade routes while creating environmental challenges [25]. Incorporating dynamic shipping distances into gravity models may reveal how these changes redistribute trade flows.

Technology is transforming the tradability of both goods and services. Digitalization enables instantaneous cross-border delivery of services and the emergence of new business models such as software-as-a-service or online education [7]. These developments reduce the relevance of physical distance but increase the importance of data regulation, cybersecurity, and digital infrastructure—variables that traditional gravity models often omit.

Artificial intelligence (AI) and advanced analytics are further reshaping production and trade. AI-driven supply chain management can lower coordination costs and expand firms' ability to operate in multiple markets. At the same time, regulatory differences in AI ethics and data privacy may create new forms of trade barriers. Future gravity models may need to include indicators of technological readiness or AI regulation to capture these effects.



Human mobility interacts strongly with both climate and technology. Migration and tourism facilitate knowledge transfer, create diaspora networks, and stimulate demand for home-country products [9]. Visa policies, recognition of qualifications, and digital nomad programs affect the ease with which workers and service providers can move internationally. These factors correspond to GATS Modes 2 and 4 and have a disproportionate effect on services trade [5].

Climate change also influences mobility. As some regions become less habitable or lose economic viability, migration flows may increase, potentially altering trade patterns. Gravity models that jointly analyze trade and migration can provide insights into these coupled dynamics, especially for sectors where migrant networks play a key role in market entry [9].

Technological change can mitigate some mobility constraints. Remote work, virtual reality, and online platforms allow service providers to reach foreign clients without physical relocation. This reduces the relevance of traditional distance measures but increases sensitivity to digital access and bandwidth quality—variables that can be added to gravity equations [14].

Another emerging area is the interaction between deep trade agreements and these new issues. Provisions on climate cooperation, digital trade, and temporary movement of natural persons are becoming common in modern agreements. [17] show that such provisions can produce heterogeneous effects across sectors, suggesting that policy variables must be coded with greater granularity to identify their impact on trade flows. Finally, the combined effects of climate, technology, and mobility underscore the need for adaptive gravity models. Rather than relying on static proxies, researchers should develop dynamic indicators that evolve with these trends. Doing so will allow gravity equations to remain a powerful tool for analyzing the shifting landscape of global trade.

## **VIII. CONCLUSION**

This paper has revisited the gravity model of international trade in light of the profound transformations affecting the global economy. Starting from Tinbergen's original formulation and subsequent structural refinements, we have examined how sectoral heterogeneity, digitalization, network interdependencies, and deep trade agreements reshape the determinants of bilateral flows of goods and services.

The analysis underscores that a "one-size-fits-all" approach to gravity modeling is no longer sufficient. Goods and services differ markedly in their cost structures, regulatory environments, and sensitivity to distance and policy barriers [6]. Recognizing these differences yields more accurate estimates of trade elasticities and more credible policy evaluations.



We have also highlighted the importance of improved trade cost measurement. Incorporating regulatory indices such as the STRI, digital connectivity metrics, climate indicators, and network centrality measures allows gravity models to capture frictions that traditional proxies overlook [8], [15]. These enhancements are particularly valuable for analyzing modern services trade and global value chains.

Network interdependencies mean that bilateral trade flows cannot be studied in isolation. Value-added linkages, social networks, and platform-based interactions transmit shocks and policies across countries in complex ways [10], [16]. Including network variables in gravity equations provides richer insights into resilience, spillovers, and systemic risks.

Deep trade agreements are another key driver. Provisions on digital trade, investment, movement of persons, and environmental standards produce heterogeneous effects across sectors and countries [17]. Detailed coding of these provisions and dynamic estimation methods such as PPML with lags can reveal which innovations deliver the largest gains.

Finally, emerging issues of climate change, technological transformation, and mobility will continue to reshape the geography and structure of international trade. Adaptive gravity models that incorporate dynamic, multidimensional indicators will be essential for understanding these shifts and guiding evidence-based policy.

By integrating these themes, our study provides a roadmap for updating the gravity model as a tool for empirical research and policy evaluation in the twenty-first century. Future work should extend these approaches with richer microdata, improved measurement of digital and environmental variables, and more sophisticated modeling of network and institutional effects.

In sum, the gravity model remains a powerful and versatile framework. But to remain relevant, it must evolve with the global economy—capturing not only the gravitational pull of economic size and the friction of distance, but also the complex forces of regulation, technology, and climate that increasingly shape international exchange.

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