Canada's Production Network and Shock Propagation

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Abstract

Canada's economy consists of industries that are deeply interconnected, with the structure of these connections shaping how shocks propagate across the production system. This paper provides the first comprehensive analysis of the Canadian production network that integrates both the static structure of inter-industry linkages and dynamic measures of shock transmission. We find that a small set of service sectors—Wholesale and Retail Trade, Finance and Insurance, and Professional Services—forms a dynamic core that governs both the speed and concentration of economic flows. Finance and Insurance functions as a critical hub, concentrating and amplifying shocks, while Wholesale and Retail Trade rapidly transmits disturbances to other sectors. Semi-core and resource-based industries, including Construction, Real Estate, and natural-resource sectors, have more localized influence, limiting the spread of shocks originating there. These results highlight that Canada's service-oriented economy, though highly integrated and efficient, contains concentrated points of vulnerability. Identifying the sectors that accelerate or amplify shocks provides actionable guidance for policymakers to strengthen systemic resilience and manage risks from trade, policy, or supply-chain disruptions.

Keywords: Canadian economy, sectoral production networks, Input–output linkages, Centrality and connectivity metrics, Shock propagation.

JEL Classification: C67, D57, L16, O14

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1 Introduction

Modern production economies are best understood as networks: dense, weighted systems of interdependent industries linked through flows of intermediate goods, services, finance, and information. In such systems, aggregate outcomes are shaped not only by sectoral fundamentals but by the architecture of interconnections that governs how shocks propagate, where bottlenecks arise, and whether disturbances are absorbed or amplified into systemic events. A large and influential literature has shown that production networks fundamentally alter macroeconomic dynamics, overturning the classical presumption that idiosyncratic sectoral shocks diversify away in sufficiently large economies (Acemoglu et al., 2012; Carvalho, 2014; Jones, 2011). Instead, aggregate volatility, persistence, and fragility depend critically on the structure of inter-industry linkages and the concentration of flows through key sectors (Gabaix, 2011; Baqaee and Farhi, 2019). Yet despite these advances, we still lack a comprehensive, contemporary, economy-wide network analysis for Canada. This paper fills that gap by providing the first integrated structural and dynamic mapping of the Canadian production network using modern network tools applied to detailed Input–Output data.

The Canadian case is economically consequential. Canada is a mid-sized, highly open economy whose production system has been shaped for decades by tight integration with the United States. From the Auto Pact of the 1960s, through NAFTA[1] and its successor agreements, Canadian industries have evolved in close symbiosis with U.S. demand, logistics, and financial intermediation (Trefler, 2004; Baldwin, 2016). This integration has delivered scale and efficiency, but it has also created structural exposure. Recent episodes of trade conflict—most notably the imposition and threat of U.S. tariffs on Canadian steel, aluminum, and manufactured inputs during the Trump administration—made clear how rapidly policy shocks originating abroad can reverberate through domestic production chains. These events underscore a fundamental but unresolved question for Canada: which sectors transmit external shocks most forcefully, and which sectors dampen or localize them? Answering this question requires understanding not just bilateral trade flows, but the full domestic network through which disturbances propagate.

Network economics provides a natural framework for addressing these issues. Seminal work by Acemoglu et al. (2012) demonstrated that idiosyncratic shocks hitting highly connected or strategically located industries can generate large aggregate fluctuations. Carvalho (2014) formalized these propagation mechanisms, showing that the magnitude and persistence of aggregate effects depend on the structure of inter-industry linkages and the presence of dominant suppliers. Subsequent research has emphasized that shock transmission is governed not only by connectivity, but also by structural asymmetries, substitution elasticities, and bottleneck sectors that concentrate flows and amplify disturbances (Baqaee and Farhi, 2019; Oberfield, 2018). Empirical studies confirm the relevance of these mechanisms across countries and contexts, highlighting the macroeconomic importance of granular production structures and key intermediary sectors (Horvath, 2000; **?**; Barrot and Sauvagnat, 2016). However, this literature remains heavily skewed toward large economies,

[1]NAFTA: North American Free Trade Agreement.

with little systematic evidence for countries like Canada.

This paper contributes by bringing these insights to the Canadian context and by explicitly linking structure to function. We ask two closely related questions. First, how is the Canadian production system organized when inter-industry relationships are viewed as a weighted network rather than as isolated bilateral transactions? Second, which sectors function as bottlenecks, accelerators, or stabilizers of economic flows, and what does this imply for Canada's vulnerability to shocks? These questions are not merely descriptive. They speak directly to industrial resilience, trade exposure, and the design of policies aimed at mitigating systemic risk in an environment of persistent trade and geopolitical uncertainty.

Methodologically, we combine traditional network measures with dynamic propagation metrics to distinguish between static importance and functional influence. Using the 2022 symmetric Canadian Input–Output tables, we construct a weighted, directed production network and compute standard structural indicators—degree, strength, and betweenness—to characterize the network's architecture. We then introduce dynamic measures derived from a sectoral random-walk framework: Random Walk Centrality (RWC), which captures the speed with which shocks diffuse through the network, and Counting Betweenness Edge Transmission (CBET), which measures the concentration of flows through sectors acting as conduits. Random-walk methods are particularly well suited to Input–Output systems because they account for the full set of possible propagation paths rather than focusing on shortest routes alone (Newman, 2005; Schweitzer et al., 2009; Cerina et al., 2015). This integrated approach allows us to move beyond identifying "large" or "central" sectors and instead uncover the mechanisms through which shocks spread.

Our findings reveal a sharply asymmetric core–periphery structure in the Canadian production network. Although the network is topologically dense, transaction intensities are highly concentrated. A small cluster of service sectors—Wholesale & Retail Trade, Finance & Insurance, and Professional Services—forms the core of the system, mediating a disproportionate share of domestic economic flows. Dynamic analysis shows that these sectors occupy distinct functional roles. Finance & Insurance emerges as the primary bottleneck, concentrating flows and amplifying disturbances, while Wholesale & Retail Trade acts as a distribution accelerator, enabling shocks to diffuse rapidly across the economy. Professional Services complements these roles by coordinating knowledge- and business-intensive inputs across sectors. This configuration implies that the same service-based architecture that underpins Canada's efficiency and integration with international markets also constitutes a source of systemic vulnerability when shocks strike the core.

By documenting these patterns, the paper makes two main contributions. First, it provides the most comprehensive and up-to-date network-based characterization of the Canadian production system, filling a longstanding empirical gap in the literature on production networks. Second, it offers a functional classification of sectors based on their dynamic roles in shock transmission, yielding a mechanism-rich perspective on systemic risk. These insights are directly relevant for trade, industrial, and resilience policy in Canada, particularly in a context of ongoing uncertainty in Canada–U.S. economic relations.

Related Literature. The study of production networks has fundamentally reshaped our understanding of macroeconomic volatility and systemic risk. Early work emphasized that the architecture of inter-industry linkages matters for aggregate outcomes: shocks hitting highly connected or strategically positioned sectors can generate substantial economy-wide fluctuations, contrary to classical assumptions of diversification in large economies (Acemoglu et al., 2012; Carvalho, 2014). These insights established network structure as a first-order determinant of macroeconomic resilience, highlighting the importance of understanding not just the presence of connections but their configuration and intensity.

Building on this foundation, subsequent research examined the mechanisms through which shocks propagate. Baqaee and Farhi (2019) and Oberfield (2018) demonstrate that the impact of a sectoral disturbance depends not only on connectivity but also on structural asymmetries, substitution elasticities, and the presence of bottleneck suppliers. Dominant sectors can concentrate flows, amplifying the effects of local shocks across the economy. Similarly, studies by Gabaix (2011) and Jones (2011) underscore that aggregate volatility is often driven by a small set of granular sectors whose propagation effects dominate, suggesting that systemic risk is deeply embedded in network topology rather than in aggregate diversification alone. These works collectively motivate the focus on both structural and functional characteristics of sectors when analyzing resilience.

Parallel to these theoretical advances, methodological research has progressively moved from static to dynamic analyses of networks. Traditional centrality measures, including degree, betweenness, and eigenvector centrality, provide useful information on a sector's positional importance (Freeman, 1978; Bonacich, 1987), but they are inherently static and cannot fully capture how shocks unfold over time. Scholars have emphasized that structural prominence does not always translate into functional influence (Borgatti and Everett, 2006). Random-walk approaches and stochastic network models have emerged as powerful alternatives, tracing the diffusion of shocks through all feasible paths in a network rather than only shortest routes. Newman (2005), Schweitzer et al. (2009), and Cerina et al. (2015) show that such dynamic metrics are particularly well suited to input-output networks, capturing both cumulative and indirect effects of disturbances.

Dynamic approaches also enable a functional classification of sectors. By measuring how shocks traverse networks probabilistically, researchers can identify which sectors act as bottlenecks, accelerators, or stabilizers of economic flows. This perspective moves beyond ranking sectors by size or connectivity, revealing the mechanisms through which disturbances propagate and accumulate—an important distinction for understanding systemic risk and resilience.

Despite these advances, empirical work on Canadian production networks is limited and fragmented. Existing studies often focus on specific sectors or regions rather than the economy as a whole. Rutherford and Holmes (2008) analyzes intersectoral linkages in the automotive industry, while Norman et al. (2007) examines energy use and greenhouse gas emissions across Canadian and U.S. manufacturing and resource sectors, highlighting sectoral heterogeneity. Leung and Secrieru (2012) extend the input-output framework by incorporating financial and income flows, showing that financial intermediation amplifies the impact of final-demand shocks. While informative, these contributions remain static and do not capture dynamic propagation patterns or the economy-wide network architecture that is central to systemic risk.

Taken together, this literature establishes a clear gap. There is no comprehensive, contemporary, economy-wide analysis of the Canadian production network that integrates both structural and dynamic perspectives. This gap is particularly salient given Canada's status as a mid-sized, open economy with a service-intensive production structure and deep integration with the United States. Without such an analysis, it remains unclear which sectors are central to the propagation of shocks, and which can buffer or stabilize the system under trade and policy disturbances.

This paper addresses this gap by providing a unified structural and dynamic mapping of the Canadian production network. Using detailed Input–Output data, we combine traditional network measures—strength, degree, and betweenness—with dynamic random-walk metrics, including Random Walk Centrality (RWC) and Counting Betweenness Edge Transmission (CBET). This approach allows us to distinguish between static structural importance and functional influence in shock propagation. Our analysis uncovers a sharply asymmetric core–periphery architecture, in which a small cluster of service sectors mediate, accelerate, and amplify flows, shaping the economy's systemic risk profile. By linking structural position to functional roles, we offer a mechanism-rich understanding of resilience in the contemporary Canadian economy.

Outline. The remainder of the paper proceeds as follows. Section 2 describes the Canadian Input–Output data, network construction, and empirical methodology. Section 3 presents the structural and dynamic findings, highlighting the core–periphery organization and functional roles of key sectors. Section 4 concludes and draws policy implications.

2 Data and Methodology

Understanding the Canadian production network requires both detailed sectoral data and a careful methodological framework. This section describes the data sources, the transformations applied to construct the network, and the analytical techniques used to uncover structural and dynamic properties of the economy.

2.1 Data

Our analysis relies on the 2022 OECD Inter-Country Input-Output (ICIO) Table, a harmonized and comprehensive database designed for cross-country economic research. These tables provide a detailed mapping of goods and services flows between industries and countries, making it possible to capture interdependencies across sectors. For Canada, the ICIO database covers fifty sectors classified according to ISIC Rev.4, encompassing primary industries, manufacturing, utilities, services, and government activities, thereby offering a complete view of the national production system.

The ICIO database records annual input-output relationships among industries and countries, expressed in monetary terms. Each matrix entry reports the value of inputs purchased by one sector from another, whether sourced domestically or internationally. In the Canadian input–output tables, each of the fifty sectors is identified by a standardized industry code (for example, Canada_C20 for chemical manufacturing), and the dataset reports both inter-industry transaction values and total gross output by industry.

To prepare the data for the network analysis, we applied two transformations. First, we excluded the sector Canada_T, which represents household activities as employers and undifferentiated production for own use, because it consistently reports zero values across the matrix and therefore does not generate measurable inter-industry flows.

Next, we extracted the data for Canada[2], focusing exclusively on inter-industry transactions and the industry total gross output. In the resulting network, nodes correspond to industries, directed edges capture input flows from one industry to another, and edge weights are given by technical coefficients, which measure the share of inputs relative to the receiving industry's output.

2.2 Network Metrics

To examine the structure of production and the systemic importance of industries within the Canadian economy, we adopt a network-based approach using Input–Output data. This framework provides a systematic way to quantify inter-industry dependencies and to identify sectors that play a disproportionate role in organizing and transmitting economic activity across the production system. Network-based methods have been widely applied in the analysis of complex systems (e.g., Noh and Rieger, 2004; Newman, 2005; Masuda et al., 2009) and, in particular, to input–output and economic networks to capture shock propagation, sectoral influence, and systemic importance (e.g., Blöchl et al., 2011; DePaolis et al., 2022; Piccardi et al., 2018; Alatriste Contreras and Fagiolo, 2014; Grazzini and Spelta, 2022).

We represent the Canadian production structure as a directed, weighted network in which nodes correspond to sectors[3] defined in the Canadian Input–Output tables, and directed edges represent flows of intermediate goods and services between sectors. The strength of each linkage is captured by an edge weight that reflects the intensity of the input relationship, allowing us to move beyond simple connectivity and assess the relative importance of sectoral interactions. Such weighted, directed networks provide a natural representation of inter-industry linkages, capturing both the magnitude and direction of economic dependencies (e.g., Blöchl et al., 2011; DePaolis et al., 2022).

Edge weights are constructed from the technical coefficient matrix, which is obtained by normalizing the inter-industry transaction matrix by sectoral output. Specifically, each element w_{ij}

[2] We do not consider international transactions, as our primary objective is to study how shocks propagate within the Canadian economy rather than between Canada and the rest of the world. That said, when an industry is exposed to an external shock, the model still allows us to trace how rapidly and how strongly this disturbance spreads to other domestic sectors. In this sense, the framework captures the role of industries as intermediaries in transmitting shocks across the Canadian production network.

[3] Sectors are indexed by $i = 1, 2, \ldots, N$, where N denotes the total number of sectors in the economy.

measures the share of sector i's output that relies on inputs sourced from sector j:

$$w_{ij} = \frac{x_{ij}}{Y_i}, \quad \text{for all } i, j \in \{1, 2, 3, ..., N\}, \tag{1}$$

where x_{ij} denotes the value of intermediate inputs that sector i purchases from sector j, and Y_i is the gross output of sector i. These coefficients summarize the underlying production dependencies and provide the quantitative foundation for constructing the weighted network representation of the economy, which has been widely employed in both theoretical and applied IO network analyses (e.g., Alatriste Contreras and Fagiolo, 2014; Grazzini and Spelta, 2022).

This network structure allows us to apply a range of graph-theoretic tools to characterize both local and systemic features of the production system. We examine standard measures of connectivity and centrality, as well as higher-order indicators that capture clustering, community structure, and the potential for shock propagation (e.g., Blöchl et al., 2011; DePaolis et al., 2022; Piccardi et al., 2018). By combining network theory and input–output applications, our approach enables a nuanced assessment of sectoral roles in the Canadian economy, from direct interactions to broader systemic influence.

Connectivity. We begin by characterizing sectoral connectivity using both unweighted and weighted measures. Unweighted degree metrics provide a basic description of network structure. The in-degree k_i^{in} counts the number of upstream suppliers to a sector and reflects the diversity of its input sources, while the out-degree k_i^{out} counts the number of downstream users and captures the breadth of its supply relationships. In the context of IO networks, however, the high density of inter-industry transactions implies that degree measures are nearly uniform across sectors and therefore offer limited discriminatory power.

To obtain a more informative characterization, we rely on weighted connectivity measures that account for the intensity of inter-sectoral linkages. For each sector i, the in-strength S_i^{in} measures the total weight of incoming links and captures the magnitude of backward linkages, that is, the overall reliance of the sector on intermediate inputs:

$$S_i^{in} = \sum_{j=1}^{N} w_{ij}, \quad j \neq i. \tag{2}$$

Conversely, the out-strength S_i^{out} aggregates the weights of outgoing links and reflects forward linkages, measuring the extent to which sector i supplies intermediate inputs to the rest of the economy:

$$S_i^{out} = \sum_{j=1}^{N} w_{ji}, \quad j \neq i. \tag{3}$$

Taken together, these measures summarize the economic footprint of a sector within the production network. We define the total strength S_i as the sum of in- and out-strength, which provides a composite indicator of a sector's overall involvement in inter-industry transactions:

$$S_i = S_i^{in} + S_i^{out}. \tag{4}$$

Propagative Power. Connectivity alone does not fully capture a sector's role in the transmission of shocks. In particular, a large out-strength may reflect substantial intermediate sales, but it does not indicate whether a sector primarily acts as a conduit that amplifies shocks or as a node that absorbs them through its own input requirements. Measures of relative influence in directed networks emphasize how directionality and structural position determine propagation capacity (e.g., Masuda et al., 2009), and, in the context of production systems, shock propagation is strongly shaped by the asymmetry of intersectoral linkages (Alatriste Contreras and Fagiolo, 2014). Empirical analyses of global production networks also show that network topology and sectoral influence indices derived from calibrated general equilibrium models are closely related to how productivity shocks propagate to aggregate outcomes (Grazzini and Spelta, 2022). To address this distinction, we introduce a measure of relative propagative capacity.

Specifically, we define the sectoral influence index I_i as the ratio of out-strength to in-strength:

$$I_i = \frac{S_i^{out}}{S_i^{in}}. \tag{5}$$

This ratio normalizes a sector's outward influence by its dependence on upstream inputs, allowing us to distinguish sectors that predominantly transmit shocks from those that mainly absorb them. Values of I_i greater than one identify net suppliers of intermediate inputs, for which disturbances are more likely to propagate downstream through the production network. In contrast, values below one characterize net consumers, whose input-intensive structure tends to dampen or internalize shocks. By construction, the influence index captures the functional role of each industry in shock transmission in a way that out-strength alone cannot, as it explicitly accounts for the balance between forward and backward linkages.

Economic Distance. To characterize how production linkages propagate through the economy, we introduce the notion of economic distance between sectors. This concept does not rely on any new structural assumptions but is constructed directly from the previously defined input–output weights. Distance captures the intensity and direction of input use along production chains and allows indirect linkages to be taken into account.

The direct economic distance $d(j, i)$ from sector j to sector i is defined as the inverse of the input weight, $1/w_{ij}$, whenever a direct input relationship exists. Consequently, stronger input flows correspond to shorter economic distances. This distance function differs from standard metric distances in several important respects. First, $d(i, i)$ is non-zero by definition, as distance is not interpreted as self-separation but as a measure derived from production intensities. Second, $d(\cdot, \cdot)$ is asymmetric: in general, $d(j, i) \neq d(i, j)$, reflecting the directional nature of input use. Third, $d(\cdot, \cdot)$ is not transitive. Even if sector j supplies an intermediate sector n and sector n supplies sector i, the implied distance from j to i is not given by $1/w_{ij}$, which may be undefined when $w_{ij} = 0$.

To accommodate indirect production chains and the presence of zero direct weights, economic distance between sectors is defined in terms of shortest paths. Consider a directed path $\mathcal{P}_{ji} = (j = s_0, s_1, \ldots, s_K = i)$ such that $w_{s_k s_{k-1}} > 0$ for all k. Each step therefore corresponds to a directed input–output linkage from s_{k-1} to s_k. The length of this path is given by $\sum_{k=1}^{K} 1/w_{s_k s_{k-1}}$. The economically relevant distance from sector j to sector i is then defined as the shortest-path distance:

$$d(j,i) = \min_{\mathcal{P}_{ji}} \sum_{k=1}^{K} \frac{1}{w_{s_k s_{k-1}}}. \tag{6}$$

This definition ensures that sectors with no direct input relationship can nevertheless be economically connected through intermediate sectors, and that the most relevant connection is the one minimizing cumulative input frictions. Importantly, the shortest path between two sectors need not correspond to direct input use; sufficiently strong indirect linkages may generate a shorter effective distance.

Centrality. Given this distance structure, centrality measures identify sectors that occupy structurally important positions within the production network. These measures capture how sectors are embedded in economy-wide production chains rather than focusing solely on direct input intensities.

Betweenness centrality measures the extent to which a sector serves as an intermediary along shortest paths connecting other sectors. Formally, the betweenness centrality of sector n is defined as

$$C_B(n) = \sum_{i \neq j \neq n} \frac{\sigma_{ji}(n)}{\sigma_{ji}}, \tag{7}$$

where σ_{ji} denotes the total number of shortest paths from sector j to sector i, with $i \neq j$, and where the indices i and j range over all ordered pairs of distinct sectors. The term $\sigma_{ji}(n)$ counts, among these shortest paths, those that pass through sector n. The summation in Equation (7) thus aggregates, across all pairs (j,i) with $j \neq i$ and $j, i \neq n$, the fraction of shortest paths for which sector n lies on the path. Shortest paths are computed using the distance definition introduced above in Equation (6), so that stronger production linkages correspond to shorter effective paths. High betweenness centrality therefore identifies sectors that act as bridges or bottlenecks within production chains.

Closeness centrality captures a complementary notion of importance by measuring how close a sector is, on average, to all other sectors in the network. It is defined as

$$C_C(i) = \frac{N-1}{\sum_{j \neq i} d(j,i)}, \tag{8}$$

where $d(j,i)$ denotes the shortest-path distance and N is the total number of sectors. Sectors with high closeness centrality are those that can be reached with relatively few intermediate steps, implying a greater capacity for rapid transmission of shocks across the production network.

Despite their usefulness, these centrality measures face well-known limitations when applied to dense input–output networks. High network density reduces the discriminatory power of both degree- and path-based indicators, as many sectors become connected through multiple, similarly short production chains. In such settings, weighted shortest-path measures may place disproportionate emphasis on a single dominant route, while overlooking economically relevant alternative pathways. Moreover, the presence of intra-sectoral transactions (w_{ii}) introduces recursive loops in production chains that are typically ignored by standard shortest-path algorithms, thereby constraining the realism of structural interpretations. These limitations motivate the use of alternative, flow-based approaches that explicitly account for the magnitude of transactions and the dynamic propagation of shocks across the production network.

2.3 Random Walk Framework for IO Networks

To address the limitations of shortest-path and degree-based centrality measures in dense input–output networks, we implement random walk-based centrality measures that incorporate both the magnitude of intersectoral flows and the dynamic propagation of shocks. The framework models a "walker," representing a unit of demand or a shock, moving stochastically across sectors according to transition probabilities derived from the technical coefficients:

$$P_{ij} = \frac{w_{ij}}{\sum_{n=1}^{N} w_{in}} \tag{9}$$

or equivalently,

$$P_{ij} = \frac{x_{ij}}{\sum_{n=1}^{N} x_{in}}, \tag{10}$$

where x_{ij} represents the value of intermediate inputs used in sector i sourced from sector j. This transition matrix $P = [P_{ij}]$ encodes both the structure of the production network and the intensity of intersectoral linkages, including intra-sectoral feedback (w_{ii}) that standard centrality measures often neglect. Within this framework, two random walk-based indicators are computed:

Random Walk Centrality (RWC). Random Walk Centrality of sector i is defined as the inverse of the mean first passage time (MFPT) to i, denoted $\langle T_i \rangle$, which measures the expected number of steps for a walker starting from a randomly chosen sector to reach i for the first time. The MFPT satisfies the system of equations:

$$\langle T_i \rangle = \frac{1}{N-1} \sum_{j \neq i} T_{ji}, \quad T_{ji} = 1 + \sum_{k \neq i} P_{jk} T_{ki}, \quad j \neq i, \tag{11}$$

where T_{ji} is the expected number of steps for a walker starting at sector j to reach sector i for the first time. By construction, $T_{ii} = 0$. Random Walk Centrality is then

$$\mathrm{RWC}(i) = \frac{1}{\langle T_i \rangle}. \tag{12}$$

Sectors with high RWC are reached quickly by shocks or units of demand, reflecting their immediate responsiveness and exposure within the production network. Because MFPT incorporates all possible paths weighted by transition probabilities, RWC captures both direct and indirect linkages, not just the shortest paths.

Counting Betweenness (CBET). Counting Betweenness quantifies the extent to which a sector mediates the propagation of shocks by being visited on first-passage random walks between all pairs of sectors. For sector n, CBET is defined as

$$\mathrm{CBET}(n) = \sum_{i \neq j \neq n} f_{ji}(n), \tag{13}$$

where $f_{ji}(n)$ denotes the probability that a walker starting at sector j reaches sector i for the first time and passes through sector n along the way. This probability satisfies the recursive relation

$$f_{ji}(n) = \begin{cases} 0, & j = i, \\ P_{jn} + \sum_{k \neq i,n} P_{jk} f_{ki}(n), & j \neq i, \end{cases} \tag{14}$$

with $f_{ii}(n) = 0$. The first term accounts for paths where the walker moves directly to n on the first step, while the sum handles paths where the walker initially moves to other sectors and eventually passes through n. High CBET values indicate that a sector serves as a persistent conduit in the network, mediating the transmission of shocks and demand between other sectors.

The use of random walk processes to define centrality reflects their ability to capture the propagation of influence through all network paths rather than only shortest paths. Similar formulations of random walk centrality and related measures have been developed in the network literature (e.g., Noh and Rieger, 2004; Newman, 2005) and specifically for input–output networks (e.g., Blöchl et al., 2011; DePaolis et al., 2022; Piccardi et al., 2018). These approaches formalize the role of mean first passage times and visitation probabilities in quantifying structural importance in weighted, directed economic networks.

Random walk-based measures therefore provide a dynamic and comprehensive depiction of systemic influence. Random Walk Centrality (RWC) highlights sectors most immediately affected by shocks, capturing their responsiveness, while Counting Betweenness (CBET) identifies sectors that act as persistent mediators, transmitting shocks throughout the production network. By incorporating the full network of flows and intra-sectoral loops, this framework overcomes key limitations of traditional centrality measures and yields a more realistic and nuanced assessment of structural importance in dense input–output networks.

3 Results and Interpretation

This section presents the main findings[4] on how industries in Canada are connected through production and trade. We show how some sectors play a central role in moving goods, services, and payments across the economy, while others remain more isolated. The results clarify which industries matter most for spreading economic shocks and why.

3.1 Analysis of Production Networks in Canada

The Canadian input–output system, comprising 49 sectors in our analysis, forms a fully connected network in which each sector simultaneously acts as a supplier and a user of intermediate inputs. While this complete connectivity reflects the highly integrated nature of modern production, it is largely uninformative about the underlying economic structure of the system. Meaningful differentiation emerges only once inter-sectoral linkages are weighted by the intensity of monetary transactions. These weighted interactions reveal a sharply defined core–periphery organization, consistent with production network theories that emphasize the role of heterogeneous link strengths in shaping aggregate dynamics (Acemoglu et al., 2012; Carvalho, 2014).

Weighted connectivity captures the total magnitude of intersectoral transactions and provides a natural way to identify the most active suppliers and consumers in the economy. Figure 1 situates each sector according to its in-strength and out-strength, with bubble size reflecting total strength and color indicating the Influence Index. This representation highlights a pronounced asymmetry in the distribution of connectivity across sectors.

On the supply side, Wholesale and Retail Trade emerges as the dominant provider of domestic intermediate inputs, with an out-strength far exceeding that of all other sectors. It is followed, at a considerable distance, by Finance and Insurance, Professional Services, Warehousing and Support Services, and Land Transport. Together, these activities form the backbone of the domestic supply network, channeling goods, coordination services, financial intermediation, and logistics across virtually all production stages. Their prominence aligns with evidence showing that disruptions in key intermediate service providers generate disproportionately large aggregate effects (Barrot and Sauvagnat, 2016; Baqaee and Farhi, 2019).

On the demand side, Coke and Refined Petroleum, Air Transport, Accommodation and Food Services, Water Transport, and Basic Non-Ferrous Metals exhibit the highest in-strength values. Because the analysis relies on the domestic IO matrix, these patterns reflect sectors that rely most heavily on domestically supplied intermediate goods and services, making them particularly exposed to internal supply shocks.

Combining inflows and outflows into a single measure of total strength further sharpens the picture of network centrality. Wholesale and Retail Trade overwhelmingly dominates this ranking, followed by a second tier composed of Warehousing and Support Services, Coke and Refined Petroleum, Finance and Insurance, Professional Services, and Land Transport. Construction and

[4] While we discuss aggregate patterns in the main text, detailed sector-level metrics, including connectivity, centrality, and random walk measures, are reported in Appendix A.

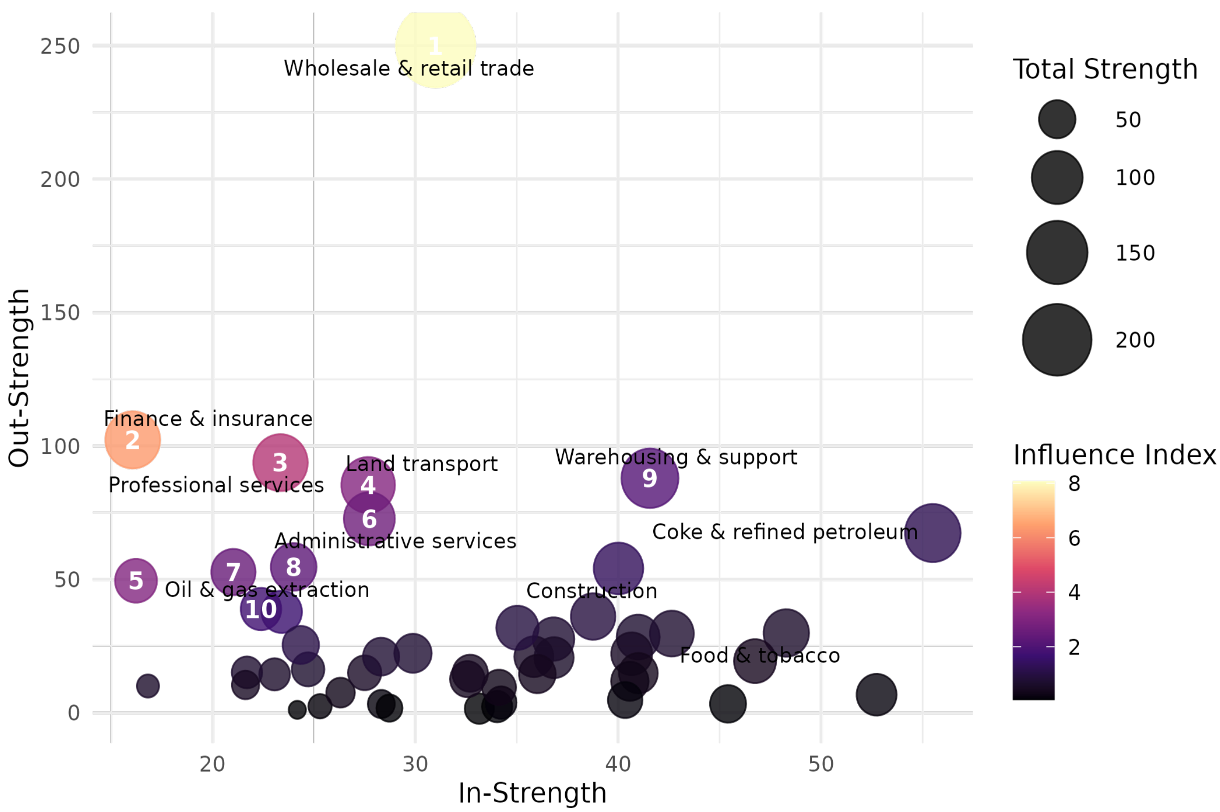

Figure 1: Sectoral Connectivity and Influence in Canada: Strength and Influence Metrics

Note:Note: This figure displays sectors according to their connectivity strengths. The horizontal axis reports in-strength, the vertical axis reports out-strength, bubble size represents total strength, and color corresponds to the influence index. Sector names are displayed for the ten sectors with the highest total strength, and numbers inside the bubbles indicate their ranking by influence. Full metrics for all sectors can be found in Table A.2 in Appendix A.

Administrative Services also exhibit strong two-sided integration. Overall, the evidence confirms a production network in which distribution, logistics, finance, and business services constitute the central organizing forces of economic activity.

The influence index provides a complementary perspective by integrating upstream and downstream dependencies to assess a sector's potential to propagate shocks throughout the economy. Wholesale and Retail Trade again ranks as the most influential sector, followed by Finance and Insurance and Professional Services. Land Transport and Energy Supply also display high influence values, reflecting their pivotal role in sustaining flows of goods, energy, and logistics across production chains. These sectors are structurally positioned to transmit disturbances widely due to their dense embedding on both the supply and demand sides of the network.

A second group of sectors—including Administrative Services, Real Estate, Oil and Gas Extraction, IT Services, and Metal Ore Mining—exhibits moderate influence. These activities anchor key segments of manufacturing, resource extraction, and advanced business services, acting as important intermediaries without dominating system-wide transmission. At the lower end of the distribution, Fishing, Pharmaceuticals, Shipbuilding, Textiles, and Water Transport display minimal influence, indicating limited propagation capacity beyond their immediate value chains.

Taken together, these findings underscore the primacy of service-oriented and distributional activities in shaping economic transmission channels in Canada. Influence is concentrated not in final-demand sectors, but in those that coordinate, finance, transport, and intermediate production across the economy.

The weighted network structure reveals a clear core–periphery configuration shaped jointly by transaction intensity and influence. At the core of the system lie Wholesale and Retail Trade, Finance and Insurance, Professional Services, Administrative Services, Land Transport, and Warehousing and Support Services. These sectors combine high total strength with high influence, positioning them as the primary coordination and transmission centers of the Canadian production network. Their role extends beyond scale, encompassing the facilitation of goods movement, capital allocation, information flows, and logistical coordination. Surrounding this core is a semi-core

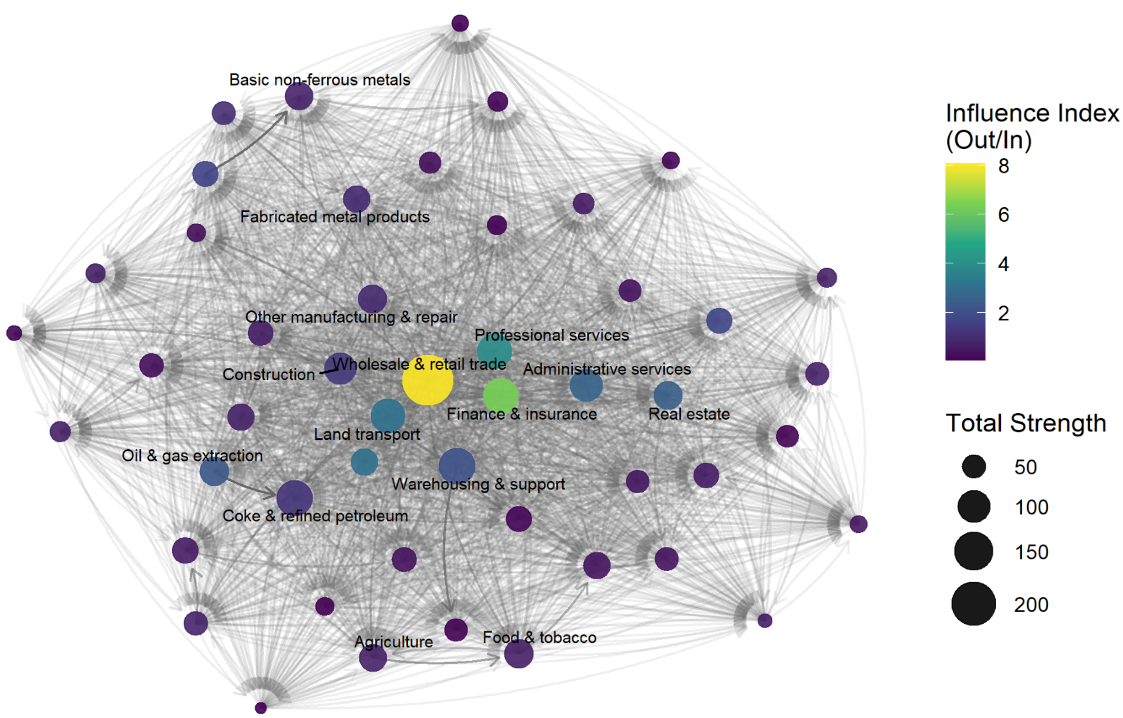

Figure 2: Canadian Input–Output Network Structure

Note: This figure illustrates the structure of the Canadian production network. Nodes correspond to sectors, with size proportional to total strength and color indicating the Influence Index. Directed edges represent inter-sectoral transactions, with thickness and shading (light to dark grey) proportional to the technical coefficient, reflecting the relative importance of the transaction for the receiving sector.

composed of Energy Supply, Real Estate, Construction, Oil and Gas Extraction, and IT Services.

These activities provide essential infrastructure, energy, property services, and advanced business inputs. Their intermediate influence reflects a bridging role, linking the central service hub to manufacturing and resource-based sectors. The peripheral layer consists of Fishing, Textiles and Apparel, Shipbuilding, Education, Arts and Entertainment, and Health and Social Work. These sectors exhibit low levels of both strength and influence, reflecting more specialized or locally contained production processes with limited economy-wide propagation potential.

Figure 2 provides a graphical representation of the network, constructed using the Fruchterman–Reingold algorithm (Fruchterman and Reingold, 1991). Each sector is represented by a node whose size reflects total strength and whose color captures influence, while directed edges represent intersectoral transactions weighted by technical coefficients. The algorithm treats nodes as repelling particles while transaction links act as attractive forces, such that sectors with stronger and more numerous linkages are drawn closer together. As a result, highly interconnected service sectors cluster tightly at the center of the network, while more weakly connected activities are positioned toward the periphery. This spatial organization provides a visually intuitive confirmation of the core–periphery structure identified in the quantitative metrics.

The network visualization highlights that, despite the dense and nearly complete connectivity of the Canadian input–output system, economic influence is unevenly distributed across sectors. This unevenness does not arise from differences in network connectivity *per se*, but from heterogeneity in the intensity of intersectoral transactions. Variation in link weights gives rise to a small set of highly interconnected intermediation sectors—most notably Wholesale and Retail Trade, Finance and Insurance, and Professional Services—that occupy central positions in the production structure. By concentrating both upstream input dependencies and downstream demand linkages, these sectors effectively anchor the network and generate a clear economic hierarchy even in the absence of topological sparsity.

This weighted hierarchical structure has direct implications for aggregate dynamics. Because central sectors are deeply embedded in multiple layers of intermediate production, shocks originating in these activities are more likely to propagate widely through the economy, generating disproportionately large macroeconomic effects. In contrast, disturbances affecting less central industries tend to remain largely confined to their immediate value chains, producing limited spillovers. This pattern is consistent with evidence from economy-wide input–output analyses showing that the aggregate impact of microeconomic shocks depends critically on the position and transactional importance of the originating sector (Acemoglu et al., 2012; Inoue and Todo, 2019; Carvalho, 2014).

In sum, these findings indicate that the Canadian input–output network is densely interconnected yet economically hierarchical in its functioning. Trade, finance, logistics, and business services jointly form the core of the production system, shaping the circulation of goods, capital, and information across virtually all sectors and underpinning both systemic resilience and aggregate fluctuations.

3.2 Random Walk Centrality Analysis

Building on the weighted connectivity and structural analyses, we next employ random walk centrality measures to capture the dynamic propagation of economic shocks through the network. While static measures such as strength and influence identify transaction volumes and structural positioning, random walk–based metrics characterize the actual pathways and speed through which disturbances diffuse across sectors. This approach provides a dynamic perspective on how shocks originating in one sector may cascade throughout the economy (Newman, 2005; Blöchl et al., 2011).

Random Walk Centrality (RWC) and the Speed of Shock Transmission. Random Walk Centrality (RWC) captures the expected speed with which shocks originating in a given sector can spread throughout the production network by following weighted input–output linkages. Sectors with higher RWC values are more frequently encountered along random walks on the network, indicating that they are both easily reachable from, and effective at reaching, other sectors. As such, RWC provides a dynamic measure of a sector's capacity to transmit disturbances rapidly across the economy.

Table 1: Random Walk Centrality Rankings

Sector	RWC Score	Rank
Wholesale & Retail Trade	0.1017	1
Finance & Insurance	0.0828	2
Professional Services	0.0737	3
Administrative Services	0.0646	4
Real Estate	0.0506	5

Note: This table reports Random Walk Centrality (RWC) scores and ranks for selected sectors in the Canadian production network. RWC captures the expected frequency with which a sector is visited along random walks on the weighted input–output network, reflecting its accessibility and systemic importance in mediating production flows. Higher values indicate sectors that are more central to the circulation of intermediate goods and services. Full metrics for all sectors are shown in Table A.4.

Table 1 reports RWC scores and corresponding rankings for the most central sectors in the Canadian production network. Wholesale and Retail Trade emerges as the dominant conduit for shock transmission, ranking first with a substantial margin over all other sectors. Finance and Insurance and Professional Services follow closely, reflecting their pervasive transactional ties across a wide range of production activities. Administrative Services and Real Estate also appear among the top-ranked sectors, underscoring the central role of business-oriented services in mediating economic interactions.

The concentration of high RWC values in service-intensive sectors reinforces their position at the core of the production system, while adding an explicitly dynamic dimension to their importance. These sectors not only account for large volumes of intermediate transactions, as indicated by strength-based measures, but also exhibit the greatest capacity to accelerate the diffusion of shocks through the network. In particular, the prominence of Wholesale and Retail Trade confirms its role as the primary transmission hub, through which disturbances can propagate quickly across multiple layers of production.

Counting Betweenness (CBET) and the Concentration of Economic Flows. While Random Walk Centrality highlights the speed with which shocks can propagate, Counting Betweenness (CBET) identifies sectors that function as critical intermediaries within the network. CBET measures the extent to which random walks pass through a given sector, capturing the concentration of economic flows and highlighting potential amplification points for disturbances.

Table 2: Top Sectors by CBET Centrality in the Canadian Economy

Sector	CBET Score	Rank
Finance & Insurance	69.95	1
Professional Services	35.00	2
Wholesale & Retail Trade	34.79	3
Administrative Services	29.47	4
IT Services	26.27	5

Note: This table reports CBET (current-flow betweenness) centrality scores and corresponding ranks for selected sectors in the Canadian production network. Higher CBET values indicate sectors that play a more important intermediary role in transmitting flows across the input–output system.

Table 2 reports CBET scores and rankings for the most central sectors in the Canadian economy[5]. Finance and Insurance emerges as the dominant flow concentrator, with a CBET value nearly twice that of the next-ranked sector, Professional Services. Wholesale and Retail Trade, despite its leading role in transaction volume and shock velocity (as shown in Table 1), ranks third, illustrating that its capacity to transmit shocks quickly does not necessarily imply a comparable concentration of flows. Administrative Services and IT Services complete the top five, reflecting the importance of service-oriented activities in mediating intermediate transactions.

These results reveal a complementary mechanism to that captured by RWC: while sectors like Wholesale and Retail Trade accelerate the diffusion of shocks, Finance and Insurance amplifies and channels economic flows, acting as a structural bottleneck that can magnify disturbances across the network (Newman, 2005). This distinction underscores the value of combining dynamic and

[5]Full metrics for all sectors are shown in Table A.4 in Appendix A.

intermediary measures to understand both the speed and the concentration of shock propagation in the Canadian production system.

Figure 3 integrates the two dynamic dimensions by positioning sectors according to their shock transmission velocity (RWC) and flow concentration (CBET). The scatter plot reinforces the hierar-

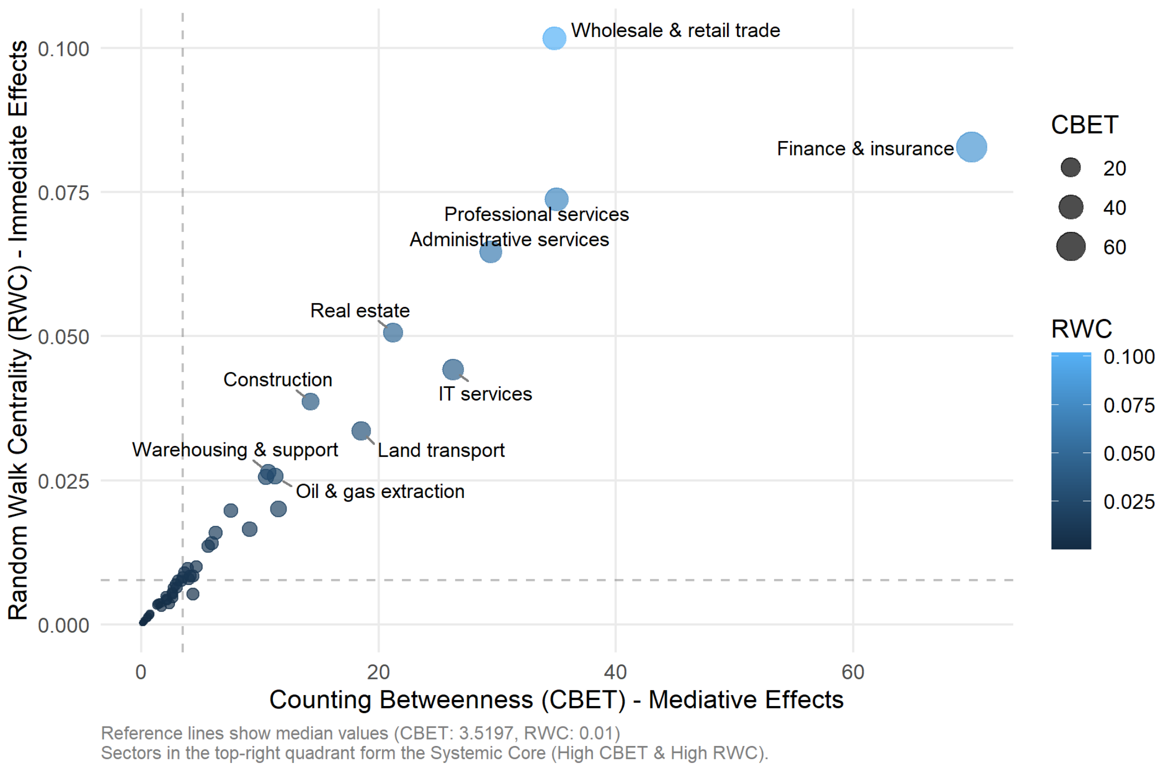

Figure 3: Dynamic Network Influence: Shock Transmission versus Flow Mediation

Note: This figure illustrates sectors according to random walk–based centrality measures. Bubble size reflects Counting Betweenness (CBET), while color intensity corresponds to Random Walk Centrality (RWC). Sector labels are shown for the ten sectors with the highest RWC values or the ten sectors with the highest CBET values.

chical structure of the network identified earlier, with the same service-oriented sectors—Wholesale and Retail Trade, Finance and Insurance, and Professional Services—clustered in the region of both high transmission velocity and high flow concentration. Finance and Insurance stands out along the CBET dimension, underscoring its dual role as a central transaction hub and the primary amplifier of economic flows. In contrast, sectors such as Construction and Real Estate, while highly connected in static strength measures, occupy more moderate positions in the dynamic space, suggesting that their contribution lies mainly in stabilizing the network rather than rapidly propagating shocks.

3.3 Discussion and Policy Implications

Integrating dynamic centrality measures—Random Walk Centrality (RWC) and Counting Betweenness (CBET)—with static strength metrics reveals a coherent and hierarchically organized Canadian production network. These results illuminate not only which sectors occupy central positions, but also how shocks propagate and where economic flows are concentrated, providing a richer understanding of systemic structure and dynamics.

At the heart of the network lies a dynamic core composed of Finance and Insurance, Wholesale and Retail Trade, and Professional Services. Each of these sectors occupies a distinct position within the dynamic spectrum, combining rapid transmission capacity with substantial flow-concentration effects. Finance and Insurance emerges as a financial amplifier: its exceptionally high CBET indicates that a significant share of economy-wide flows passes through its intermediation structure, while its elevated RWC confirms its ability to transmit shocks at high speed. Wholesale and Retail Trade acts as a distribution accelerator, exhibiting the highest RWC in the network and enabling disturbances to diffuse quickly across sectors. Professional Services completes the dynamic core, functioning as a knowledge and coordination channel with balanced influence across both dimensions. Together, these sectors form the operational and financial backbone of the Canadian economy, governing both structural and dynamic connectivity.

Surrounding the core is a semi-core of sectors that play complementary propagation roles. IT Services functions as a digital conduit, concentrating information-intensive flows despite moderate transmission velocity. Administrative Services operates as an operational integrator, supporting the core with stable intermediation capacity. Land Transportation and Warehousing and Support Services act as physical distribution channels, mediating goods flows across regions and sectors with moderate speed and substantial betweenness. Construction and Real Estate occupy a similar semi-core tier: while they do not match the core in transmission velocity or flow concentration, their moderate CBET and RWC position them as essential anchors linking upstream resources to downstream production and investment activities.

Resource-based sectors, including Coke and Refined Petroleum Products and Oil and Gas Extraction, exhibit a different type of dynamic relevance. Their moderate RWC and CBET values suggest limited capacity for rapid shock propagation, yet their foundational role as providers of critical upstream inputs renders them structurally indispensable. In contrast, peripheral sectors such as Fishing, Textiles, and Shipbuilding consistently display very low RWC and CBET, indicating minimal involvement in shock transmission or flow intermediation and confirming their marginal role in systemic dynamics.

The dynamic analysis reinforces and extends the static findings. Service-oriented sectors not only dominate transaction volumes but also drive shock propagation and flow concentration, validating the core–periphery organization identified earlier (Carvalho, 2014). While Wholesale and Retail Trade leads in transaction volume and shock velocity, Finance and Insurance functions as the primary economic amplifier (Battiston et al., 2012), highlighting the differentiated roles within the core. This configuration generates a fundamental velocity–stability tradeoff: the service core's capacity for rapid transmission and concentration enhances efficiency but also increases vulnerability, as disturbances originating in these sectors can propagate with exceptional speed and magnitude (Acemoglu et al., 2012). Semi-core sectors such as Construction and Real Estate, by contrast, contribute stability by anchoring flows without serving as primary accelerators.

These insights carry important policy implications. Systemic stability in the Canadian production network is closely tied to the coordinated functioning of the service-oriented core. Effective monitoring, targeted risk management, and resilience strategies should prioritize Finance and Insurance, Wholesale and Retail Trade, and Professional Services, ensuring that both financial intermediation and transaction pathways remain robust to shocks. Complementary policies supporting semi-core sectors—particularly those linking production, logistics, and investment—can enhance overall stability while preserving efficient flow distribution. By identifying the sectors most central to both the speed and concentration of economic activity, this analysis provides actionable guidance for safeguarding economic continuity and mitigating systemic vulnerability.

4 Conclusion

This paper provides the first comprehensive, economy-wide analysis of the Canadian production network that integrates both structural and dynamic perspectives. By representing interindustry linkages as a weighted network and combining traditional centrality measures with random-walk–based metrics, we distinguish between static structural importance and functional influence in shock propagation. Our results reveal a sharply asymmetric core–periphery architecture, dominated by a small cluster of service sectors—Wholesale and Retail Trade, Finance and Insurance, and Professional Services—that mediate, accelerate, and amplify economic flows across the entire economy.

The dynamic analysis demonstrates that these core sectors perform complementary functions: Finance and Insurance operates as a critical bottleneck, concentrating and amplifying shocks, while Wholesale and Retail Trade serves as a primary accelerator, rapidly diffusing disturbances throughout the network. Peripheral sectors, by contrast, have minimal systemic influence, indicating that shocks originating outside the core remain largely localized. These findings underscore a fundamental trade-off inherent in Canada's production system: the same service-based architecture that supports efficiency and coordination of domestic flows also generates points of systemic vulnerability when external or domestic shocks strike the core.

Our study contributes to the literature in three ways. First, it provides a detailed, contemporary mapping of the Canadian production network, moving beyond sectoral or environmental case studies to capture economy-wide interdependencies. Second, it integrates static and dynamic metrics to uncover functional roles of sectors in shock propagation, offering a mechanism-rich perspective on systemic risk. Third, by connecting network position to functional influence, the analysis delivers actionable insights for resilience-oriented policy design, including targeted monitoring of financial and trade hubs, protection of service-core functions, and reinforcement of stability anchors in construction, transportation, and real estate.

These results have clear policy implications. Canada's deep integration with the U.S., combined with the hierarchical service-oriented structure of its production network, implies that trade or policy shocks originating abroad can propagate rapidly and disproportionately through the domestic economy. Policymakers seeking to enhance resilience should prioritize interventions that reinforce the stability of core sectors, manage exposure to concentrated flows, and enhance the absorptive capacity of peripheral sectors. More broadly, the framework developed here can serve as a blueprint for monitoring systemic risk in mid-sized, open, and service-intensive economies, providing a quantitative basis for anticipating vulnerabilities before they manifest in aggregate macroeconomic volatility.

Future research could extend this analysis in several directions. First, incorporating interprovincial flows and regional heterogeneity would provide a finer-grained view of domestic transmission channels. Second, integrating international input-output linkages could quantify Canada's exposure to shocks in global value chains, particularly from the United States and other major trading partners. Finally, applying scenario-based simulations of policy or trade shocks could further elucidate the dynamics of resilience, guiding both public and private-sector decisions in an increasingly interconnected economic landscape.

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A Appendix

This appendix presents detailed sector-level metrics in tabular form that complement the analyses in the main text. These tables provide a comprehensive view of the structural and functional roles of sectors within the Canadian production network.

A.1 Sector Table

Table A.1 reports the sector classification used in the analysis. The first column lists the sector codes in the OECD Inter-Country Input-Output (ICIO) Table, the second column provides the sector name used throughout the paper, and the third column gives the corresponding full industry definitions. Sector definitions follow the standard input–output industry classification for Canada.

Table A.1: Sector Classification

ICIO Code	Sector	Description
Canada_A01	Agriculture	Crop and animal production, hunting and related service activities
Canada_A02	Forestry	Forestry and logging
Canada_A03	Fishing	Fishing and aquaculture
Canada_B05	Coal mining	Mining of coal and lignite
Canada_B06	Oil & gas extraction	Extraction of crude petroleum and natural gas
Canada_B07	Metal ore mining	Mining of metal ores
Canada_B08	Other mining	Other mining and quarrying
Canada_B09	Mining support services	Mining support service activities
Canada_C10T12	Food & tobacco	Manufacture of food products, beverages and tobacco products
Canada_C13T15	Textiles & apparel	Manufacture of textiles, wearing apparel and leather products
Canada_C16	Wood products	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
Canada_C17_18	Paper & printing	Manufacture of paper and paper products; Printing and reproduction of recorded media
Canada_C19	Coke & refined petroleum	Manufacture of coke and refined petroleum products

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ICIO Code	Sector	Description
Canada_C20	Chemicals	Manufacture of chemicals and chemical products
Canada_C21	Pharmaceuticals	Manufacture of basic pharmaceutical products and pharmaceutical preparations
Canada_C22	Rubber & plastics	Manufacture of rubber and plastic products
Canada_C23	Non-metallic minerals	Manufacture of other non-metallic mineral products
Canada_C24A	Basic ferrous metals	Manufacture of basic metals (Ferrous Metals)
Canada_C24B	Basic non-ferrous metals	Manufacture of basic metals (Non-Ferrous Metals)
Canada_C25	Fabricated metal products	Manufacture of fabricated metal products, except machinery and equipment
Canada_C26	Computer & electronics	Manufacture of computer, electronic and optical products
Canada_C27	Electrical equipment	Manufacture of electrical equipment
Canada_C28	Machinery & equipment	Manufacture of machinery and equipment n.e.c.
Canada_C29	Motor vehicles	Manufacture of motor vehicles, trailers and semi-trailers
Canada_C301	Shipbuilding	Building of ships and boats
Canada_C302T309	Other transport equipment	Manufacture of other transport equipment
Canada_C31T33	Other manufacturing & repair	Other manufacturing; Repair and installation of machinery and equipment
Canada_D	Energy supply	Electricity, gas, steam and air conditioning supply
Canada_E	Water & waste management	Water supply; sewerage, waste management and remediation activities
Canada_F	Construction	Construction
Canada_G	Wholesale & retail trade	Wholesale and retail trade; repair of motor vehicles and motorcycles
Canada_H49	Land transport	Land transport and transport via pipelines

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ICIO Code	Sector	Description
Canada_H50	Water transport	Water transport
Canada_H51	Air transport	Air transport
Canada_H52	Warehousing & support	Warehousing and support activities for transportation
Canada_H53	Postal & courier	Postal and courier activities
Canada_I	Accom. & food services	Accommodation and food service activities
Canada_J58T60	Publishing & broadcasting	Publishing, audiovisual and broadcasting activities
Canada_J61	Telecommunications	Telecommunications
Canada_J62_63	IT services	IT and other information services
Canada_K	Finance & insurance	Financial and insurance activities
Canada_L	Real estate	Real estate activities
Canada_M	Professional services	Professional, scientific and technical activities
Canada_N	Administrative services	Administrative and support service activities
Canada_O	Public administration	Public administration and defence; compulsory social security
Canada_P	Education	Education
Canada_Q	Health & social work	Human health and social work activities
Canada_R	Arts & entertainment	Arts, entertainment and recreation
Canada_S	Other services	Other service activities

A.2 Sector Influence and Strength Metrics

Table A.2 reports sector-level connectivity and influence measures computed on the directed input–output production network. *In Strength* and *Out Strength* denote the weighted sums of incoming and outgoing link intensities, respectively. *Total Strength* is defined as the sum of in- and out-strength. The *Influence Index* captures the relative importance of a sector in transmitting economic activity through the network by jointly accounting for upstream and downstream linkages. Sectors are ordered by descending *Influence Index*.

Table A.2: Network Connectivity and Influence Metrics by Sector

Sector	In Strength	Out Strength	Influence Index	Total Strength
Wholesale & retail trade	31.00	249.86	8.06	280.86
Finance & insurance	16.07	102.25	6.36	118.32
Professional services	23.35	93.73	4.01	117.08
Land transport	27.67	85.33	3.08	113.00
Administrative services	27.73	72.69	2.62	100.42
Real estate	21.03	52.74	2.51	73.77
Oil & gas extraction	24.00	54.65	2.28	78.65
Warehousing & support	41.56	87.88	2.11	129.44
IT services	22.39	38.87	1.74	61.26
Metal ore mining	23.41	37.82	1.62	61.23
Construction	40.01	54.09	1.35	94.10
Coke & refined petroleum	55.50	67.35	1.21	122.85
Basic ferrous metals	24.35	25.42	1.04	49.77
Other manufacturing & repair	38.76	36.08	0.93	74.84
Fabricated metal products	35.03	31.84	0.91	66.87
Chemicals	36.81	27.63	0.75	64.44
Forestry	29.88	22.29	0.75	52.17
Publishing & broadcasting	28.31	21.03	0.74	49.34
Basic non-ferrous metals	42.64	29.68	0.70	72.32
Telecommunications	21.70	15.14	0.70	36.84
Agriculture	40.98	28.36	0.69	69.34
Other mining	24.71	16.27	0.66	40.98
Food & tobacco	48.28	29.90	0.62	78.18
Mining support services	23.06	14.40	0.62	37.46
Education	16.82	10.03	0.60	26.85
Rubber & plastics	35.84	21.02	0.59	56.86
Public administration	36.83	20.65	0.56	57.48
Other transport equipment	27.50	14.98	0.54	42.48
Wood products	40.66	22.10	0.54	62.76
Postal & courier	32.70	14.81	0.45	47.51
Water & waste management	32.56	12.61	0.39	45.17
Paper & printing	40.99	14.84	0.36	55.83
Non-metallic minerals	40.57	11.81	0.29	52.38
Motor vehicles	26.31	7.55	0.29	33.86
Machinery & equipment	34.12	9.52	0.28	43.64

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Sector	In Strength	Out Strength	Influence Index	Total Strength
Air transport	52.73	6.77	0.13	59.50
Computer & electronics	28.32	3.29	0.12	31.61
Electrical equipment	34.22	3.81	0.11	38.03
Coal mining	25.30	2.45	0.10	27.75
Textiles & apparel	34.03	2.34	0.07	36.37
Water transport	45.41	3.34	0.07	48.75
Shipbuilding	28.72	1.75	0.06	30.47
Fishing	24.18	1.10	0.05	25.28
Pharmaceuticals	33.15	1.55	0.05	34.70

A.3 Sector Centrality Metrics

Table A.3 reports betweenness and closeness centrality measures for all sectors in the production network. *Betweenness* captures the extent to which a sector intermediates flows along shortest input–output paths, while *closeness* reflects a sector's average proximity to all other sectors and thus its potential speed of shock transmission. Measures are computed on the directed input–output network. Sectors are ordered by descending closeness measure.

Table A.3: Centrality Metrics by Sector

Sector	Betweenness	Closeness
Wholesale & retail trade	0.33	3.98
Professional services	0.12	2.76
Finance & insurance	0.07	2.62
Real estate	0.21	2.28
Administrative services	0.02	2.11
Construction	0.32	1.99
Land transport	0.07	1.78
Coke & refined petroleum	0.05	1.63
IT services	0.10	1.63
Warehousing & support	0.00	1.59
Wood products	0.13	1.56
Oil & gas extraction	0.02	1.61
Fabricated metal products	0.08	1.35
Mining support services	0.02	1.40
Forestry	0.03	1.44

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Sector	Betweenness	Closeness
Agriculture	0.08	1.29
Non-metallic minerals	0.02	1.28
Textiles & apparel	0.00	1.23
Basic ferrous metals	0.03	1.22
Energy supply	0.01	1.22
Other mining	0.00	1.16
Food & tobacco	0.05	1.14
Basic non-ferrous metals	0.03	1.12
Metal ore mining	0.01	1.11
Other manufacturing & repair	0.04	1.09
Postal & courier	0.02	0.97
Chemicals	0.01	0.96
Accommodation & food services	0.00	0.88
Publishing & media	0.03	0.88
Rubber & plastics	0.00	0.89
Telecommunications	0.02	0.79
Other transport equipment	0.02	0.71
Education	0.00	0.70
Motor vehicles	0.00	0.65
Paper & printing	0.00	0.65
Coal mining	0.00	0.56
Air transport	0.00	0.55
Public administration	0.04	0.55
Health & social work	0.00	0.53
Other services	0.00	0.53
Arts & entertainment	0.00	0.52
Water & waste management	0.00	0.50
Fishing	0.00	0.49
Machinery & equipment	0.00	0.45
Shipbuilding	0.00	0.41
Water transport	0.00	0.38
Electrical equipment	0.00	0.36
Computer & electronics	0.00	0.27
Pharmaceuticals	0.00	0.22

A.4 Sector Random Walk Metrics

Table A.4 reports sector-level Random Walk Centrality (RWC) and Cumulative Betweenness (CBET) metrics computed on the directed input–output production network. RWC captures the expected proportion of time a random walker spends at a sector, reflecting its potential for propagating shocks through the network. CBET measures the cumulative importance of a sector as an intermediary along shortest paths. Sectors are ranked in descending order of RWC.

Table A.4: Random Walk Metrics by Sector

Sector	**RWC**	**CBET**
Wholesale & retail trade	0.1017	34.7851
Finance & insurance	0.0828	69.9528
Professional services	0.0737	34.9961
Administrative services	0.0646	29.4654
Real estate	0.0506	21.2362
IT services	0.0442	26.2711
Construction	0.0386	14.3024
Warehousing & support	0.0264	10.7043
Oil & gas extraction	0.0257	11.3056
Coke & refined petroleum	0.0256	10.5289
Publishing & broadcasting	0.0200	11.5987
Energy supply	0.0198	7.5896
Telecommunications	0.0165	9.1424
Accommodation & food services	0.0159	6.2609
Postal & courier	0.0141	5.9360
Public administration	0.0136	5.6735
Fabricated metal products	0.0100	4.6239
Other services	0.0098	3.9149
Education	0.0090	3.6399
Paper & printing	0.0085	4.1352
Mining support services	0.0082	3.5197
Food & tobacco	0.0078	4.0332
Metal ore mining	0.0077	3.1110
Water & waste management	0.0076	3.3685
Other manufacturing & repair	0.0070	2.8965
Chemicals	0.0064	2.9820
Rubber & plastics	0.0064	2.7319
Non-metallic minerals	0.0054	2.6245

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Sector	**RWC**	**CBET**
Basic ferrous metals	0.0053	4.3573
Agriculture	0.0053	2.6914
Arts & entertainment	0.0049	2.0833
Forestry	0.0046	2.6618
Health & social work	0.0044	2.0979
Basic non-ferrous metals	0.0043	2.1621
Machinery & equipment	0.0037	1.6036
Other mining	0.0036	1.4778
Other transport equipment	0.0036	2.4090
Air transport	0.0034	1.3724
Motor vehicles	0.0031	1.7174
Electrical equipment	0.0018	0.7810
Water transport	0.0016	0.7085
Computer & electronics	0.0014	0.5955
Coal mining	0.0011	0.4653
Textiles & apparel	0.0006	0.3071
Pharmaceuticals	0.0004	0.2046
Shipbuilding	0.0003	0.1703
Fishing	0.0002	0.1178