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U.S. Semiconductor Export Structure under Innovation and Trade Policy

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ABSTRACT

Semiconductors are a foundational input for modern economic activity, and their international trade is shaped by both market forces and government policy. This study examines how U.S. innovation and trade policies are associated with changes in the structure of semiconductor exports, focusing on shifts in export allocation, destination concentration, and specialization rather than export volumes alone.

Using bilateral UN Comtrade data classified by harmonized system (HS) codes from 2015 to 2024, the analysis applies measures of export concentration and comparative export strength to assess changes in market dependence and positioning. The results indicate that major policy changes coincide with export reallocation across destination markets, while U.S. exports remain concentrated in technologically advanced segments. Overall, the findings link policy environments to observable changes in export structure in a technology-intensive industry.

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Introduction

Semiconductors are foundational technologies underpinning digital infrastructure, advanced manufacturing, artificial intelligence, and national defense systems. As critical inputs to both civilian and strategic applications, integrated circuits (ICs) occupy a central position in global innovation systems and industrial policy agendas [1]. Because semiconductor production is technologically complex, capital intensive, and geographically fragmented, it has become a focal point of trade regulation, industrial strategy, and national security policy [2,3].

For decades, the industry was organized around efficiency-driven global fragmentation. The United States retained leadership in chip design and R&D, while fabrication and assembly were concentrated in East Asia. This structure reflected broader patterns of vertical specialization and global value chain integration [4,5]. However, since 2018, escalating trade tensions, expanded export controls, investment screening, and the enactment of the U.S. CHIPS and Science Act have reshaped the institutional environment governing semiconductor trade [6]. These interventions reflect a shift from efficiency-oriented globalization toward resilience- and security-driven governance.

While existing research evaluates semiconductor policy through domestic capacity expansion or competitiveness metrics less attention has been paid to how policy interventions translate into observable changes in export structure [3,7]. Export controls, subsidy regimes, and alliance-based coordination frameworks may alter not only trade volumes but also destination allocation, geographic concentration, and specialization patterns. From a network perspective, such policies can reshape the topology of global value chains and the distribution of trade relationships.

This study examines U.S. exports across three integrated circuit subcategories—processors and controllers (HS 854231), memory devices (HS 854232), and amplifiers (HS 854233)—from 2015 to 2024. These segments occupy distinct technological and structural positions within the semiconductor value chain and vary in policy sensitivity and market concentration. Using bilateral trade data, the analysis evaluates export destination reallocation, geographic concentration (HHI), and specialization (RCA) to assess how major policy milestones coincide with shifts in export structure.

Rather than seeking broad cross-country generalization, the paper treats the United States as a strategically significant case to identify mechanisms through which innovation and trade policy reshape export topology in technology-intensive industries. By linking policy developments to structural trade indicators, the study contributes to understanding how industrial and security policies manifest in measurable changes in global trade architecture.

Materials and Methods

Data Sources and Scope

This study uses bilateral trade data from the United Nations

Comtrade database, covering the period 2015–2024. The dataset includes U.S. exports classified at the six-digit Harmonized System (HS) level. To capture structurally distinct segments of the semiconductor value chain, the analysis focuses on three integrated circuit subcategories:

- HS 854231 – Processors and controllers (electronic integrated circuits)
- HS 854232 – Memory devices (e.g., DRAM, NAND flash)
- HS 854233 – Amplifiers

These three categories account for the largest trade values in dollar terms among U.S. semiconductor export classifications over the sample period. Focusing on the highest-value segments ensures that the analysis reflects the core structure of U.S. semiconductor trade rather than being disproportionately influenced by smaller or more volatile categories. This selection therefore captures the primary commercially and strategically significant components of U.S. integrated-circuit exports while minimizing noise from low-volume subcategories. Bilateral export values (current U.S. dollars) were aggregated annually by destination economy. The analysis focuses on structural changes in export allocation rather than nominal trade growth.

Measurement of Export Structure

To assess export reconfiguration under changing policy conditions, three complementary structural indicators are employed: export destination shares, the Herfindahl–Hirschman Index (HHI), and Revealed Comparative Advantage (RCA).

- **Export Destination Shares**

For each HS category and year, export destination shares are calculated as:

$$s_{ij}(\mathrm{t}) = \frac{x_{ij}(t)}{\sum_k x_{ik}(t)} \qquad (1)$$

where $X_{ij}(t)$ is exports from the U.S. (i) to partner j in year t. Changes in export shares reflect reallocation across markets and provide a direct measure of geographic restructuring.

- **Export Concentration: Herfindahl–Hirschman Index (HHI)**

Export concentration is measured using the Herfindahl–Hirschman Index (HHI), defined as:

$$HHI(t) = \sum_j (s_{ij}(t))^2 \qquad (2)$$

The HHI is widely used to evaluate concentration and diversification patterns in economic analysis [8]. Values closer to 1 indicate high concentration in a small number of markets, while lower values reflect diversification across destinations.

In the context of semiconductor trade, declining HHI values may indicate geographic diversification and reduced reliance on specific partner economies, whereas rising HHI values suggest concentration risk or dependency.

- **Export Specialization: Revealed Comparative Advantage (RCA)**

To assess changes in specialization, this study employs the Balassa (1965) Revealed Comparative Advantage (RCA) index [9]:

$$RCA_{US}(t) = \frac{x_{US,IC}(t)/x_{US,total}(t)}{x_{world,IC}(t)/x_{world,total}(t)} \qquad (3)$$

where $X_{US,k,t}$ represents U.S. exports of product category k in year t, and $X_{World,k,t}$ represents total world exports of the same category.

An RCA value greater than 1 indicates relative export specialization. RCA is widely used in trade analysis to assess comparative positioning across industries [9,10]. In this study, changes in RCA are interpreted as shifts in relative export strength rather than as direct measures of technological capability.

Policy Timeline and Structural Breakpoints

To contextualize structural changes in export patterns, the analysis aligns trade indicators with major policy milestones, including:

- Escalation of U.S.–China trade tensions (2018–2019)
- Expanded semiconductor export restrictions (2015–2022)
- The enactment of the CHIPS and Science Act [6]
- Post-2022 allied coordination and investment screening measures

The objective is not to establish causal identification but to examine whether observable changes in export structure coincide temporally with major policy interventions. This approach follows recent policy-oriented analyses examining how regulatory shifts affect semiconductor trade flows and value chain positioning [2,11,12]. It is also consistent with historical evidence emphasizing that government action often matters most during key phases of semiconductor industry development—especially early commercialization and scale-up at the technology frontier and capability-building in follower economies through procurement, coordination, and policies facilitating international technology transfer and diffusion [12]. In this sense, policy milestones serve as contextual anchors for interpreting potential breakpoints in trade structure, even when the analysis remains descriptive rather than causal.

Analytical Approach

The empirical strategy is descriptive and structural rather than econometric. By tracking changes in export allocation, concentration, and specialization across three technologically differentiated segments, the study evaluates whether post-2018 policy developments correspond with:

1. Reallocation of export destinations
2. Changes in geographic concentration risk
3. Shifts in relative specialization

The analysis treats export structure as an observable outcome of adjustment within global value chains. While firm-level decision-making cannot be directly observed in aggregated trade data, structural indicators provide measurable proxies for reconfiguration dynamics in response to evolving policy constraints.

Results

• Policy Accumulation and Strategic Reorientation

Figures 3 and 4 report the cumulative number of national semiconductor policies related to resilience and competitiveness, based on Goldberg et al. and authors' calculations [12]. Rather than using annual policy flows alone, we accumulate policy counts beginning in 2010. This approach reflects the assumption that semiconductor industrial policy operates with mid-term and delayed effects, particularly given long investment cycles in fabrication facilities, R&D ecosystems, and supply-chain restructuring.

The cumulative trajectories show two distinct patterns. First, competitiveness-oriented policies rise steadily throughout the 2010s, indicating a persistent focus on technological leadership.

Second, resilience-related policies accelerate sharply after 2020, particularly in the United States, Japan, and Europe. This post-2020 inflection suggests that supply-chain security and strategic autonomy became central policy objectives following pandemic disruptions and escalating export controls.

The accumulated policy framework therefore provides a structural backdrop for interpreting subsequent trade adjustments: export reallocation should be understood as responding not only to contemporaneous policy announcements but also to the cumulative policy environment built over the preceding decade.

• Export Destination Reallocation

Table II presents U.S. integrated-circuit exports by HS category and major destination partners from 2015 to 2024. Analysis of export shares reveals differentiated structural adjustments across subcategories after 2018, with more pronounced shifts following the 2021–2022 policy interventions. Figure 2 further illustrates this geographic redistribution by presenting the evolving shares of the top ten export destinations between 2018 and 2024.

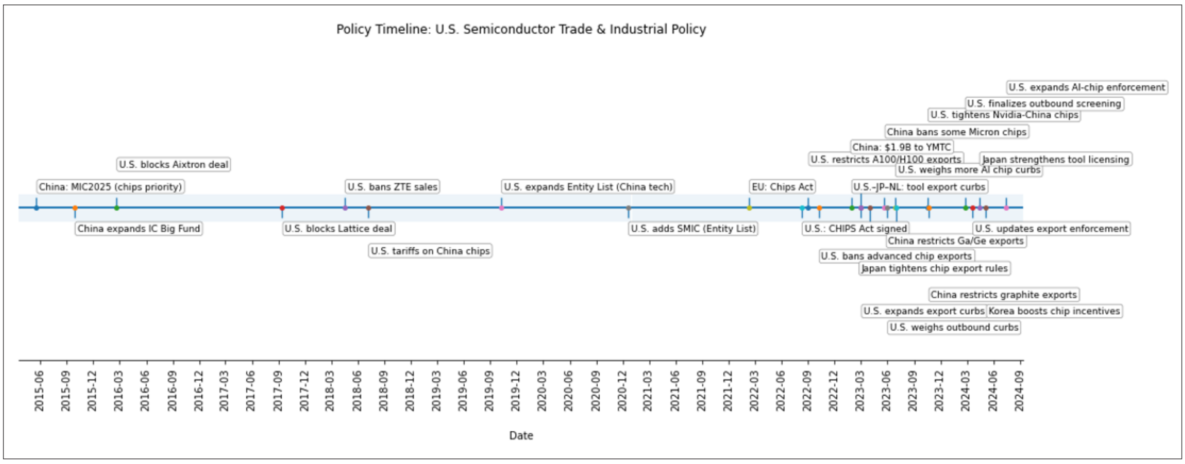

Figure 1: Policy Timeline of the semiconductor between 2015 to 2023. Source: Reuters, Deutsche Bank, Bloomberg Finance LP, Financial Times.

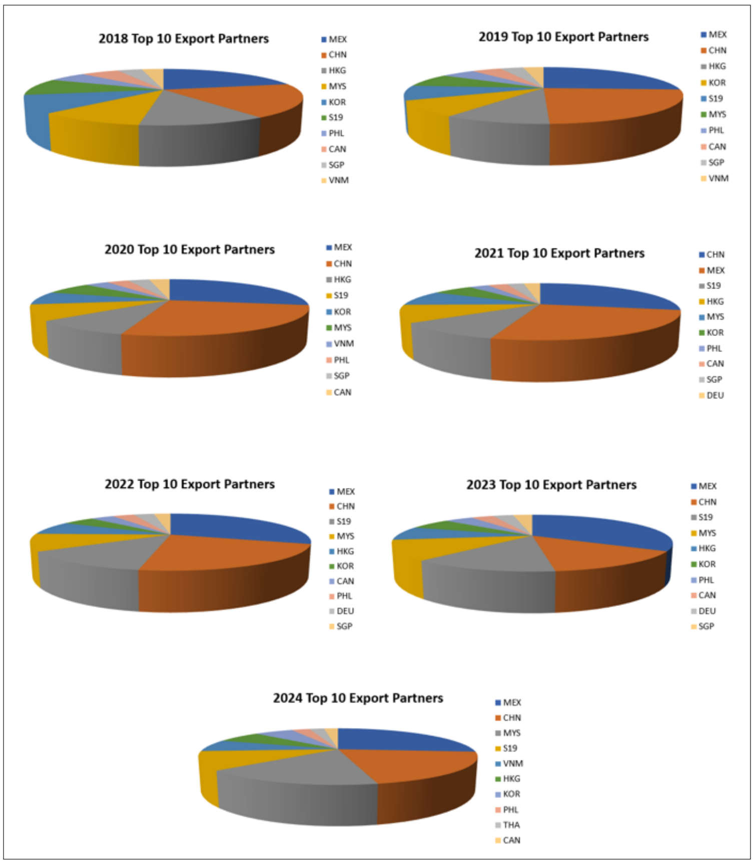

Figure 2: Top 10 Destination Partners Pie Chart for U.S. Integrated Circuit Exports, 2018–2024. **Source:** United Nations Comtrade Database; author's calculations.

Table 1: HS Codes and Their Strategic Roles in the Global Semiconductor Value Chain

HS Code	Description	Interpretation
854231	Processors and controllers, electronic integrated circuits	Reflects reliance on East Asian downstream partners for advanced computing components; post-2015 stabilization is consistent with diversification and regional realignment strategies under rising geopolitical risk
854232	Memories (e.g., DRAM, flash)	Indicates structural dependence on a limited number of dominant East Asian memory producers, highlighting persistent specialization and limited short-term substitutability in global value chains.
854233	Amplifiers	Suggests short-term export reorientation during the trade conflict period, followed by normalization as firms adjusted sourcing and market strategies.

Table 2: U.S. Integrated Circuit Exports by HS Category and Top 7 Export Destinations, 2015–2024 (Billion USD)

HS_ Category	Country	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
854231	CHN	3.47	3.85	3.11	3.93	6.54	8.21	9.72	6.6	2.51	5.76
	MEX	2.77	3.31	3.62	3.91	6.63	8.27	8.31	9.35	9.17	9.34
	KOR	2.75	2.09	2.51	2.57	2.52	2.45	2.14	1.45	1.75	1.82
	MYS	2.56	2.39	2.45	1.78	1.33	1.38	2.11	2.36	2.52	5.9
	CAN	1.09	0.93	0.94	1.13	0.85	0.69	0.61	0.62	0.58	0.47
	S19	0.84	1.56	1.13	1.13	1.06	1.42	1.75	1.95	1.83	1.06
	HKG	0.55	0.71	0.59	0.57	0.56	0.52	0.75	0.69	0.53	0.61
854232	S19	1.25	1.05	1.08	1.03	0.73	0.64	0.64	0.46	0.48	0.44
	SGP	0.66	0.44	0.61	0.6	0.54	0.59	0.42	0.37	0.34	0.23
	CHN	0.59	0.37	0.47	0.35	0.11	0.07	0.09	0.15	0.04	0.03
	MEX	0.5	0.49	0.5	0.56	0.42	0.64	0.5	0.42	0.38	0.62
	THA	0.26	0.16	0.15	0.16	0.01	0.01	0.02	0.04	0.03	0.04
854233	MYS	0.25	0.4	0.26	0.23	0.15	0.11	0.13	0.19	0.07	0.08
	KOR	0.22	0.13	0.11	0.06	0.04	0.02	0.02	0.02	0.02	0.01
	MEX	0.17	0.18	0.2	0.24	0.13	0.13	0.14	0.2	0.15	0.21
	HKG	0.15	0.24	1.43	1.14	0.95	0.75	0.57	0.46	0.46	0.26
	CHN	0.15	0.13	0.43	0.45	0.36	0.39	0.44	0.4	0.39	0.37
	MYS	0.09	0.09	0.08	0.11	0.08	0.12	0.11	0.12	0.09	0.09
	S19	0.07	0.05	0.06	0.08	0.09	0.14	0.2	0.26	0.1	0.11

Source: UN Comtrade.

For HS 854231 (processors and controllers), exports to China peak in 2021 (USD 9.72 billion) before declining sharply in 2022–2023, followed by partial recovery in 2024. Concurrently, exports to Mexico and Malaysia expand significantly, particularly Malaysia's increase to USD 5.9 billion in 2024. This pattern indicates measurable geographic redistribution in advanced logic segments, consistent with partial supply-chain reorientation toward North America and Southeast Asia.

In contrast, HS 854232 (memory devices) displays comparatively limited geographic redistribution. Export values remain modest and concentrated, with no sustained large-scale reallocation across destinations. The persistence of concentration reflects the structural dominance of a small number of global memory producers and limited short-term substitutability in this segment.

For HS 854233 (amplifiers), export shares show temporary reorientation during periods of heightened trade tension (notably 2017–2019), followed by partial normalization. Compared to processors, the amplifier segment exhibits greater flexibility and less persistent structural disruption.

Overall, the data suggest that export restructuring is most visible in advanced logic products (854231), while memory exports remain structurally rigid.

• Export Concentration

Figure 5 reports the Herfindahl–Hirschman Index (HHI) for U.S. integrated-circuit exports by HS category from 2015 to 2024.

In the processors category (854231), export concentration rises beginning around 2019–2020, reaching approximately 0.22–0.23 before moderating slightly in 2024. This indicates that reallocation initially occurred toward a narrower set of alternative destinations rather than immediate broad diversification.

Memory exports (854232) remain structurally concentrated, with HHI values fluctuating within a relatively narrow band. This stability underscores the rigid structure of global memory supply chains.

Amplifiers (854233) display intermediate dynamics: concentration spikes around 2017, then declines gradually, suggesting temporary disruption rather than persistent structural consolidation.

Taken together, concentration patterns indicate restructuring without severe fragmentation. The data do not show runaway concentration, but rather targeted redistribution consistent with geopolitical rebalancing.

• Export Specialization

Figure 6 presents Revealed Comparative Advantage (RCA) across integrated-circuit categories.

The United States maintains RCA values near or slightly above unity in HS 854231, indicating continued specialization in advanced logic components, though the intensity moderates after 2021.

For HS 854232 (memory), RCA remains persistently below 1, confirming structural comparative disadvantage in memory manufacturing relative to East Asian producers.

HS 854233 shows high RCA earlier in the period (peaking above 2.5) before trending downward toward unity by 2024, suggesting gradual erosion of relative advantage in that segment.

Importantly, despite shifts in export destinations and moderate changes in concentration, specialization patterns remain broadly intact. Structural change appears to operate primarily through geographic reallocation, rather than abrupt capability loss.

Discussion

The results indicate uneven export reconfiguration across semiconductor segments. Processors and controllers (854231) show the clearest signs of destination realignment, consistent with their exposure to export controls and regulatory scrutiny. Memory devices (854232) remain structurally rigid, reflecting concentrated global production capacity and limited short-term substitutability. Amplifiers (854233) display more moderate and reversible adjustments.

Importantly, cumulative policy trends help explain these patterns. Figure 3 shows a marked increase in resilience-oriented national policies after 2020 for US. This rise coincides with shifts in export concentration (Figure 5), particularly in 854231, where HHI increases during periods of heightened policy activism. The evidence suggests that resilience-driven policy frameworks influence market concentration by redirecting exports toward a narrower set of strategic or allied destinations.

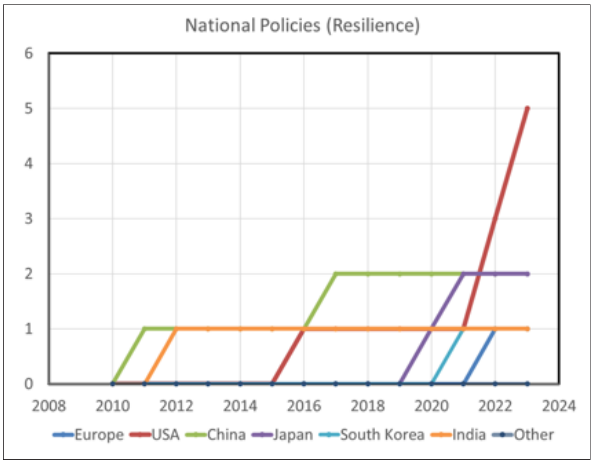

Figure 3: Accumulative National Policies Number Related to Resilience. Source: Goldberg et al. (2024) and authors' calculations

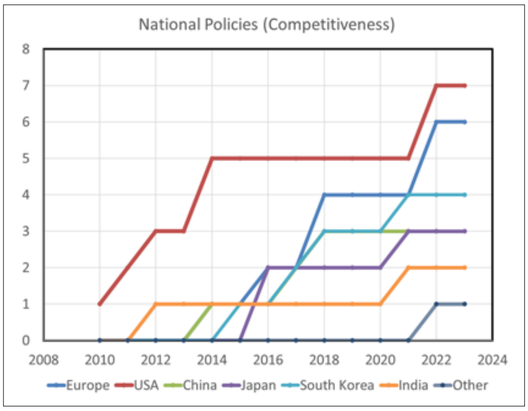

Figure 4: Accumulative National Policies Number Related to Competitiveness. Source: Goldberg et al. (2024) and authors' calculations.

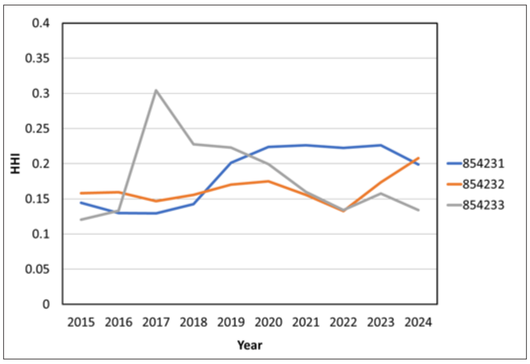

Figure 5: Herfindahl–Hirschman Index (HHI) for U.S. Integrated-Circuit Exports by HS Category, 2015–2024. Source: Author's calculations based on data from UN Comtrade

Figure 4 documents the steady accumulation of competitiveness-oriented policies throughout the 2010s. This longer-run policy build-up aligns more closely with RCA dynamics (Figure 6). Specialization patterns remain broadly intact, indicating that competitiveness policies operate through capability reinforcement rather than abrupt structural shifts.

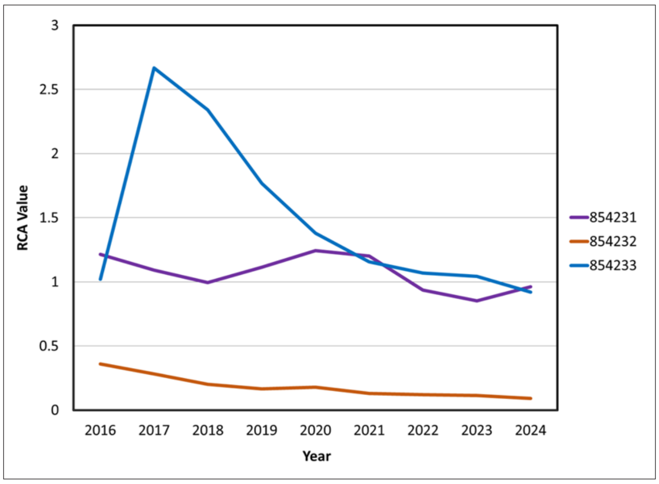

Figure 6: Revealed Comparative Advantage (RCA) of U.S. Integrated-Circuit Exports, 2015–2024. The shaded band indicates the range across five HS sub-categories (854231–854233). **Source:** Author's calculations based on data from UN Comtrade and ITC Trade Map.

The amplifier category (854233) exhibits a notable peak in both HHI and RCA during 2017–2019. This surge is consistent with heightened global demand associated with 5G infrastructure deployment, which temporarily strengthened U.S. specialization and concentrated exports in specific high-demand markets. The subsequent normalization reflects demand stabilization rather than policy-driven contraction.

Overall, the evidence supports three concise conclusions. First, policy accumulation matters: resilience policies appear more closely associated with concentration shifts (HHI), while competitiveness policies align with longer-run specialization trends (RCA). Second, adjustment is segment-specific, with advanced logic products responding more visibly to regulatory changes. Third, restructuring occurs primarily through geographic reallocation rather than systemic erosion of export capability.

These findings suggest that semiconductor industrial policy reshapes trade architecture gradually, with effects differing across technological functions and market structures.

Limitation

First, the analysis relies on six-digit HS bilateral trade data. Although this allows differentiation across processors (854231), memory (854232), and amplifiers (854233), it does not capture variation in technology nodes, product sophistication, or firm-level heterogeneity. The results therefore reflect structural trade patterns rather than firm-specific strategic behavior.

Second, the framework focuses on export allocation and does not account for upstream import dependencies, intermediate inputs, or intra-firm transfers within global value chains. Given the interdependent nature of semiconductor production, observed export shifts may partially reflect upstream adjustments not captured in the dataset.

Third, the approach is descriptive rather than causal. While changes in concentration and allocation coincide with major policy interventions, the analysis does not formally identify causal effects. Demand cycles—especially in memory markets—as well as macroeconomic conditions may also influence export dynamics [13-18].

Finally, the focus on the United States limits direct cross-country generalization. The findings illustrate mechanisms through which policy may reshape export structure in strategic sectors but should not be interpreted as statistically representative across economies.

Conclusion

This study analyzes U.S. semiconductor exports from 2015 to 2024 to assess how trade tensions, export controls, and industrial policy coincide with structural changes in export allocation. Focusing on processors (854231), memory devices (854232), and amplifiers (854233), the results show differentiated adjustment patterns across technological segments.

Advanced logic components exhibit the clearest signs of geographic diversification and reduced destination concentration following major policy interventions. Memory exports remain structurally concentrated, reflecting limited short-term substitutability and production rigidity. Amplifiers display more moderate and reversible shifts.

Overall, the findings suggest that national innovation and trade policy increasingly shapes the geography of semiconductor exports, primarily through selective regional realignment rather than abrupt specialization loss. The semiconductor case illustrates how policy intervention can alter export topology in strategic technology sectors while preserving relative comparative positioning.

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