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Resource Dependence in Semiconductor Manufacturing: The EU`s Vulnerability to Non-EU Sources of Critical Raw Materials and the Impact of Geopolitical Shocks

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# Abstract

Die vorliegende Arbeit untersucht die ökonomischen Anpassungsreaktionen auf die im August 2023 von China eingeführten Exportbeschränkungen für Gallium und Germanium. Ziel ist es zu analysieren, ob diese Maßnahme zu einer veränderten Importstruktur der Europäischen Union führt und ob sich darüber hinaus Auswirkungen auf die industrielle Produktion im europäischen Halbleitersektor beobachten lassen. Die Analyse kombiniert monatliche Handelsdaten mit Produktionsdaten auf Branchenebene. Zur Identifikation relativer Anpassungsmuster wird ein Difference-in-Differences-Ansatz mit Two-Way Fixed Effects sowie ergänzenden Event-Study-Spezifikationen verwendet. Aufgrund nicht vollständig paralleler Vortendenzen werden die Ergebnisse als deskriptive Evidenz interpretiert. Auf Produktebene zeigt sich nach Einführung der Exportlizenzpflicht ein deutlicher relativer Rückgang des chinesischen Importanteils bei Gallium und Germanium. Auf Branchenebene sind zugleich relative Produktionsrückgänge im europäischen Halbleitersektor gegenüber einer Kontrollindustrie zu beobachten. Zusätzliche Preisanalysen deuten darauf hin, dass die Anpassung primär über Mengenreaktionen und nicht über signifikante Preissteigerungen erfolgt. Die Ergebnisse dokumentieren damit eine systematische Reorganisation von Handelsstrukturen sowie eine begleitende relative Produktionsanpassung entlang der Wertschöpfungskette. Die Arbeit liefert einen empirischen Beitrag zur Analyse rohstoffpolitischer Eingriffe in hochkonzentrierten Vorleistungsmärkten.

# Abstract

This thesis examines the economic adjustment responses following China's introduction of export licensing requirements for gallium and germanium in August 2023. The objective is to assess whether this policy intervention is associated with changes in the European Union's import structure and whether downstream production effects can be observed in the European semiconductor sector. The empirical analysis combines monthly trade data at the commodity level with industrial production data at the sector level. Relative adjustment patterns are estimated using a Difference-in-Differences framework with two-way fixed effects, complemented by event-study specifications. Given the presence of non-parallel pre-treatment trends, the estimates are interpreted as descriptive evidence rather than strictly causal effects. At the commodity level, the results indicate a pronounced relative decline in China's import share for gallium and germanium following the introduction of export controls. At the industry level, relative production reductions are observed in the European semiconductor sector compared to a related control industry. Complementary price analysis suggests that the adjustment operates primarily through quantity responses rather than through significant producer price increases. Overall, the findings document a systematic reorganization of trade patterns accompanied by relative downstream production adjustments along the value chain. The thesis contributes empirical evidence on the effects of upstream export restrictions in highly concentrated input markets.

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# List of Abbreviations

**CN8** Combined Nomenclature.

**CRMA** Critical Raw Materials Act.

**DiD** Difference-in-Differences.

**EU** European Union.

**HHI** Herfindahl-Hirschman Index.

**NACE** Nomenclature of Economic Activities.

**PPI** Producer Price Index.

**SUTVA** Stable Unit Treatment Value Assumption

**TWFE** Two-Way Fixed Effects.

# 1. Introduction

Semiconductors are a foundational input for modern economies, underpinning productivity growth, technological innovation, and strategic autonomy. Their central role in digital infrastructure, industrial applications, and defense systems has placed the semiconductor industry at the center of economic and geopolitical debates, particularly in the context of increasing supply chain fragmentation and geopolitical rivalry (Bown & Wang, 2024, p. 81).

While much of the policy and academic discourse focuses on fabrication capacity and technological leadership, a critical but less visible vulnerability lies upstream in the supply of specific raw materials. Semiconductor production relies on a narrow set of technologically essential inputs, including gallium and germanium, which are indispensable for compound semiconductors, radio-frequency applications, and power electronics. Their economic relevance does not stem from large volumes, but from their functional necessity and the absence of short-run substitutes (Frenzel et al., 2016, pp. 38–40).

The global supply of these materials is highly concentrated, with China dominating both extraction and refining. For import-dependent regions such as the European Union (EU), this concentration creates structural vulnerabilities that extend beyond price volatility and directly affect physical access to critical inputs (European Commission, 2020, p. 5; OECD, 2025, p. 16). These vulnerabilities became particularly salient in July 2023, when China introduced export licensing requirements for gallium and germanium, effective from August 2023. This intervention constituted a politically driven change in access conditions and was widely interpreted as part of broader geopolitical contestation over strategic technologies (Bown, 2025, pp. 11–12; Glencross, 2024, pp. 731–732).

At the same time, European industrial and resource policy has undergone a significant reorientation. Initiatives such as the Critical Raw Materials Act (CRMA) and the European Chips Act (Chips Act) aim to reduce dependence on single third-country suppliers through diversification and capacity expansion, although their effects are expected to materialize primarily over the medium to long term (Farrand, 2025, pp. 283–284). This coexistence of heightened upstream supply risk and ambitious downstream industrial targets raises important questions about the resilience of the European semiconductor value chain.

Despite the policy relevance of these developments, empirical evidence on the economic effects of China's 2023 export licensing requirements remains limited. Existing studies predominantly focus on descriptive market developments, price dynamics, or geopolitical interpretations, often at the global level or for individual commodities. In particular, there is a lack of empirical research that jointly links upstream trade adjustments and downstream industrial outcomes for the European semiconductor sector within a unified analytical framework.

This thesis addresses this gap by empirically analyzing Europe's dependence on non-EU sources of gallium and germanium and by examining how the licensing requirements introduced in August 2023 altered upstream material access conditions and affected both trade patterns and the semiconductor industry. The analysis combines commodity-level trade data with industry-level production data to trace adjustment dynamics along the semiconductor value chain.

The empirical analysis is structured around three research questions:

1. To what extent were European imports of gallium and germanium concentrated and dependent on China prior to the introduction of export controls?
2. Was the introduction of export licensing in 2023 associated with a systematic change in China's share of European import values for these materials, and how robust are these patterns across alternative empirical specifications and control groups?
3. Were upstream changes in material access reflected in relative changes in industrial production in the European semiconductor sector compared to closely related industries?

Methodologically, the thesis employs a Difference-in-Differences (DiD) framework combined with event study analysis to examine the pre- and post-policy periods. Given the volatility of raw material markets, the empirical strategy adopts a cautious interpretative approach, focusing on documenting post-intervention patterns and interpreting DiD estimates as structured associations rather than point-identified causal effects.

The remainder of the thesis is organized as follows: After reviewing the relevant literature and institutional context in Chapter 2, Chapter 3 details the data and empirical methodology.

The resulting empirical findings are presented in Chapter 4, followed by a discussion of their limitations and policy implications in Chapter 5. Finally, Chapter 6 provides concluding remarks.

# 2. Background and Literature Review

This chapter provides the conceptual and institutional framework required to evaluate the 2023 Chinese licensing requirements within the European semiconductor value chain. It first characterizes the structural features of the global semiconductor industry, with a specific focus on its technical dependence on critical raw materials such as gallium and germanium. By analyzing the high degree of concentration in upstream supply markets, the chapter identifies the primary channels through which geopolitical supply shocks and export interventions propagate. Furthermore, it situates these dynamics within the current European policy landscape, specifically examining the strategic objectives of the CRMA and the Chips Act. Together, these considerations form the analytical basis for the empirical strategy and the formulation of the hypotheses in Chapter 3.

## 2.1. Economic Foundations of Semiconductor Manufacturing

Semiconductors are essential microelectronic components characterized by precisely controllable electrical conductivity. They constitute the technological foundation of the digital economy, enabling advancements ranging from consumer electronics to 5G telecommunication networks and artificial intelligence (Bown & Wang, 2024, p. 81; Hillrichs & Wölfl, 2025, p. 5). The industry is organized as one of the most complex, capital-intensive, and research-driven value chains globally, predicated on a highly specialized international division of labor and dense technological interdependencies (Ciani & Nardo, 2022, pp. 3–4).

The production process can be categorized into three strictly interconnected phases: (1) research and development, (2) front-end wafer fabrication, and (3) back-end processes, including assembly, testing, and packaging. This analysis focuses primarily on the wafer fabrication stage, as it represents the most technologically sophisticated and material-dependent phase, where a substantial portion of value added is derived from the utilization of specific metallic precursors (Ciani & Nardo, 2022, pp. 7–8; Hillrichs & Wölfl, 2025, p. 7).

Since these specific inputs are directly integrated into the physical architecture of the semiconductor layers, disruptions in the material supply chain immediately constrain effective production capacity. Short-term substitution is often technically and economically unfeasible. This is due to the rigid material specifications of modern chip architectures (Ciani & Nardo, 2022, pp. 7–8; Li, 2025, p. 338). Furthermore, the exceptionally high fixed costs of fabrication facilities (fabs) imply a high sensitivity to disruptions. The economic relevance of such supply disruptions is amplified by the scale of semiconductor manufacturing. The European semiconductor industry reached a historic peak in 2022, with annual billings exceeding USD 50 billion (European Semiconductor Industry Association (ESIA) & World Semiconductor Trade Statistics (WSTS), 2025). At the same time, the empirical setting of this study coincides with pronounced cyclical dynamics in the global semiconductor market. Following a severe supply shortage between 2020 and 2022, excess inventories and weakening demand led to a broad-based industry downturn in 2023, affecting global production and revenues independently of upstream trade policy measures. This cyclical environment provides important context for assessing how supply-side shocks interact with broader market conditions.

The global production geography is characterized by extreme spatial concentration. Approximately 75 percent of fabrication capacity and nearly all advanced manufacturing nodes are clustered in Taiwan and South Korea. In particular, TSMC's dominance in high-performance logic chips constitutes a systemic choke point (Bown & Wang, 2024, pp. 90–91). Within the escalating geoeconomic rivalry between the United States and China, access to these capacities has emerged as a primary strategic resource (Gao et al., 2023, p. 2). While the U.S. utilizes export controls to restrict Chinese access to leading-edge technology, China interprets this dependence as a structural vulnerability and has responded with massive subsidies for domestic capacity building (Shattuck, 2020, pp. 101–103).

Within this configuration, the EU occupies an ambivalent and structurally dependent position. Despite maintaining critical competencies in semiconductor manufacturing equipment (SME), most notably ASML's advanced lithography systems, Europe's share of global fabrication has declined to below 10 percent. The European industry remains heavily reliant on external actors for both advanced manufacturing services and the supply of critical upstream raw materials (European Commission, 2020, p. 20; Hancké & Garcia Calvo, 2022, p. 4).

Consequently, the semiconductor landscape represents a geopolitical hierarchy in which control over technology and materials functions as an instrument of economic statecraft. This asymmetric exposure to external shocks provides the analytical foundation for Chapter 2.2, which evaluates the strategic importance of gallium and germanium as well as the resulting vulnerabilities of European supply chains.

## 2.2. Industrial Relevance and Applications of Gallium and Germanium

The production geography of the semiconductor industry reveals a deep strategic concentration. Notably, this concentration extends far beyond manufacturing stages to include the access to essential raw materials. Within this upstream architecture, gallium and germanium occupy a central position. They serve as technologically indispensable base materials for advanced device structures. To date, no economically viable substitutes for these materials exist (Mei et al., 2024, p. 2; Wesselkaemper et al., 2025, p. 2).

A defining structural feature of these materials is their extraction as by-products. Germanium is predominantly recovered during zinc smelting and from coal fly ash. Similarly, gallium is primarily extracted from bauxite residues within the aluminum industry (Lu et al., 2017, p. 106; Mei et al., 2024, p. 2). This co-production structure results in a highly inelastic supply. Since output levels are mechanically tied to production decisions in primary metal markets, the supply cannot easily scale. Consequently, this link severely limits the ability of gallium and germanium producers to respond to demand shocks or trade disruptions (Han et al., 2024, p. 6).

Although used only in minute quantities, these materials function as critical micro-inputs. Their availability constitutes a necessary condition for the entire value chain. Furthermore, their unique physical properties cannot be replicated by silicon-based technologies. Even small supply disruptions can therefore trigger disproportionate production losses in downstream high-tech industries (Han et al., 2024, pp. 4–5). This vulnerability is further amplified by a pronounced dual-use character. Gallium- and germanium-based semiconductors are essential for 5G infrastructure. They are equally vital for sensitive defense technologies, including satellite communications and military signal processing (Frenzel et al., 2016, p. 3; Frenzel et al., 2017, p. 327; Zhou, 2024, p. 65).

The lack of substitutability reinforces deep technological path dependencies. Any material shift would require a fundamental redesign of fabrication processes and manufacturing equipment (European Commission, Joint Research Centre, 2020, p. 28). This technical necessity coincides with an extreme spatial concentration of production. Currently, China accounts for nearly all global primary low-purity gallium production. It also controls approximately 70 percent of global germanium refining and processing (Mei et al., 2024, p. 2; U.S. Geological Survey, 2023, p. 73). Such concentration confers substantial leverage through administrative and regulatory controls. As a result, access can be restricted effectively without the use of formal quantity quotas.

For the EU, this concentration transforms resource access into a structural dependency. The high reliance on a limited number of non-European suppliers constitutes a fundamental vulnerability. This is especially critical because the vast majority of extraction and refining activities take place outside Europe (European Commission, Joint Research Centre, 2020, p. 15). Access to gallium and germanium therefore emerges as a central structural risk factor. It directly affects the stability and strategic resilience of the European semiconductor industry (Lewicka et al., 2021, p. 13).

## 2.3. Analysis of Trade Interventions and Export Restrictions

The technological relevance and limited substitutability of these materials, as established in Section 2.2, create significant economic constraints. These factors imply that upstream disruptions cannot be offset by short-term demand-side adjustments. In the absence of viable substitutes, even temporary supply shocks translate directly into downstream vulnerabilities. This structural dependence becomes economically binding when external shocks or trade restrictions interrupt the supply of critical inputs. Recent developments illustrate this mechanism; due to high spatial concentration and low supply elasticity, even brief political interventions trigger profound impacts on global availability (Nassar et al., 2024, p. 3). In this context, the COVID-19 pandemic served as an initial stress test. Logistical disruptions led to a sharp contraction in global production and exposed the lack of buffering capacity within these markets (Kowalski & Legendre, 2023, p. 8).

Escalating geopolitical polarization has since weaponized this vulnerability. In October 2022, the United States introduced comprehensive export controls on advanced semiconductors and manufacturing equipment to restrict China's technological advancement (Bown, 2025, p. 12). In response, Chinese policymakers realigned resource policy to link national security more closely with the control of critical raw materials and the pursuit of technological independence (Li, 2025, pp. 320–321).

The central geoeconomic rupture occurred in 2023. On July 3, China announced an export licensing system for fourteen chemical compounds, including gallium arsenide (GaAs) and germanium wafers, which took effect on August 1. Rather than imposing explicit quotas, the measure introduced case-by-case administrative requirements, subjecting access to regulatory discretion. This marked the first targeted application of the Chinese Export Control Law (ECL) to critical high-tech metals (Li, 2025, pp. 321–323; U.S. Geological Survey, 2024, p. 81). While officially justified by national security concerns, the timing and design suggest a strategic utilization of China's dominant refining position (Li, 2025, pp. 320–321). The shift from transparent trade barriers toward a regime based on administrative discretion constitutes a qualitative change in geoeconomic statecraft. By requiring individual export licenses without clearly defined approval criteria, Chinese authorities created an environment of strategic ambiguity (Li, 2025, pp. 321–323). This induces a persistent uncertainty shock, which often carries greater economic weight than mere price increases as it hampers long-term planning and forces a "wait-and-see" approach among market participants.

These requirements triggered immediate reactions across the global semiconductor value chain. USGS data document a sharp disruption of price signals and pronounced regional decoupling. European prices for high-purity germanium rose from USD 1,150 per kilogram in early 2023 to approximately USD 1,550 by October (U.S. Geological Survey, 2024, p. 81). For gallium, international prices spiked by over 43 percent following the announcement. Conversely, Chinese domestic prices initially remained stable or declined before rising later in 2023, reflecting administrative uncertainty rather than immediate physical shortages (Powers-Riggs et al., 2025, p. 4; U.S. Geological Survey, 2024, p. 71).

This asymmetric price response functions as an implicit industrial subsidy. It strengthens the cost competitiveness of China's downstream sector while increasing costs for international competitors (International Energy Agency, 2023, p. 117). Beyond price effects, the 2023 shock acted as a catalyst for institutional "de-risking" strategies. In the EU, licensing uncertainty intensified efforts to develop alternative supply chains (Teer & Seaman, 2025, p. 29).

Literature on oligopolistic raw material markets suggests that such restrictions generate shock channels beyond simple price volatility. Anticipated restrictions induce persistent planning uncertainty, which delays capital allocation and shifts risk from observable prices to real availability constraints (Kowalski & Legendre, 2023, p. 48). Theoretically, these interventions act as asymmetric subsidies: quantitative controls lower relative input costs for domestic sectors, thereby eroding foreign competitive advantages (Wichmann, 2017, p. 1). At the macroeconomic level, these measures trigger retaliation and value chain fragmentation, potentially forcing a reallocation of trade flows through diversification or "friend-shoring" (Evenett & Fritz, 2023, p. 65).

For "micro-inputs" like gallium and germanium, export restrictions often materialize as immediate output-binding shocks. Due to high material specificity, downstream industries encounter physical production constraints when access is disrupted (Kowalski & Legendre, 2023, p. 48). In the semiconductor industry, such shocks propagate systemically along interconnected value chains (Kleinhans, 2021, p. 37; Powers-Riggs et al., 2025, p. 7). While initial disruptions impact downstream sectors heavily, long-term adjustments are constrained by investment cycles and persistent uncertainty (Kowalski & Legendre, 2023, p. 47; Wachtmeister, 2025, p. 3). Whether the European semiconductor ecosystem possesses the structural elasticity to activate endogenous adjustment mechanisms under these conditions remains a central empirical question.

## 2.4. European Policy Responses and Raw Material Governance

Building on the analysis of upstream dependencies and the immediate market reactions discussed in the previous sections, this chapter examines the policy instruments designed to mitigate vulnerabilities in both the supply of critical raw materials and the performance of the European semiconductor industry. Recent years mark a shift from market-oriented approaches to a strategic framework integrating competitiveness and geopolitical resilience (Glencross, 2024, p. 735). This transformation is embodied in the CRMA, the Chips Act and external partnerships under the principle of open strategic autonomy (Hool et al., 2024, pp. 662–663).

The CRMA constitutes the central instrument addressing upstream dependencies by establishing binding 2030 benchmarks for domestic extraction, processing, and recycling, while capping dependence on single third-country suppliers.

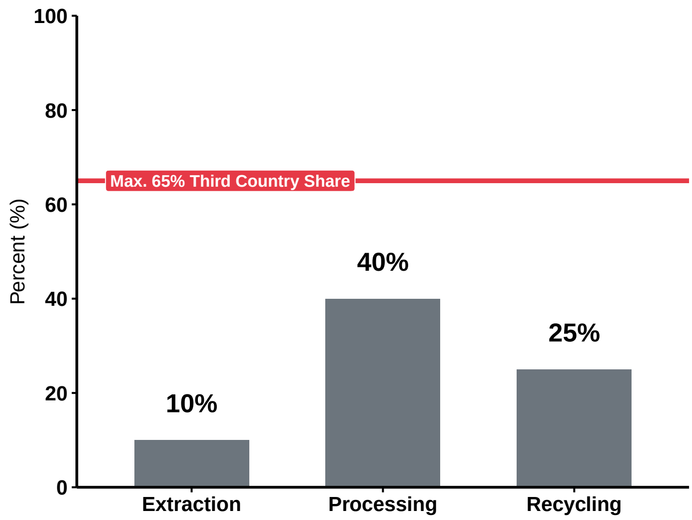


**Figure 1.:** Quantitative 2030 Benchmarks for Strategic Raw Materials (CRMA).
*B*ars show the CRMA 2030 targets for the share of EU annual consumption covered by domestic capacities: 10% extraction, 40% processing, 25% recycling. The dashed line indicates the maximum 65% share from a single third-country supplier.

*Source:* Regulation (EU) 2024/1252 (European Parliament and the Council of the European Union, 2024).

As illustrated in Figure 1, these quantitative targets define the specific capacities the Union aims to develop within the next decade. These benchmarks are designed to counteract supply concentration, most notably vis-à-vis China, and stimulate investment in European refining projects (European Parliament and the Council of the European Union, 2024, p. 21). Beyond numerical benchmarks, the CRMA designates strategic projects as being of overriding public interest. This status grants accelerated permitting: twenty-four months for extraction and twelve for processing (Hool et al., 2024, p. 664)

The RESourceEU Action Plan complements this by focusing on demand-side resilience through resource efficiency and enhanced access to secondary raw materials. While RESourceEU strengthens the industrial base long-term, it does not substantially alter short-run exposure to externally controlled refining capacities for technologically specific inputs like gallium and germanium (European Commission, 2025).

The Chips Act targets downstream manufacturing, aiming to increase the Union's global production share from 10 percent to 20 percent by 2030 (Hancké & Garcia Calvo, 2022, pp. 7). It rests on three pillars: research and pilot lines via Chips for Europe with 11€ billion in funding, supply security through first-of-a-kind manufacturing facilities supported by 30€ billion in incentives, and a crisis response mechanism overseen by the European Semiconductor Board. Despite this 43€ billion volume, critics note that international programs often exceed the EU package, questioning the attainability of these objectives (Dachs, 2023, pp. 2–4).

The external dimension forms the third pillar, pursuing strategic partnerships with countries like Canada, Namibia, and Ukraine since 2021 to diversify supply (Glencross, 2024, p. 734). However, implementation is hindered by institutional fragmentation and diverging national initiatives, risking a lack of coherent coordination (Carry et al., 2025, p. 57).

Overall, this framework represents a significant institutional shift. However, it is characterized by a clear temporal asymmetry. While it aims to enhance long-term resilience, it offers limited protection against immediate supply shocks. The semiconductor industry serves as a paradigmatic case here. Its dependence on gallium and germanium highlights the tight interlinkage between raw material policy and technological sovereignty.

Taken together, this chapter has shown that the global semiconductor industry is marked by pronounced structural vulnerabilities arising from the reliance on technologically indispensable micro inputs, the extreme concentration of upstream extraction and refining capacities, and China's dominant position in these segments. Within this configuration, European high-technology industries, and the semiconductor sector in particular, emerge as highly exposed due to their limited domestic raw material base and deep integration into globally fragmented value chains.

At the same time, the existing literature on critical raw materials and export restrictions has largely focused on price effects and aggregate trade reallocation, providing only limited empirical evidence on how upstream interventions translate into changes in Europe's effective dependence on China and into downstream industrial outcomes. This gap is both analytically and policy relevant, as it directly concerns the resilience of a strategically important industry and the effectiveness of European de-risking initiatives.

While existing studies often rely on simulation-based models to predict long-term shifts, there is a lack of ex-post econometric evidence that evaluates the immediate impact of the 2023 licensing system using real-world trade and production data

The following chapter therefore develops a DiD research design to empirically assess how the introduction of the 2023 Chinese export licensing regime coincided with changes in China's share of European gallium and germanium imports and with relative production dynamics in the European semiconductor sector.

# 3. Methodology

In this chapter, the empirical framework used to analyze the impact of Chinese licensing requirements on European semiconductor supply chains is established. A DiD approach combined with an event study methodology is employed to quantify the effects of trade interventions in gallium and germanium markets on both upstream import patterns and downstream industrial performance. The chapter is structured as follows: First, the data set and the construction of the sample are presented. Second, the identification strategy is explained and the selection of control groups is justified. Thirdly, the model specification is described in depth, including the functional form and the variables used. Finally, the underlying hypotheses to be tested by the empirical analysis are presented.

## 3.1. Data and Sample Construction

To capture the immediate supply shock at the raw material level and its subsequent transmission along downstream value chains, this study integrates four complementary datasets from Eurostat.

The commodity-level analysis utilizes monthly extra-EU trade data from the Eurostat database

“Extra-EU imports since 2010 by partner and other partner, by HS2-4-6 and CN8” (dataset code `DS-059332`). These microdata are reported according to the Combined Nomenclature (CN8), an eight-digit EU product classification that facilitates the precise identification of individual raw materials. The dataset is restricted to extra-EU trade flows between the EU-27 and non-EU countries, thereby systematically excluding intra-European trade. It differentiates between individual partner countries notably and an aggregate “other partners” category representing all remaining non-EU suppliers.

For the empirical analysis, the raw data are transformed into a balanced monthly panel at the EU level. The unit of observation is the $product \times month$ over the period from June 2022 to May 2025. This timeframe was specifically selected to commence in mid-2022, ensuring that distortions from the preceding global semiconductor shortage do not bias the results. The final long-format dataset comprises 144 observations and 13 variables. The primary variables are the total extra-EU import value (*total_value*), the corresponding import value from China (*china_value*), and the resulting value-based share of Chinese imports (*value_share*). These are supplemented by monthly time indicators (*date*, *rel_month*) as well as group- and period-specific dummy variables for the econometric specifications.

Beyond the primary production value, the microdata provide detailed trade statistics. Although not the focus of the baseline estimate, supplementary trade volumes are examined to confirm that the observed adjustments reflect actual volume shifts and not just nominal price fluctuations. Aggregation to the EU total, combined with the focus on value-based import shares, ensures a consistent representation of the temporal profile of Chinese supply dependence at the product level. The formal definition of treatment groups, comparison groups, and intervention periods is detailed in the subsequent section on the identification strategy.

The industry-level analysis is based on production data within the Nomenclature of Economic Activities (NACE) Rev. 2 classification, the EU’s hierarchical taxonomy for economic activities. To examine short-run industrial developments, monthly data from the Eurostat database “Production in industry – monthly data” (`sts_inpr_m`) are utilized. This dataset provides seasonally and calendar-adjusted indices of industrial production (base year 2021 = 100), available at the 3-digit NACE division level.

The raw data encompass several industrial divisions, including NACE 26.1 to 26.5. For the empirical estimation, a cleaned long-format panel dataset is employed, where the unit of observation is the $industry\ division \times month$. The final dataset consists of 84 observations and five variables spanning July 2022 to December 2024. The central variable is the production index (*production*), alongside the necessary time indicators (*date*) and sector-specific variables for the econometric analysis. The focus lies on NACE 26.1 (manufacture of electronic components). Given that monthly production data for the semiconductor industry are unavailable at a more disaggregated level, NACE 26.1 represents the highest possible resolution for analyzing monthly developments. Other industry divisions serve as comparison sectors but are not subject to detailed interpretation.

To address the aggregation of subsectors within NACE divisions, annual PRODCOM data at the four-digit level are integrated. PRODCOM provides harmonized EU statistics on industrial production, reporting both quantities and production values. Within this study, PRODCOM data facilitate a more granular sectoral differentiation, particularly for NACE 26.11 (semiconductor manufacturing). Annual information on production quantities and values for NACE 26.11 is available through 2024 and serves to structurally contextualize the results derived from the monthly indices.

Although these annual series do not enter the core monthly regression specifications, combining CN8-based trade data with NACE-based production data allows for the tracing of the initial raw material shock within a consistent empirical framework. This integrated structure provides the necessary granularity to isolate political interventions from broader macroeconomic trends without mechanically mixing aggregation levels in the econometric setup. Additionally, Producer Price Indices (PPI) from the Eurostat (`sts_inppd_m`) dataset for the period July 2022 to December 2024 are incorporated to control for sectoral price dynamics in NACE 26.1 and 26.5. To ensure that the subsequent analysis captures a true causal effect rather than unrelated market shifts, the following section defines the structural boundaries of the study. It details the selection of treated units and the construction of robust control groups at both the commodity and industry levels.

## 3.2. Identification Strategy and Control Groups

The causal effects of the Chinese export controls are identified using a DiD design. This approach is particularly suitable in the present context because the policy intervention was neither randomly assigned nor introduced in isolation from other contemporaneous shocks, such as business cycle fluctuations or energy price shifts. By combining variation over time and across groups, DiD makes it possible to "difference out" common macroeconomic developments and identify the dynamic deviation of treated units relative to an unaffected reference group (Angrist & Pischke, 2008, p. 172). The empirical implementation proceeds in two steps: first at the commodity level to analyze import dependence, and subsequently at the industry level to examine production effects.

At the commodity level, gallium and germanium are defined as the treated group due to their direct exposure to China's 2023 export restrictions. To construct a robust counterfactual, a composite basket of indium and magnesium is employed. Indium serves as the primary control component due to its comparable technological applications in semiconductors and optoelectronics (Frenzel et al., 2017, p. 327). Furthermore, indium and gallium share a similar metallurgical origin, as both are primarily obtained as by-products of zinc smelting (U.S. Geological Survey, 2023, p. 73). This shared origin ensures that general supply-side dynamics, such as changes in smelting capacities, affect both materials symmetrically.

Empirical pre-tests reveal that Indium alone is insufficient as a control due to significant pre-treatment trend deviations (Appendix A.1). While indium captures sector-specific volatility, it lacks structural stability. To correct for this, magnesium is integrated into the basket. Magnesium provides the necessary stability, shares the high Chinese market dominance, and the EU's CRM classification, but remained unaffected by the 2023 export licensing requirements (Appendix A.2) (Seaman, 2023). However, using magnesium alone would fail to reflect the specialized high-tech market dynamics of the semiconductor-related group. The combined basket thus balances Indium's technological relevance with magnesium's statistical robustness. Other candidates, such as antimony or silicon, were excluded due to trade interventions or insufficient monthly variation (Seaman, 2023).

At the industry level, NACE division 26.1 (manufacture of electronic components and boards) is defined as the treated unit. As the most disaggregated level available for monthly production data, 26.1 serves as a proxy for the European semiconductor industry. This is supported by the sectoral composition: as shown in Table 1, approximately 81 percent of the production value of NACE 26.1 is accounted for by NACE 26.11 (semiconductor manufacturing).

**Table 1.:** Structural composition of NACE sector 26.1 (2022)

| Sub-sector | Production value (EUR) | Share (%) |
|---|---|---|
| 26.11 (Semiconductors) | 42,342,179,649 | 80.9 |
| 26.12 (Loaded electronic boards) | 9,982,563,427 | 19.1 |
| **Total NACE 26.1** | **52,324,743,076** | **100.0** |

*T*he high concentration of production value in 26.11 motivates using the 3-digit NACE 26.1 group as a proxy for the European semiconductor industry.

*Source:* Own calculations based on Eurostat PRODCOM (2024).

It is therefore plausible to assume that observed production effects in 26.1 are predominantly driven by the semiconductor segment.

NACE division 26.5 (manufacture of instruments and appliances for measuring, testing and navigation) is selected as the primary control group. This choice follows a systematic exclusion of alternative sectors within NACE division 26. NACE 26.2 (computers and peripheral equipment) is excluded due to idiosyncratic post-pandemic demand cycles that diverge from semiconductor trends (Silva-Atencio, 2025, p. 3). NACE 26.3 (manufacture of communication equipment) is ruled out to ensure that the *Stable Unit Treatment Value Assumption* (SUTVA) holds. Given the sector's direct technological dependence on gallium and germanium-based components, its inclusion would likely lead to treatment spillovers, thereby inducing a downward bias in the estimated effects (Eurostat, 2024; Butts, 2024, p. 2). Finally, NACE 26.4 (consumer electronics) is excluded due to insufficient data continuity. Consequently, NACE 26.5 constitutes the most plausible comparison sector, as it shares similar cyclical and investment-driven dynamics with NACE 26.1 without being directly affected by the specific raw material shock.

## 3.3. Model Specification

The empirical analysis employs a DiD design estimated within a Two Way Fixed Effects (TWFE) framework, following the canonical setup outlined in (Angrist & Pischke, 2008).

This approach leverages both cross sectional and temporal variation to estimate relative outcome changes associated with China's introduction of export licensing requirements for gallium and germanium in August 2023.

All specifications include unit and time fixed effects. Unit fixed effects absorb time invariant heterogeneity across sectors or products, such as technological characteristics, typical downstream applications, or capital intensity. Time fixed effects control for shocks that affect all observational units simultaneously, including macroeconomic fluctuations, energy price changes, or global trade disturbances (Callaway & Sant'Anna, 2021). By accounting for these confounding factors, the TWFE structure ensures that identification relies on deviations between treated and untreated units net of shared aggregate trends (Angrist & Pischke, 2008).

Treatment effects are identified from differential changes in outcomes for treated units after the intervention, relative to the evolution of the control group, conditional on unit specific baselines and common time effects. Standard errors are computed assuming independently and identically distributed (i.i.d.) disturbances. Given the industry-level design with only two cross-sectional units, cluster-robust variance estimators would not be reliable.

### 3.3.1. Commodity-Level Specifications

At the commodity level, the outcome variable $Y_{pt}$ denotes the share of Chinese supplies in total extra-EU import values of product $p$ in month $t$. This value-based measure captures changes in the relative importance of Chinese suppliers within EU import sourcing.

Treatment status is defined at the product level. The indicator $Treated_p$ equals one for gallium and germanium, which are directly subject to China's export licensing regime, and zero for the composite control basket consisting of indium and magnesium. The time indicator $Post_t$ equals one for all months from August 2023 onwards and zero otherwise.

#### Model (1): Baseline TWFE Specification

$$Y_{pt} = \alpha + \beta\,(Treated_p \times Post_t) + \eta_p + \lambda_t + \varepsilon_{pt}. \tag{3.1}$$

Here, $\alpha$ denotes a constant term. The interaction $Treated_p \times Post_t$ captures exposure to the export restrictions. The coefficient $\beta$ measures the average post-intervention difference in China's import value share between treated commodities and the control basket. Product fixed effects $\eta_p$ absorb all time-invariant differences across commodities, while time fixed effects $\lambda_t$ control for common monthly shocks. The error term $\varepsilon_{pt}$ captures idiosyncratic fluctuations.

This specification imposes a homogeneous treatment effect over the entire post-intervention period and serves as a parsimonious benchmark.

#### Model (2): Time-Differentiated Effects

To allow for gradual adjustment dynamics in international raw material trade, the post-intervention period is divided into multiple phases:

$$
\begin{aligned}
Y_{pt} = \alpha + \beta_1 \left(Treated_p \times Post_t^{0\text{–}3}\right) + \beta_2 \left(Treated_p \times Post_t^{4\text{–}11}\right) \\
+ \beta_3 \left(Treated_p \times Post_t^{12+}\right) + \eta_p + \lambda_t + \varepsilon_{pt}. \quad (3.2)
\end{aligned}
$$

The indicators $Post_t^{0\text{–}3}$, $Post_t^{4\text{–}11}$, and $Post_t^{12+}$ denote short-run, medium-run, and longer-run post-intervention periods, respectively. The corresponding coefficients $\beta_1$, $\beta_2$, and $\beta_3$ capture how the relative import share of China evolves over time following the introduction of the export restrictions. This specification accounts for inventory buffering, contractual rigidities, and delayed responses to administrative licensing requirements.

#### Model (3): Product-Specific Trends

Given the pronounced volatility and heterogeneous pre-intervention dynamics in raw material markets, a third specification augments the model with product-specific linear trends:

$$Y_{pt} = \alpha + \beta_1 \left(Treated_p \times Post_t^{0-3}\right) + \beta_2 \left(Treated_p \times Post_t^{4-11}\right) + \beta_3 \left(Treated_p \times Post_t^{12+}\right) + \theta_p t + \eta_p + \lambda_t + \varepsilon_{pt}. \quad (3.3)$$

The term $\theta_p t$ allows each product to follow its own linear trajectory over time, independent of the policy intervention. In this specification, the DiD coefficients identify discrete level shifts associated with the export licensing regime, conditional on underlying trend heterogeneity. This model serves as a robustness check against spurious attribution of long-run trends to the policy shock.

To examine dynamic treatment effects and to assess pre-intervention dynamics, an event-study specification is estimated:

$$Y_{pt} = \alpha + \sum_{k \neq -1} \beta_k \left(Treated_p \times D_t^k\right) + \eta_p + \lambda_t + \varepsilon_{pt}. \quad (3.4)$$

The indicators $D_t^k$ measure months relative to the introduction of export licensing in August 2023, with July 2023 ($k = -1$) serving as the reference period. The coefficients $\beta_k$ trace the evolution of relative import shares before and after the intervention. Rather than serving as a strict test of the parallel trends assumption, this specification documents the timing, persistence, and stability of post-intervention adjustments.

#### 3.3.2. Industrial-Level Specifications

This subsection describes the empirical specifications used to analyse downstream production effects in the European semiconductor industry following China's licensing requirements on gallium and germanium.

At the industry level, the outcome variable is the logarithm of monthly industrial production, $\ln(\text{Production}_{it})$, for sector $i$ in month $t$, as reported in the Eurostat Short-Term Statistics. The logarithmic transformation allows the estimated coefficients to be interpreted as approximate percentage changes in output.

Treatment status is defined discretely. The treated unit is NACE division 26.1 (manufacture of electronic components and boards), which serves as a proxy for semiconductor manufacturing at monthly frequency. The control group consists of NACE division 26.5 (manufacture of instruments and appliances for measuring, testing and navigation). As discussed in the previous section, this sector is exposed to similar cyclical and investment-driven dynamics but is not directly dependent on gallium or germanium as critical production inputs.

The post-intervention indicator $Post_t$ equals one for all months from August 2023 onwards and zero otherwise.

#### Model (1): Baseline TWFE Specification

The baseline industry-level specification is given by

$$\ln(\text{Production}_{it}) = \alpha + \beta\,(Treated_i \times Post_t) + \eta_i + \lambda_t + \varepsilon_{it}. \tag{3.5}$$

The coefficient $\beta$ captures the average post-intervention difference in production between the treated sector and the control sector. Sector fixed effects $\eta_i$ absorb time-invariant differences in production technologies, capital intensity, and sectoral specialization, while time fixed effects $\lambda_t$ control for common macroeconomic shocks affecting all industries, such as business cycle fluctuations or changes in aggregate demand. Finally, $\varepsilon_{it}$ denotes the idiosyncratic error term, representing unobserved factors that vary across both sectors and time. Given the limited number of sectoral units, clustering at the industry level would not yield reliable inference. Therefore, heteroskedasticity-robust standard errors are reported, and statistical significance is interpreted with caution.

This specification imposes a homogeneous treatment effect over the entire post-intervention period and serves as a benchmark for assessing whether the licensing requirements are associated with a relative decline in semiconductor production.

#### Model (2): Time-Differentiated Effects

To allow for adjustment dynamics in industrial production, the post-intervention period is partitioned into short-run and medium-run phases:

$$\ln(\text{Production}_{it}) = \alpha + \beta_1 \left(Treated_i \times Post_t^{0\text{–}6}\right) + \beta_2 \left(Treated_i \times Post_t^{>6}\right) + \eta_i + \lambda_t + \varepsilon_{it}. \quad (3.6)$$

The indicator $Post_t^{0\text{–}6}$ captures the first six months following the introduction of the export licensing regime, while $Post_t^{>6}$ denotes all subsequent months. The corresponding coefficients $\beta_1$ and $\beta_2$ measure whether production responses differ between the immediate adjustment phase and the subsequent period.

This specification reflects the expectation that disruptions in critical input availability may translate into output adjustments with a delay, as firms initially rely on inventories, contractual arrangements, or short-term process adjustments before reducing production levels.

#### Model (3): Sector-Specific Trends

Given the pronounced heterogeneity in long-run production dynamics across industries, a third specification augments the model with sector-specific linear time trends:

$$\ln(\text{Production}_{it}) = \alpha + \beta_1 \left(Treated_i \times Post_t^{0\text{–}6}\right) + \beta_2 \left(Treated_i \times Post_t^{>6}\right) + \sum_{j \in \{26.1,\, 26.5\}} \theta_j \left(Sector_j \times t\right) + \eta_i + \lambda_t + \varepsilon_{it}. \quad (3.7)$$

The terms $\theta_j(Sector_j \times t)$ allow each sector to follow its own linear growth path over time, independent of the policy intervention. In this specification, the DiD coefficients identify discrete deviations from these sector-specific trends that coincide with the introduction of the export restrictions.

This model serves as a robustness check against the possibility that observed post-intervention differences merely reflect divergent underlying growth trajectories rather than policy-related disruptions.

To capture the temporal dynamics, an event study is also conducted at the industry level. This specification verifies the identification assumptions by mapping trends prior to the intervention and the timing of industrial adjustments. The analysis thus identifies both the immediate and delayed responses of downstream sectors to the licensing requirements on gallium and germanium.

## 3.4. Hypotheses

This section derives the empirical hypotheses tested in Chapter 4 based on the conceptual framework and literature discussed in Chapter 2. The preceding analysis has highlighted three central elements: the structurally high concentration and import dependence of the EU in gallium and germanium, the introduction of China's 2023 requirements as an exogenous policy shock affecting access to these materials, and the potential transmission of upstream material shocks to downstream semiconductor production.

Accordingly, the hypotheses are structured along three dimensions. The first set of hypotheses documents the degree of structural dependence and supplier concentration in EU imports of gallium and germanium prior to the export restrictions. The second hypothesis examines the causal effect of China's 2023 requirements on EU import patterns at the raw material level. The final hypothesis tests whether changes in upstream access conditions translate into measurable downstream effects in the European semiconductor industry. The resulting hypotheses are summarized in Table 2. First, EU imports of gallium and germanium are expected to exhibit persistently high external dependence and strong supplier concentration on China, reflecting the upstream production and processing structure described in Chapter 2. Supplier concentration is measured using the Herfindahl–Hirschman Index (HHI), defined as

$$HHI = \sum_{i=1}^{N} s_i^2,$$

where $s_i$ denotes the import share of supplier country $i$, expressed as a decimal between 0 and 1 (Tirole, 1988, pp. 221–222). According to EU standards, values exceeding 0.25 (or 2,500 HHI points) indicate high market concentration (Bauer et al., 2023, p. 9). Given China's dominant position in gallium and germanium processing, such values are hypothesized.

**Table 2.:** Overview of Hypotheses

| No. | Hypothesis | Empirical Approach | Expected Outcome |
|---|---|---|---|
| H1 | HHI for EU imports of gallium and germanium exceeds 0.25 prior to the introduction of export restrictions. | Descriptive analysis (HHI) | High supplier concentration |
| H2 | Imports from China account for more than 80% of total EU imports of gallium and germanium prior to the export restrictions. | Descriptive analysis (China import share) | China share > 80% |
| H3 | China's 2023 licensing requirements reduce China's share in EU import values for gallium and germanium. | Commodity-level DiD | Negative treatment effect |
| H4 | Industrial production in the semiconductor sector declines more strongly after 2023 relative to a closely related control sector. | Industry-level DiD | Stronger decline in treated sector |

*Source: Own illustration.*

These patterns are examined using descriptive indicators of import dependence and concentration.

Second, China's 2023 licensing requirements are hypothesised to reduce China's share in EU import values for gallium and germanium. These effects are analysed using a commodity-level DiD framework.

Finally, industrial production in the semiconductor sector (NACE 26.1) is expected to decline more strongly after 2023 than in a closely related control sector (NACE 26.5), reflecting the downstream transmission of material-specific supply shocks. This hypothesis is tested using an industry-level DiD approach.

# 4. Results

Chapter 4 presents the empirical results of this study, evaluating the effects of China's licensing requirements through a combination of descriptive and econometric analyses. The chapter first establishes the baseline by documenting structural market concentrations and the resulting import dependencies. Subsequent sections provide quantitative estimates of the policy-induced shocks; specifically, the analysis measures China's market share at the commodity level and changes in production volumes at the industry level. Finally, the statistical validity of these findings is verified through comprehensive robustness tests, with a particular focus on testing the parallel trends assumption and employing alternative model specifications.

## 4.1. Descriptive Analysis of Market Concentration and Supply Dependencies

As a first step, the descriptive analysis documents the degree of concentration and supplier dependence in European import markets for gallium and germanium prior to the introduction of China's export licensing regime. Establishing this baseline is essential for assessing both the structural vulnerability of these markets and the scope for subsequent adjustment. Table 3 summarizes the development of market concentration (HHI) and the Chinese import share for unwrought gallium and germanium between 2018 and 2022.

**Table 3.:** EU Import Structure for Gallium and Germanium (2018–2022)

| Year | HHI | China Share | Quantity (t) | Value (Mio. €) |
|---|---|---|---|---|
| *Panel A: Unwrought Gallium* | | | | |
| 2018 | 0.449 | 0.504 | 38.4 | 6.19 |
| 2019 | 0.725 | 0.845 | 25.5 | 4.43 |
| 2020 | 0.747 | 0.862 | 40.0 | 6.95 |
| 2021 | 0.723 | 0.845 | 50.0 | 8.79 |
| 2022 | 0.950 | 0.975 | 50.1 | 15.40 |
| *Panel B: Unwrought Germanium* | | | | |
| 2018 | 0.567 | 0.732 | 21.0 | 23.00 |
| 2019 | 0.565 | 0.729 | 14.6 | 10.70 |
| 2020 | 0.480 | 0.587 | 6.8 | 7.16 |
| 2021 | 0.731 | 0.844 | 21.0 | 20.10 |
| 2022 | 0.709 | 0.828 | 13.3 | 14.90 |

*Source:* Own illustration based on Eurostat (2024).

For unwrought gallium, the indicators reveal a profound structural shift toward total dependency. While the HHI started at a moderate level of 0.449 in 2018, it surged to 0.950 by 2022. Concurrently, China's share of total EU imports increased from 50.4 percent to 97.5 percent over the same period, indicating a near-monopolistic market structure. Despite this drastic increase in concentration and a tripling of the import value from 4.43 to 15.40 million EUR, physical quantities only rose from 25.5 to 50.1 tonnes between 2019 and 2022, suggesting significant price pressure prior to the 2023 restrictions.

In the case of unwrought germanium, market concentration exhibits higher volatility but remains at elevated levels. The China share peaked at 84.4 percent in 2021 before stabilizing at 82.8 percent in 2022. Correspondingly, the HHI for germanium fluctuated between a minimum of 0.480 in 2020 and a maximum of 0.731 in 2021. Across both product groups, the data demonstrates that overall market concentration is highly synchronized with the share of imports originating from China, establishing a high-risk baseline for the subsequent export licensing shocks.

## 4.2. Analysis of Import Dynamics at the Commodity Level

This section presents the results of the DiD analysis at the commodity level, focusing on changes in China's share of European import values for gallium and germanium following the introduction of the export licensing regime in August 2023. The empirical analysis begins with an assessment of the identifying assumptions underlying the DiD framework.

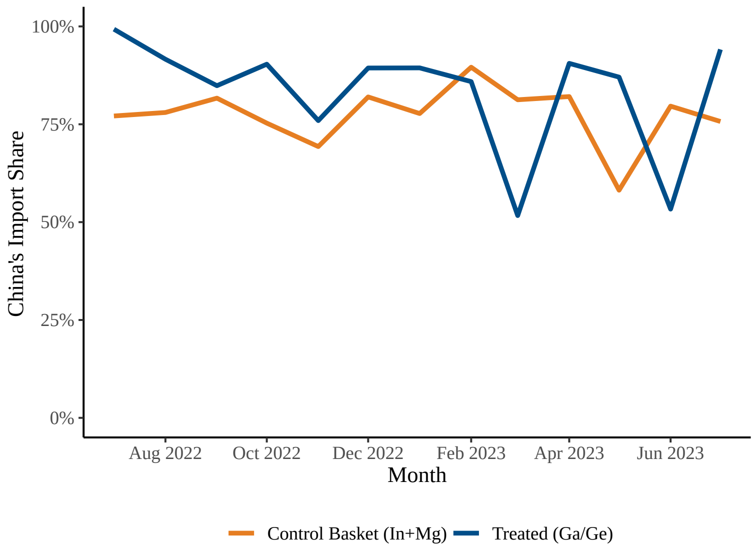


**Figure 2.:** China's Share of Import Value: Pre-Intervention Trends (July 2021–July 2023)

*Monthly share of extra-EU import value originating from China for gallium/germanium (treated group) and indium (control commodity).*

*Source:* Own illustration based on Eurostat (2024).

As illustrated in Figure 2, the treated commodities (gallium and germanium) and the composite control basket (indium and magnesium) exhibit broadly similar movements during the pre-intervention period from July 2021 to July 2023. At the same time, noticeable differences in levels and volatility are visible already prior to the intervention, indicating that pre-treatment dynamics are not strictly parallel. This visual impression is confirmed by a formal Wald test on the joint significance of all pre-treatment coefficients, which rejects the null hypothesis of parallel trends ($p < 0.001$). In line with recent methodological contributions, event-study estimates are therefore used as diagnostic tools to characterize pre-intervention dynamics and to assess the sensitivity of post-intervention patterns to underlying trend heterogeneity (Roth et al., 2023, pp. 235–236). As emphasized by Rambachan and Roth (2023), such diagnostics are particularly relevant in settings where identifying assumptions are only imperfectly satisfied.

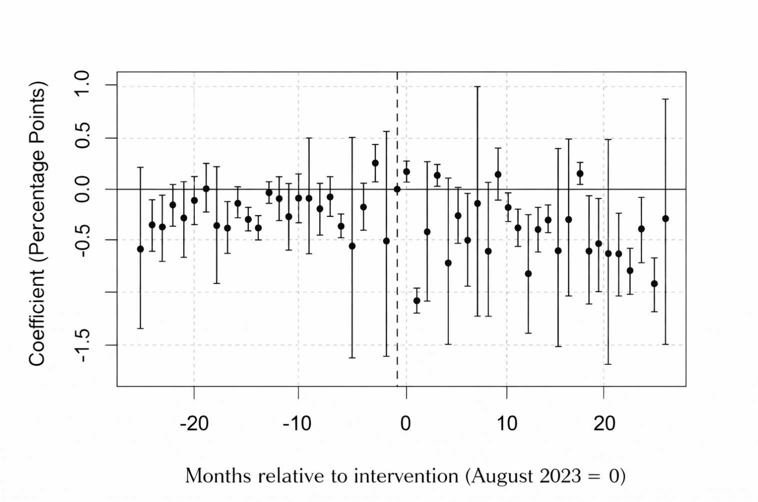


**Figure 3.:** Event-Study Estimates: Relative Change in China's Import Value Share

*Coefficients from an event-study (95% CI).* $t = 0$ *represents August 2023.*

*Source:* Own illustration based on Eurostat (2024).

Figure 3 displays the event-study estimates, normalized to the month immediately preceding the intervention ($t = -1$), with 95% confidence intervals. In the pre-intervention period, estimated coefficients fluctuate around zero but exhibit substantial dispersion. These fluctuations reflect the inherent volatility of highly concentrated raw material markets, where trade flows are shaped by irregular bulk shipments, inventory cycles, and administrative interventions rather than smooth trends (Arriola et al., 2024, p. 30). Importantly, no distinct outlier is visible in the announcement month of July, suggesting that sharp anticipatory adjustments are not evident in the data. Following the implementation of the export licensing regime ($t \geq 0$), the event-study coefficients shift persistently into negative territory. While individual monthly estimates vary in precision, a joint Wald test rejects the null hypothesis of no post-intervention deviation ($\chi^2 = 54.3$, $p < 0.001$), indicating a systematic downward shift in China's import value share coinciding with the policy intervention.

Given the documented pre-intervention heterogeneity, the following estimates are interpreted as descriptive evidence of relative post-intervention adjustments (Roth et al., 2023). Against this background, Table 4 summarizes the DiD estimates between treated commodities and the control basket.

**Table 4.:** Impact of Export Controls on China's Import Value Share (DiD Estimates)

| Dependent Variable: | China's Import Value Share | | |
|---|---|---|---|
| Model: | (1) Overall | (2) Dynamics | (3) Trend |
| *Variables* | | | |
| DiD (Overall) | -0.2405* | | |
| | (0.0558) | | |
| DiD (0–3m) | | -0.1907 | -0.1106 |
| | | (0.0698) | (0.0714) |
| DiD (4–11m) | | -0.1980 | -0.0613 |
| | | (0.1463) | (0.1963) |
| DiD (12m+) | | -0.2895** | -0.0632 |
| | | (0.0469) | (0.2057) |
| Linear Trend | | | -0.0094 |
| | | | (0.0068) |
| Fixed Effects | Product/Time | Product/Time | Product/Time |
| Observations | 144 | 144 | 144 |
| $R^2$ | 0.486 | 0.490 | 0.493 |

Standard errors in parentheses. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
*Source:* Own illustration based on Eurostat (2024).

Model (1) presents the baseline specification and yields an estimated average DiD coefficient of $-0.2405$, corresponding to a decline in China's import value share of approximately 24 percentage points in the post-intervention period relative to the control basket.The estimate is statistically significant at the 10 percent level, with a standard error of 0.0558, and the model explains around 49 percent of the overall variation in import value shares. Model (2) examines the temporal evolution of the post-intervention association. While short-run and medium-run coefficients are not statistically significant at conventional levels, the long-run estimate (12 months and beyond) increases in magnitude to $-0.2895$ and is statistically significant at the

5% level. This pattern indicates that the divergence between treated and control commodities intensifies over time, consistent with gradual adjustment dynamics rather than an immediate reallocation.

Model (3) augments the baseline specification with product-specific linear trends to account for the documented pre-intervention heterogeneity. Although the estimated differential trend coefficient is small and statistically insignificant, its inclusion substantially attenuates the dynamic DiD coefficients and reduces precision. This sensitivity suggests that the observed post-intervention deviations are partly intertwined with underlying market-specific trajectories. Nevertheless, the direction of the association remains negative across all specifications.

Taken together, the commodity-level results document a pronounced decline in China's import value share for gallium and germanium in the period following the introduction of the export licensing regime. While violations of the parallel trends assumption preclude a strictly causal interpretation, the consistency of the negative post-2023 association across specifications and diagnostic approaches points to a meaningful reorganization of European sourcing patterns.

## 4.3. Analysis at the Industry Level

This section examines whether the upstream adjustments documented at the commodity level are associated with observable changes in downstream industrial production. The analysis focuses on the European semiconductor sector (NACE 26.1) and compares its production dynamics to a closely related control industry (NACE 26.5). Figure 4 illustrates the evolution of indexed production volumes for both sectors during the pre-intervention period.

From July 2021 to July 2023, the two series display pronounced cyclical co-movement, including a synchronized peak in late 2022 and a subsequent contraction in early 2023. At the same time, production in the semiconductor sector exhibits larger amplitudes and higher idiosyncratic volatility, reflecting its exposure to the global semiconductor shortage and subsequent demand normalization. A joint Wald test rejects the null of equal pre-intervention coefficients ($p < 0.01$), indicating non-parallel pre-trends. In line with the diagnostic interpretation of DiD designs by (Roth et al., 2023), the subsequent analysis explicitly accounts for these divergent trajectories.

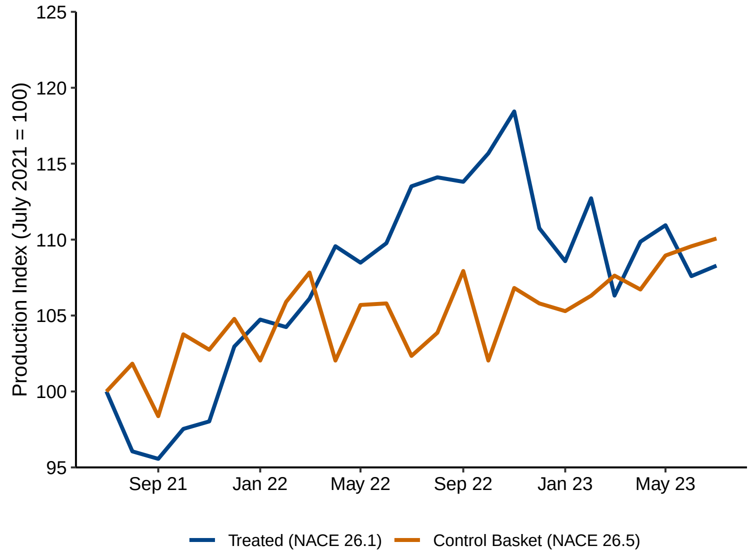


**Figure 4.:** Evolution of Production Levels and the Parallel Trends Assumption (NACE 26.1 vs. 26.5)

*The figure displays indexed production levels for NACE 26.1 as the treated group and NACE 26.5 as the control group.*

*Source:* Own illustration based on Eurostat (2024).

The dynamic response of industrial production is captured by the event-study estimates shown in Figure 5. In the pre-treatment phase, coefficients fluctuate around zero without indicating a systematic anticipatory response.

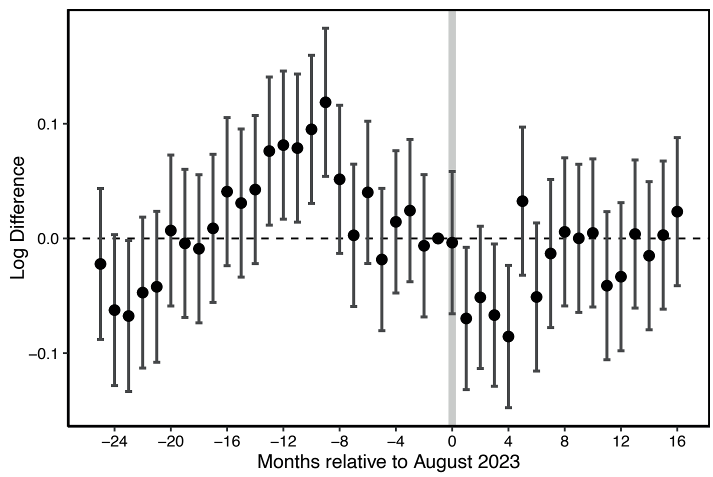


**Figure 5.:** Event Study: Dynamic Production Response to Export Restrictions

Point estimates and 95% CIs for the log-difference (NACE 26.1 vs. 26.5).Vertical bar at $t = 0$ marks the implementation (Aug 2023).

*Source:* Own illustration based on Eurostat (2024).

Following the implementation of the export licensing regime in August 2023, the estimates shift persistently into negative territory. The decline reaches its maximum magnitude several months after the intervention, and a joint test rejects the null hypothesis of no post-intervention deviation at conventional significance levels. This pattern indicates a sustained downward deviation in semiconductor production relative to the control sector that exceeds historical volatility. Given the documented differences in pre-intervention trends, these results are interpreted as descriptive evidence of relative post-2023 production adjustments rather than as causal effects attributable solely to the export restrictions.

Table 5 reports the corresponding DiD estimates. Model (1) presents the baseline specification and yields an estimated post-intervention coefficient of $-0.0440$, corresponding to an average relative decline in semiconductor production of approximately 4.4 percent compared to the control sector. The estimate is statistically significant at the 1% level and the model explains around 55% of the overall variation in production indices.

**Table 5.:** DiD Estimates for Industrial Production

| | (1) Baseline | (2) Phases | (3) Trends |
|---|---|---|---|
| Dep. Variable | log(Production) | | |
| DiD (Total) | -0.0440*** | | |
| | (0.0122) | | |
| DiD Short (6m) | | -0.0542*** | -0.0961*** |
| | | (0.0153) | (0.0183) |
| DiD Medium | | -0.0340* | -0.1057*** |
| | | (0.0152) | (0.0256) |
| Trend (NACE 26.1) | | | 0.0045*** |
| | | | (0.0012) |
| Trend (NACE 26.5) | | | 0.0015 |
| | | | (0.0010) |
| Fixed Effects | Yes | Yes | Yes |
| Observations | 84 | 84 | 84 |
| $R^2$ | 0.551 | 0.558 | 0.629 |

Standard errors in parentheses. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
*Source:* Own illustration based on Eurostat (2024).

Model (2) decomposes the response into temporal phases. The short-run coefficient of $-0.0542$ is highly statistically significant, indicating a pronounced relative decline in production in the initial post-intervention period, while the medium-run coefficient of $-0.0340$ is significant only at the 10% level. The modest increase in explanatory power relative to the baseline suggests that allowing for dynamic adjustment phases improves model fit only marginally, consistent with persistent heterogeneity in sectoral production dynamics.

Model (3) explicitly accounts for these differences by incorporating sector-specific linear trends. A highly statistically significant positive trend is identified for the semiconductor sector, confirming its distinct pre-intervention growth trajectory relative to the control group. Accounting for this trend substantially improves model fit ($R^2 = 0.629$) and increases both the magnitude and precision of the estimated post-intervention deviations. The trend-adjusted estimates are associated with relative production differences of approximately 9.6% in the short run and 10.6% in the medium run, indicating a persistent downward level shift in semiconductor production relative to the control sector that is less pronounced in the simpler specifications.

Overall, the industry-level results suggest that the upstream trade adjustments documented for gallium and germanium coincided with economically meaningful relative declines in European semiconductor production. While pre-intervention trend heterogeneity cautions against a strictly causal interpretation, the consistency of the negative post-2023 pattern across specifications and diagnostic checks points to a systematic association between upstream raw material disruptions and downstream industrial outcomes.

## 4.4. Robustness and Sensitivity Analyses

In light of the documented violations of the parallel trends assumption across both analysis levels, the following checks do not aim for causal identification in the strict sense. Adopting the framework of (Roth et al., 2023), this section evaluates whether the observed declines in China's import share and European industrial output represent systematic empirical patterns. Following the diagnostic logic of (Angrist & Pischke, 2008), the analysis examines the sensitivity of the results to alternative control groups and timing assumptions to ensure that the findings are not merely artifacts of sectoral volatility or sample specific idiosyncrasies.

A first robustness check examines the sensitivity of the baseline results to the choice of the comparison group. The DiD specification is therefore re-estimated using indium and magnesium separately as control commodities instead of the composite basket. The corresponding estimates are reported in Table 6. Across both specifications, the estimated post-intervention interaction coefficients remain highly similar in magnitude, amounting to $-0.241$ when indium is used as the control commodity and to $-0.240$ when magnesium serves as the benchmark.

**Table 6.:** Sensitivity to the Choice of the Control Group

| | Indium as Control | Magnesium as Control |
|---|---|---|
| Dependent variable | Value Share | |
| Treated × Post (overall) | $-0.2414^{***}$ | $-0.2396^{***}$ |
| | (0.0629) | (0.0629) |
| Fixed effects | Product, Date | |
| Observations | 108 | 108 |
| $R^2$ | 0.43155 | 0.54104 |
| Within $R^2$ | 0.05685 | 0.06584 |

Standard errors in parentheses. Significance levels: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

*Source:* Own illustration based on Eurostat (2024).

In both cases, statistical significance is achieved only at the 10% level, indicating limited precision.

The stability of the point estimates across alternative control groups suggests that the observed post-intervention decline in China's import value share is not mechanically driven by the construction of the composite control basket. However, the relatively weak statistical significance highlights the limited power of the commodity-level analysis and reinforces the need for a cautious, descriptive interpretation of the results.

To assess whether the pooled estimates mask heterogeneous responses across treated commodities, the analysis is repeated separately for gallium and germanium, each compared to the composite control basket. Table 7 reports the corresponding results.

The estimated post-intervention coefficients are negative and highly statistically significant for both commodities. The magnitude of the decline is substantially larger for gallium, with an estimated coefficient of $-0.300$, compared to $-0.181$ for germanium. This difference points to heterogeneous adjustment dynamics across critical raw materials.

Importantly, however, the consistency in sign and statistical precision across both commodities indicates that the aggregate results are not driven by a single treated product. Instead, the observed post-intervention pattern reflects a broad-based decline in China's import value share across multiple critical inputs.

**Table 7.:** Commodity-Specific DiD Estimates

| | Gallium | Germanium |
|---|---|---|
| Dependent variable | Value Share | |
| Treated × Post (overall) | $-0.2996^{***}$ | $-0.1814^{***}$ |
| | (0.0009) | (0.0009) |
| Fixed effects | Product, Date | |
| Observations | 108 | 108 |
| $R^2$ | 0.58632 | 0.58588 |
| Within $R^2$ | 0.11687 | 0.06246 |

Standard errors in parentheses. Significance levels: $^{***}$ $p < 0.01$; $^{**}$ $p < 0.05$; $^{*}$ $p < 0.1$.

*Source:* Own illustration based on Eurostat (2024).

Finally, sensitivity to potential anticipation effects is examined by excluding July 2023, the month in which the licensing requirements were publicly announced. The resulting donut DiD estimates are presented in Appendix A.1. Excluding the announcement month leaves the estimated coefficient largely unchanged in magnitude, with only a modest reduction in statistical precision. This suggests that the baseline estimates are not solely driven by a discrete announcement-related adjustment or short-run stockpiling behavior concentrated in a single month. Additional placebo tests based on an artificial intervention date in August 2022 are reported in Appendix A.2. The placebo coefficient is statistically significant, indicating that treated and control commodities already displayed diverging dynamics prior to the formal implementation of export licensing in August 2023. Given the short pre-treatment period and the substantial restructuring of semiconductor-related input markets during 2022, this result is not interpreted as a falsification of the empirical design. Rather, it reflects the broader structural adjustment processes and heightened volatility that characterized the market environment following the global semiconductor shortage, within which the 2023 policy was introduced.

Taken together, the robustness tests suggest that the observed decline in China's import value share after the intervention represents a consistent empirical pattern across alternative specifications. The negative post-2023 association persists irrespective of the specific definition of the control group, the individual commodities analyzed, or adjustments to the intervention timing. While the documented violations of the parallel trends assumption, in line with the methodological concerns raised by (Roth et al., 2023), preclude a strictly causal interpretation, the stability of the direction and approximate magnitude of the estimates supports the descriptive interpretation of a post-2023 shift in trade dynamics. Following the diagnostic logic of (Angrist & Pischke, 2008), the results are best understood as evidence of a systematic reorientation pattern rather than as a purely random fluctuation driven by market volatility or sample-specific idiosyncrasies.

While the upstream analysis allowed for a wide range of alternative control groups and specifications, robustness testing at the industry level is necessarily more constrained due to the lower dimensionality of the data and the limited number of closely comparable sectors. The objective of the following exercises is therefore not to establish causal identification in a strict sense, but to assess whether the estimated post-2023 production decline reflects a systematic adjustment pattern rather than a model-driven artifact.

A first diagnostic check examines the sensitivity of the results to the timing of the intervention. Figure 6 reports an event-study specification using an artificially advanced placebo intervention date in August 2022.

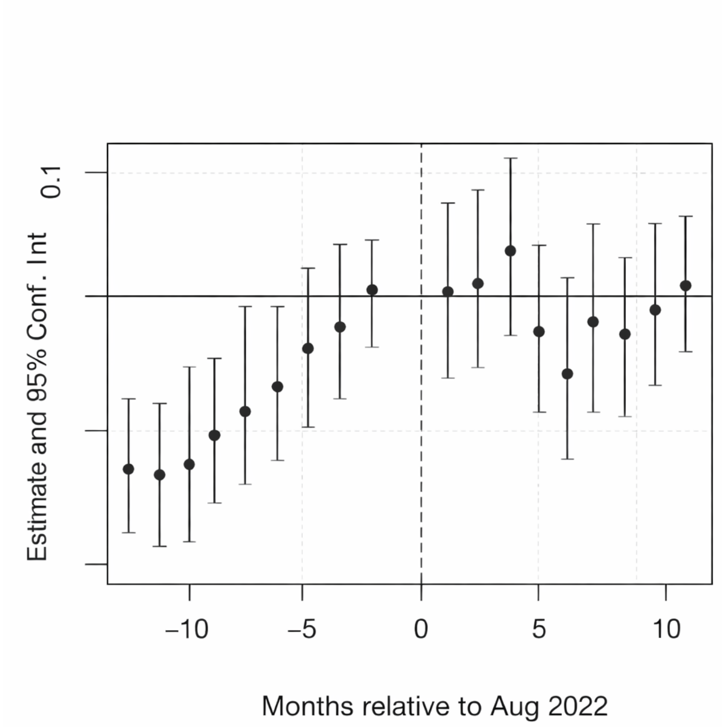


**Figure 6.:** Placebo Test: Artificially Advanced Intervention (August 2022)
*E*vent-study coefficients for a fictitious treatment start in August 2022.
*Source:* Own illustration based on Eurostat data.

In the period preceding the fictitious intervention, the estimated coefficients display pronounced fluctuations that are consistent with the ongoing adjustment dynamics following the global semiconductor shortage in 2021 and 2022. Crucially, however, no discrete or persistent structural break occurs at the placebo date itself. This indicates that the production decline observed after August 2023 does not arise mechanically in periods without policy intervention. To assess robustness with respect to the functional form of the outcome variable, the baseline specification is re-estimated using production indices in levels instead of logarithms. Figure 7 shows that the resulting dynamic pattern closely mirrors the log-based estimates. This indicates that the observed production decline is not driven by the transformation of the dependent variable but reflects economically meaningful losses in output.

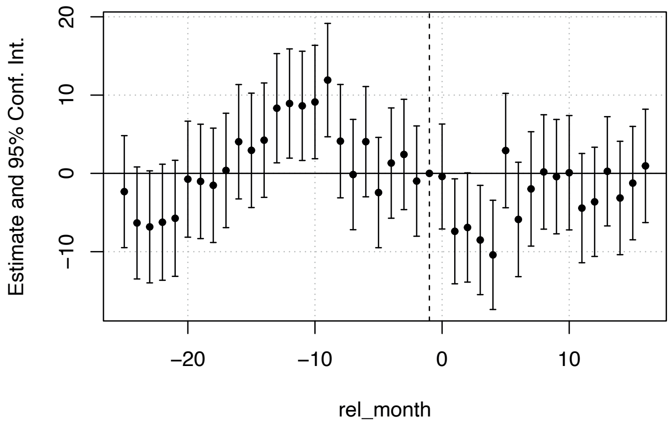


**Figure 7.:** Sensitivity Analysis: Production Index in Levels

*Event-study coefficients and 95% confidence intervals using the production index in levels as the dependent variable.* $t = 0$ *corresponds to the start of the intervention in August 2023.*

*Source:* Own illustration based on Eurostat (2024).

Finally, a wide-donut DiD specification is estimated in which the three months surrounding the introduction of the export licensing regime (July–September 2023) are excluded from the estimation sample.

Table 8 shows that the estimated post-treatment coefficient remains similar in magnitude relative to the baseline model. The similarity of the point estimates suggests that the main results are not driven by short-run adjustment dynamics, anticipation effects, or transitory disruptions around the policy introduction.

Additional diagnostic exercises using alternative industry control groups are reported in Appendix A.4 and interpreted as falsification tests due to non-parallel pre-treatment dynamics.

**Table 8.:** Robustness Check: Main Model vs. Wide Donut Specification

| Dependent Variable: | log(production) | |
|---|---|---|
| | Main Model | Wide Donut |
| Model: | (1) | (2) |
| *Variables* | | |
| DiD (Post) | -0.0440*** | -0.0391** |
| | (0.0145) | (0.0154) |
| *Fixed-effects* | | |
| Sector | Yes | Yes |
| Date | Yes | Yes |
| *Fit statistics* | | |
| # Date | 42 | 39 |
| Observations | 84 | 78 |
| $R^2$ | 0.72456 | 0.72633 |
| Within $R^2$ | 0.14386 | 0.13649 |

Standard errors in parentheses. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

*Source:* Own illustration based on Eurostat (2024).

As a complementary mechanism check, this subsection examines whether the post-2023 adjustment documented at the commodity and industry levels materializes through prices rather than quantities. An event-study specification using PPI) for the treated semiconductor sector (NACE 26.1) and the control sector (NACE 26.5), normalized to August 2023, is employed for this purpose.

To identify the underlying transmission channel, the analysis examines whether the export controls induced a cost-push shock to producer prices, as measured by the PPI. A relative divergence in the PPI becomes apparent after August 2023; however, this is primarily driven by rising prices in the control sector, while semiconductor prices remain remarkably stable. This absence of an inflationary response in the treated sector suggests that the observed output decline is unlikely to be primarily driven by price-setting behavior. Instead, the impact appears to be transmitted primarily through physical quantity adjustments, where supply-side bottlenecks constrain production regardless of stable nominal prices. Given the non-parallel pre-trends, these dynamics are interpreted as descriptive evidence. The corresponding DiD regression with sector and time fixed effects is reported in Appendix A.3.

Taken together, the robustness and sensitivity analyses indicate that the estimated post-2023 production decline is not driven by specific modeling choices, short-run anticipation effects, or functional form assumptions. Across alternative timing assumptions, outcome definitions, and exclusion windows, the direction and magnitude of the estimated effect remain stable. Consistent with recent DiD guidance, these results are therefore best interpreted as evidence of a systematic industry-level adjustment rather than as a precisely identified causal effect.

# 5. Discussion

The following section discusses and interprets the empirical findings of the main specifications and the complementary analyses at both the commodity and industry levels. The discussion first revisits the descriptive evidence on market concentration and import dependence to situate the magnitude of the estimated trade adjustments. It then interprets the DiD results for upstream trade structures, followed by an analysis of the industry-level production effects in the European semiconductor sector. The findings are subsequently contextualized within the literature on export restrictions, supply-side shocks, and critical raw material dependencies. Finally, the limitations of the empirical approach are discussed, and implications for European raw material and industrial policy, as well as directions for future research, are outlined.

## 5.1. Interpretation of the Results

The descriptive analysis strongly supports the central thesis of this study. Even before the 2023 Chinese export licensing regime, EU import markets for gallium and germanium were characterized by an exceptionally high concentration of supply. HHI values were significantly above the European Commission's threshold of 0.25. Above this level, markets are classified as highly concentrated and potentially problematic (Bauer et al., 2023, p. 9). This concentration manifests as a near-monopolistic import structure. Before 2023, the Chinese import share of both products often exceeded 80 percent. For gallium, the HHI reached a level of 0.95 by 2022, indicating an almost perfectly concentrated supplier structure.

The data a reveals a critical divergence between import values and physical volumes: while gallium quantities remained stagnant at approximately 50 tonnes between 2021 and 2022, the total import value tripled to 15.40 million EUR. This price-volume decoupling indicates extreme supply inelasticity and suggests that the market was already under significant stress prior to the formal de jure restrictions. Across both product groups, the synchronization between market concentration and Chinese supply confirms that no viable "outside option" existed.

Against this background, the results for trade structures (H3) are consistent with a significant structural adjustment. The estimated decline in China's import share by 24 to 29 percentage points signals a substantial reconfiguration of European sourcing patterns. This shift should not be understood as a conventional response to relative prices. Rather, the findings suggest that administrative uncertainty and doubts about physical availability constitute the central transmission channels in highly concentrated upstream markets (Kowalski & Legendre, 2023, pp. 47–48).

Such an adjustment mechanism is consistent with patterns typically observed in supply-side shocks in markets for critical raw materials. In these markets, low short-run supply elasticity and limited substitutability render price-based adjustment ineffective. In quasi-monopolistic upstream settings, firms face binding access constraints rather than gradual cost increases. They therefore reorganize sourcing strategies based on reliability and supply security (OECD, 2025, p. 16; Wachtmeister, 2025, p. 3). Trade patterns adjust through risk-based diversification and trade diversion. This reflects the primacy of physical availability over cost efficiency in critical input markets (Evenett & Fritz, 2023, pp. 41–42).

The temporal pattern of the event-study estimates supports this interpretation. The gradual but persistent decline after August 2023 matches the delayed supply chain adjustment described in the literature. Firms initially draw on inventories and existing contracts before structural changes in procurement strategies become visible (Mancheri et al., 2018, p. 47). Long-run effects exceed short-run coefficients. This argues against purely inventory-driven responses and points to deliberate de-risking strategies. In these strategies, supply security is prioritized over short-term cost efficiency (Kowalski & Legendre, 2023, pp. 47–48).

Regarding industry-level production (H4), the results indicate that the raw material shock is associated with economically meaningful relative reductions in industrial output. Complementary evidence from producer price dynamics in the semiconductor sector indicates that this adjustment materializes primarily through quantities rather than prices, consistent with an availability-driven transmission mechanism. Depending on the specification, the estimated relative production decline ranges between approximately 4 percent in the baseline model and up to 9 percent once sector-specific trends are accounted for. The larger magnitudes in the trend-adjusted specification suggest that part of the post-2023 deviation becomes more pronounced once pre-existing growth differentials are controlled for. This magnitude is particularly critical for the semiconductor sector due to its high capital intensity and limited short-run flexibility. These losses are consistent with output contractions induced by supply-side disruptions in non-substitutable upstream inputs. In such capital-intensive industries, these disruptions impose binding constraints on production that lead to measurable economic damage (Varas et al., 2021, pp. 7–9).

Beyond immediate production losses, the literature highlights uncertainty as a central amplification channel. Upstream export restrictions affect downstream industries through this channel. Even the anticipation of future export controls creates uncertainty for raw material producers and processing industries. This increases the perceived supply risk for firms that depend on imported strategic inputs. Such uncertainty regarding future availability and price developments can depress investment in new production capacities. This is particularly relevant in capital-intensive sectors with long planning horizons (Wachtmeister, 2025, p. 3).

For downstream industries reliant on critical raw materials, supply disruptions translate into binding production constraints once physical availability is affected. This vulnerability is not merely a matter of costs. It is particularly acute in sectors characterized by high material specificity. In these sectors, short-run substitution possibilities are limited or entirely absent (Kowalski & Legendre, 2023, p. 47). Semiconductor manufacturing falls squarely into this category. Its capital intensity and technological rigidity imply a specific vulnerability. Even moderate disturbances in critical mineral inputs can lead to disproportionate output losses (OECD, 2025, p. 4).

From a political economy perspective, export restrictions on critical raw materials are deliberately deployed as instruments of a subsidy-like industrial policy. They aim to generate strategic competitive advantages. This is achieved by lowering domestic input costs while simultaneously increasing marginal costs for foreign producers. Resource-rich states can exploit structural asymmetries in global value chains. They shift rents in favor of their own downstream industries without relying on traditional import tariffs on final goods (Wichmann, 2017, pp. 1–6). This strategy is part of a striking global trend. The use of export restrictions, particularly for critical minerals, has increased massively over the past decade. This development underscores the growing importance of upstream trade controls as geopolitical instruments (Evenett & Fritz, 2023, p. 41; OECD, 2025, p. 5).

## 5.2. Limitations and Implications

The empirical findings of this study are subject to several methodological and data-related limitations that must be taken into account when interpreting the results.

A first and central limitation concerns identification. At both the commodity and industry level, the parallel-trends assumption underlying the DiD framework is violated, reflecting the intrinsically volatile nature of critical raw material markets and the presence of heterogeneous pre-intervention dynamics. This is documented in the pre-trend diagnostics and robustness analyses. Consequently, the estimated coefficients cannot be interpreted as point-identified causal policy effects in a strict econometric sense. Rather, they represent structured summaries of relative post-intervention adjustments. While the results remain stable across alternative specifications and are corroborated by event-study evidence, the precise attribution between policy-induced effects and underlying trends remains subject to uncertainty.

Second, interpretation at the industry level is constrained by data aggregation and measurement limitations. Monthly production data are not available for the narrowly defined semiconductor manufacturing class (NACE 26.11), necessitating the use of the broader NACE 26.1 aggregate. Although NACE 26.11 accounts for the majority of value added within this group, the broader aggregation inevitably incorporates adjacent activities that may be subject to different demand and supply dynamics. Moreover, the reliance on production indices rather than direct measures of physical output or material input quantities limits the ability to disentangle binding input constraints from demand-side adjustments or postponed investment decisions. In addition, no systematic data on firm-level or sectoral inventory positions are available, preventing a direct assessment of short-run buffering through stockpiling or inventory drawdowns.

Third, additional limitations arise at the commodity level due to the intrinsic characteristics of critical raw material markets. Trade flows are frequently shaped by irregular bulk shipments, inventory cycles, and administrative interventions, resulting in high volatility and non-smooth time series (Evenett & Fritz, 2023, p. 1; Kowalski & Legendre, 2023, p. 8). While the empirical specifications include product fixed effects and time fixed effects to absorb time-invariant heterogeneity and common shocks, remaining idiosyncratic fluctuations may still affect short-run dynamics. Furthermore, heterogeneity in technical characteristics, such as by-product dependence, refining complexity, and recycling potential, implies that identical shocks can generate differentiated adjustment paths across materials (European Commission, Joint Research Centre, 2020).

Fourth, the analysis deliberately focuses on Extra-EU trade flows in order to capture the EU's strategic dependence on external sovereign suppliers. While this choice avoids distortions arising from internal re-exports and sharpens the analysis of external supply shocks, it necessarily abstracts from internal adjustment mechanisms within the European Single Market. In particular, the data do not capture potential intra-EU reallocation, substitution across member states, or the use of existing European inventories. As a result, the analysis provides a partial view of total material circulation within the European semiconductor value chain.

Finally, the empirical analysis is conducted over a relatively short post-intervention window following the introduction of the Chinese export licensing regime in August 2023. This period coincides with pronounced cyclical volatility in the semiconductor industry, including a broad-based demand-driven downturn in 2023 following the global shortage of 2021–2022 (Xiong et al., 2025, p. 2445). Importantly, this demand contraction also affected the control sector (NACE 26.5), which is similarly exposed to cyclical fluctuations in industrial demand but does not rely on gallium or germanium as critical inputs. While the DiD framework focuses on relative deviations, the analysis does not yet capture longer-term resilience gains or structural transformation effects associated with major European policy initiatives such as the CRMA and the Chips Act.

Despite these limitations, the findings yield relevant implications for the European semiconductor industry. First, the results show that substantial diversification is possible. This applies even in highly concentrated markets for technologically specific inputs. An exogenous trade policy shock can expose existing dependencies and trigger adjustment. The estimates indicate a relative decline in China's import share of gallium and germanium by approximately

25 percentage points compared to the counterfactual trend. This shift is consistent with a significant reorganization of European sourcing patterns. This pattern is consistent with a substantial reorganization of European sourcing patterns. From a policy perspective, this suggests that the diversification targets of the CRMA are attainable in principle. At the same time, the findings indicate that such adjustments require active policy incentives. Market forces alone are unlikely to generate diversification in these concentrated markets.

Second, the evidence suggests that geopolitical raw material shocks have real economic effects. The European semiconductor sector is directly impacted. The estimates point to relative production losses of 4 to 9 percent. These effects are economically significant. They are driven by the sector's high capital intensity and quasi-Leontief production structures. From an analytical perspective, this reinforces a new priority. Raw material risks should be treated as a core component of industrial policy. They are not merely an external constraint.

Third, the results argue for a closer integration of raw material and industrial policy. These should not be treated as separate tracks. The decline in China's import share indicates that the CRMA's 65 percent ceiling is broadly within reach. This assumes that diversification incentives are consistently implemented. However, China remains the dominant supplier. Meanwhile, the Chips Act aims to expand European fabrication capacity. Without coordinated planning, a new risk emerges. Increasing downstream capacity raises the absolute demand for gallium and germanium. This growth could outpace the establishment of alternative supply sources. In this case, Europe's exposure to shocks would remain high despite declining import shares.

In this context, existing EU instruments are essential. The CRMA emphasizes strategic projects and processing capacities. It also focuses on raw material partnerships with third countries. The empirical results suggest that these elements are vital. They help translate relative diversification into effective security of supply. Capacity expansion under the Chips Act increases the need for stable upstream supply. Without stronger resource cooperation, industrial targets risk being constrained. Persistent bottlenecks in critical inputs remain a threat.

Finally, European resilience strategies must go beyond capacity expansion. Sourcing patterns changed and China-dependence was reduced. Yet, the sector still faced relative output losses. This indicates that diversification alone does not neutralize short-term costs or risks. Resilience requires an instrument mix. Diversification must be complemented by strategic stockpiling and international partnerships. These should work alongside long-term investment programs. Overall, the results provide an empirically grounded diagnosis. They highlight the structural tensions in European de-risking strategies. A sustained reduction of vulnerability requires joint coordination. Upstream raw material policy and downstream industrial policy must be addressed together.

# 6. Conclusion

This thesis examined the critical resource dependency of the European semiconductor industry. The analysis focused on the Union's reliance on non-EU sources for gallium and germanium. It evaluated how geopolitical shocks in upstream markets affect downstream production. By analyzing China's 2023 export licensing regime, this study mapped the transmission of risk along a value chain that is foundational to the modern economy.

The semiconductor industry acts as the primary enabler for digital transformation and green technologies. Its products are essential for everything from automotive electronics to advanced telecommunications and defense systems. This strategic importance makes any disruption in the sector a systemic risk for European industrial stability. The descriptive evidence confirms that this vital industry faces an extreme and structurally anchored supplier concentration. Prior to 2023, the European market relied almost entirely on Chinese primary production for key inputs.

The empirical results show that the 2023 policy shock was associated with a significant reorganization of trade. China's import share saw a relative decline of approximately 25 percentage points compared to the counterfactual trend. However, this diversification coincided with measurable production losses in the semiconductor sector. These findings underscore a fundamental reality. In a high-tech industry with limited short-term flexibility, upstream vulnerabilities act as a powerful transmission channel for geopolitical risk.

These results must be interpreted within certain methodological limitations. The short observation window captures immediate adjustment costs rather than long-term resilience.

Furthermore, the use of aggregate industry data and the exclusion of intra-EU trade provide a focused view of external strategic dependence. While the non-parallel pre-trends necessitate caution regarding strict causality, the consistency of the patterns reveals a clear structural sensitivity.

The findings have direct implications for European industrial policy. Strengthening resilience requires more than just building new factories. The capacity objectives of the Chips Act aim to double Europe's global market share. However, these goals will remain vulnerable without secured access to raw materials. Therefore, industrial targets must be strictly aligned with the CRMA. This study suggests that the CRMA's diversification targets are attainable. Yet, they require active policy coordination rather than reliance on market forces alone.

Looking ahead, export restrictions will play an increasingly dominant role in global trade. Critical raw materials have become strategic leverage points in geopolitical competition. In this environment, the semiconductor industry is at the center of a "technology-resource-security" nexus. Future research should extend this framework to other materials and longer time horizons. Granular firm-level data could further reveal how companies manage these shocks through stockpiling or substitution. In conclusion, managing upstream dependencies is no longer a peripheral task. It is a requirement for European industrial sovereignty. As geopolitical tensions rise, the joint coordination of raw material and industrial policy will be the defining factor for a resilient and competitive high-tech sector.

# A. Appendix

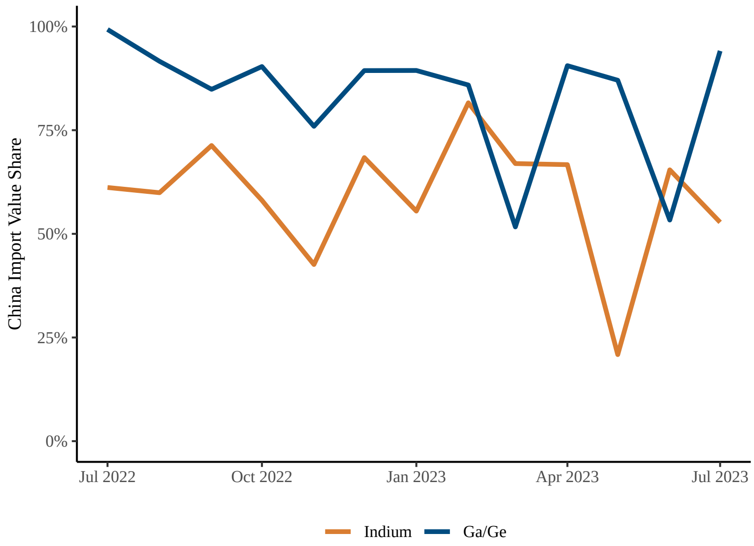


**Figure A.1.:** Pre-treatment Trend Analysis: Gallium/Germanium vs. Indium
*Source:* Own illustration based on Eurostat (2024).

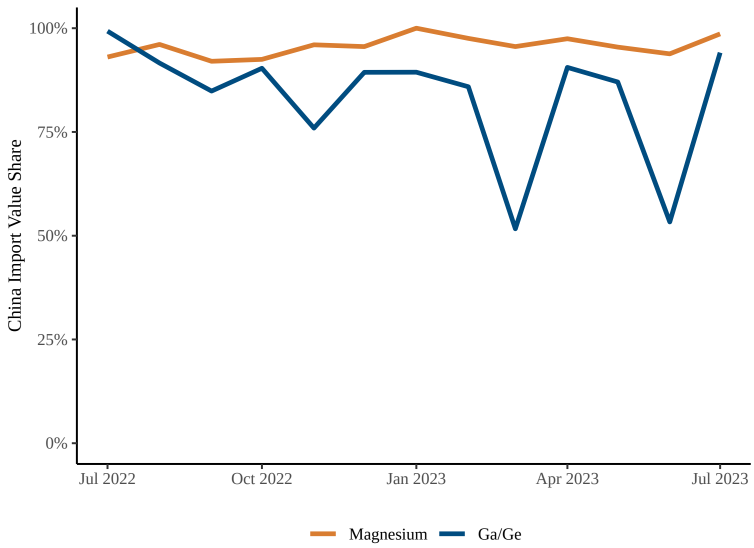


**Figure A.2.:** Pre-treatment Trend Analysis: Gallium/Germanium vs. Magnesium
*Source:* Own illustration based on Eurostat (2024).

**Table A.1.:** Baseline and Donut DiD Estimates

| | Baseline | Donut |
|---|---|---|
| Dependent variable | Value Share | Value Share |
| Treated × Post (overall) | -0.2405*** | -0.2300*** |
| | (0.0558) | (0.0517) |
| Product fixed effects | Yes | Yes |
| Date fixed effects | Yes | Yes |
| Observations | 144 | 140 |
| $R^2$ | 0.4860 | 0.4805 |
| Within $R^2$ | 0.0725 | 0.0639 |

Standard errors in parentheses. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

*Source:* Own calculations based on Eurostat (2024).

**Table A.2.:** Placebo test: Artificial intervention in August 2022 (commodity level)

| Dependent variable: | China's import value share |
|---|---|
| Model: | (1) Placebo DiD |
| *Variables* | |
| Treated × Post_placebo | -0.1770*** |
| | (0.0280) |
| *Fixed effects* | |
| Product | Yes |
| Date | Yes |
| *Fit statistics* | |
| Observations | 52 |
| $R^2$ | 0.45958 |
| Within $R^2$ | 0.01953 |

Standard errors in parentheses. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
*Source:* Own calculations based on Eurostat (2024).

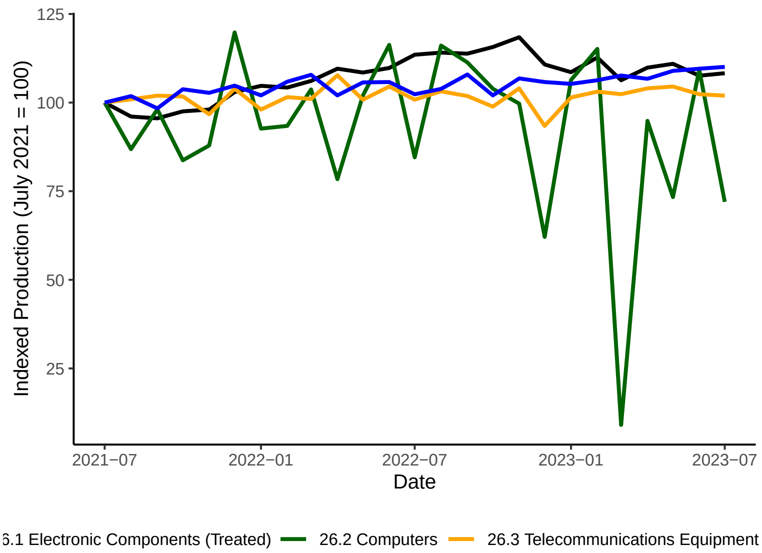


**Figure A.3.:** Pre-Treatment Dynamics: Alternative Industry Controls
*Source:* Own calculations based on Eurostat (2024).

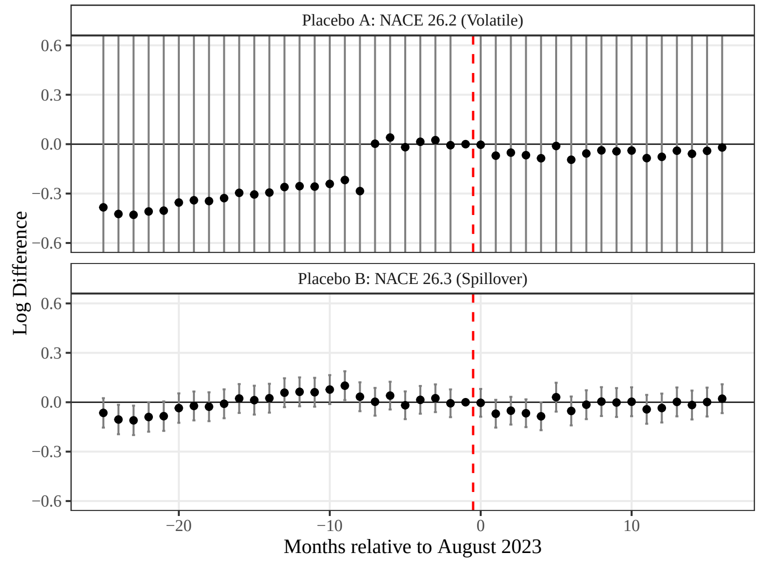


**Figure A.4.:** Placebo Event Studies: NACE 26.2 (Volatile) and NACE 26.3 (Spillover)
*Source:* Own calculations based on Eurostat (2024).

**Table A.3.:** DiD Estimates for Producer Prices

| | (1) |
|---|---|
| Dependent variable | $\log(PPI)$ |
| Treated × Post | -0.0437*** |
| | (0.0043) |
| Sector fixed effects | Yes |
| Time fixed effects | Yes |
| Observations | 120 |
| $R^2$ | 0.828 |
| Within $R^2$ | 0.542 |

Standard errors in parentheses. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

*Source:* Own illustration based on Eurostat (2024).

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