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SEMICONDUCTOR EXPORT CONTROLS AND INNOVATION RELOCATION ACROSS GLOBAL PRODUCTION NETWORKS

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Abstract:

This study examines whether semiconductor export controls are associated with China's high technology export share, addressing the global debate over evaluating targeted technological restrictions through aggregate trade outcomes. Annual secondary export data and three documented regulatory interventions support descriptive comparisons and separate ordinary least squares regressions using ten observations from 2012 to 2021. The models distinguish policy timing, annual event occurrence, and cumulative interventions. The policy period coefficient is positive at 0.0176 percentage points, event occurrence is associated with an increase of 0.3613 percentage points, and the cumulative event coefficient is approximately zero. None is statistically significant, leaving all three predicted negative relationships unsupported. Across specifications, the evidence therefore identifies no detectable aggregate decline associated with the recorded restrictions. The study refines the application of global production network theory by distinguishing targeted regulatory exposure from national export composition, without attributing aggregate patterns to unmeasured adjustment mechanisms. For international policy evaluation, these findings support matching regulatory objectives to sectoral and organizational indicators rather than treating aggregate export stability as evidence of technological resilience.

Key Words: Semiconductor Export Controls; Global Production Networks; High Technology Exports; Trade Policy

1. Introduction:

Semiconductor export controls create a policy evaluation problem: restrictions on specialized technological inputs may disrupt production relationships without producing a corresponding decline in national export shares. Bown (2020) documents how United States restrictions targeting Huawei extended the trade conflict with China into semiconductor supply chains through dependencies on specialized software, equipment, and manufacturing technologies. These dependencies make export controls relevant to firms beyond their immediate targets. They also raise an empirical question about the relationship between targeted regulatory interventions and aggregate export composition. Understanding this relationship matters because national export indicators can influence assessments of whether technology restrictions constrain commercial activity.

The geographical organization of production provides a theoretical explanation for why targeted restrictions and aggregate outcomes may diverge. Baldwin and Venables (2013) explain how production sequencing and the costs of separating activities influence offshoring and agglomeration. Antràs and de Gortari (2020) show how trade barriers interact with specialization across interconnected production stages. Their frameworks imply that restrictions affecting particular inputs can change the attractiveness of production arrangements across locations. However, such adjustments do not necessarily translate into proportional changes in national export composition. The aggregate response depends on the affected activities, their position within production networks, and their contribution to the measured export category.

Research on the trade conflict establishes that policy barriers can generate substantial commercial adjustments, while also demonstrating why different instruments require separate interpretation. Amiti et al. (2019) document increased import costs, changes in supply chain relationships, and reduced availability of imported varieties following the United States tariff increases of 2018. Fajgelbaum et al. (2020) identify trade responses and distributional consequences associated with those tariffs and foreign retaliation. These findings establish that restrictions can affect internationally connected production and exchange. Nevertheless, tariffs alter transaction costs, whereas export controls can restrict access to selected technologies and counterparties. Consequently, tariff estimates cannot establish the direction or magnitude of the relationship between semiconductor restrictions and China's high technology export share.

Policy uncertainty provides a complementary mechanism. Handley and Limão (2015) show that uncertainty over future trade policy can discourage export investment when firms face sunk market entry costs. Their analysis connects credible reductions in uncertainty to firm entry and export sales. Handley and Limão (2017) further demonstrate the importance of policy uncertainty for China's export expansion toward the United States. Applied to semiconductor restrictions, this reasoning suggests that uncertainty over continued access to technological inputs could influence commercial commitments. This theoretical expectation supports examining

export outcomes around regulatory developments, although the present analysis does not directly estimate uncertainty or investment responses. Evidence concerning reduced uncertainty also does not imply that introducing restrictions generates an equal and opposite adjustment.

The study distinguishes three observable dimensions of the documented policy chronology. Policy timing identifies the period beginning in 2019 and examines whether export composition differs across the regulatory transition. Annual event occurrence identifies years containing recorded interventions and tests whether export shares differ between event and nonevent years. The cumulative event count captures the accumulation of the recorded actions. These measures represent different temporal aspects of the same chronology. A period indicator captures a broader difference across periods, an occurrence indicator distinguishes intervention years, and a cumulative count examines the association with successive recorded actions. Their common origin requires separate interpretation rather than treating them as independent regulatory shocks.

The dependent variable is China's high technology exports as a percentage of manufactured exports. This indicator measures export composition rather than export growth or domestic technological capability. Its value can rise because high technology exports expand, because other manufactured exports contract, or because both components change at different rates. Johnson and Noguera (2012) demonstrate that gross trade flows and trade in value added reveal different patterns of international production sharing. Their findings explain why exported product values cannot directly establish where underlying value is created. Accordingly, the present study interprets the export share as an aggregate outcome and does not equate it with the geographical distribution of semiconductor innovation.

The closest literature establishes the institutional importance of semiconductor restrictions, the sensitivity of production geography to trade barriers, and the relevance of uncertainty for export investment (Antràs& de Gortari, 2020; Bown, 2020; Handley &Limão, 2015, 2017). However, the reviewed evidence does not establish whether the onset, annual occurrence, and accumulation of the selected restrictions coincide with changes in China's aggregate high technology export share. This study addresses that bounded question by evaluating alternative representations of the regulatory chronology against a common outcome. Its contribution concerns the interpretation of aggregate export responses to targeted technology restrictions.

China provides an informative empirical setting because the documented interventions concern firms embedded in international technological relationships, while the outcome captures national export composition. The study covers 2010 to 2021 and combines annual secondary export indicators with three documented regulatory events involving Huawei and SMIC. The principal analytical sample contains ten nonmissing annual observations for China from 2012 to 2021. A separate United States merchandise export value index supplies contextual information. Descriptive comparisons and separate ordinary least squares models examine the relationships between the three policy indicators and China's export share. This design matches the annual data structure and avoids estimating overlapping policy measures as independently identified effects within a single specification. Its inferential scope is temporal association.

This study aims to assess whether documented semiconductor export control developments are associated with China's high technology export share. The research question is whether that share varies with policy timing, annual event occurrence, and cumulative recorded interventions. Specifically, the study examines the difference associated with the period beginning in 2019, evaluates the association with years containing documented events, and estimates the relationship with cumulative events. The reported findings do not support the predicted negative associations across the three specifications. This result qualifies the expectation of a detectable aggregate decline within the observation period. Its practical contribution is to clarify the scope of national export composition as evidence for evaluating targeted technology restrictions. The distinction between regulatory specificity and outcome aggregation informs international policy assessment, while the estimated relationships remain specific to the study's chronology, setting, and measurement.

2. Theory, Conceptual Framework and Hypotheses Development:

2.1 Theoretical Foundation and Structural Mechanisms:

Global production networks coordinate technological specialization through international trade, intermediate inputs, and geographically distributed production activities. The organization of these networks reflects differences in production costs, market access, technological capabilities, and the costs of coordinating successive production stages. Antràs and de Gortari, 2020, demonstrate that trade barriers influence the geographical organization of production by changing the relative attractiveness of locations within interconnected value chains. This mechanism provides a theoretical basis for examining whether semiconductor export control periods coincide with changes in observable export performance.

Trade restrictions can affect production networks through higher transaction costs, reduced access to intermediate goods, and adjustments in sourcing relationships. Amiti et al., 2019, document changes in supply chain relationships and import prices following United States tariff increases, while Fajgelbaum et al., 2020, establish that protectionist measures can alter trade flows and economic welfare. These findings support the expectation that policy restrictions may coincide with measurable trade adjustments. However, tariff evidence

does not establish that semiconductor export controls produce equivalent outcomes, because the instruments, targeted firms, and technological dependencies differ.

This analysis operationalizes export control developments through documented policy periods and annual policy event indicators. Export performance is represented by China's high technology export share and the United States merchandise export value index. These observed indicators measure broader export outcomes rather than semiconductor specific production, patent relocation, or innovation mobility. Accordingly, the conceptual framework examines associations between policy timing and export performance without treating these relationships as identified causal effects.

2.2 Export Control Policy Timing and Export Performance:

Export control policy timing captures the transition from the period preceding the documented restrictions to the period beginning in 2019. This temporal distinction reflects a change in the regulatory environment affecting selected semiconductor supply chain participants. Bown, 2020, identifies the dependence of semiconductor production on specialized technologies and cross border relationships, explaining why restrictions on particular firms can influence commercial decisions beyond their immediate targets.

The theoretical mechanism operates through restricted technological access and increased uncertainty over future transactions. Firms facing uncertainty may postpone investment, reconsider sourcing arrangements, or adjust export commitments. Handley and Limão, 2015, demonstrate that uncertainty over trade policy can discourage export investment when market entry requires sunk costs. Handley and Limão, 2017, further establish that changes in trade policy uncertainty can influence trade participation and export growth. These mechanisms suggest that the onset of restrictions may coincide with changes in China's high technology export share, although the aggregate indicator cannot isolate semiconductor activity.

The expected relationship is negative because restrictions may reduce access to technological inputs and increase uncertainty surrounding production commitments. Nevertheless, the aggregate export share can increase if other high technology industries expand or if manufactured exports outside the high technology category decline more rapidly. The hypothesis therefore concerns an observable association rather than a predetermined causal outcome.

H1: The period beginning in 2019 is negatively associated with China's high technology exports as a percentage of manufactured exports relative to the preceding period.

2.3 Documented Export Control Events and Export Performance:

Documented export control events represent identifiable regulatory interventions rather than general changes in the policy environment. The available chronology records restrictions involving Huawei in 2019 and additional measures involving Huawei and SMIC in 2020. Bown, 2020, explains how semiconductor supply chain restrictions can exploit dependence on specialized software, equipment, and production technologies. These institutional interventions provide an observable basis for distinguishing years with documented policy actions from years without recorded events.

Unlike the broader policy period, the annual occurrence indicator identifies the calendar years in which the documented interventions took place. Regulatory interventions may interrupt established sourcing relationships, increase compliance costs, and alter firms' expectations about technological availability. Amiti et al., 2019, show that trade restrictions can generate adjustments across interconnected supply chains, while Fajgelbaum et al., 2020, demonstrate that protectionist interventions can coincide with reductions in international trade flows. However, these studies examine tariff policies, and their estimated effects cannot be transferred directly to semiconductor export controls.

The expected association is negative because years containing documented restrictions may experience greater commercial uncertainty and technological constraints. Antràs and de Gortari, 2020, provide a structural explanation for why disruptions at particular production stages may affect wider production networks. At the same time, domestic substitution and changes in the composition of manufactured exports may offset these pressures. The available annual data permit examination of whether policy event years exhibit different export shares, without identifying the effects of individual regulatory decisions.

H2: Years containing documented semiconductor export control events are negatively associated with China's high technology exports as a percentage of manufactured exports relative to years without recorded events.

2.4 Export Control Implementation and Export Performance:

Export control implementation represents the accumulation of documented regulatory interventions over time. The available policy chronology supports an annual cumulative event count based on the recorded actions. This measure captures the progression of documented restrictions but does not measure their legal intensity, firm coverage, enforcement effectiveness, or economic magnitude.

Cumulative restrictions may influence export performance by increasing uncertainty surrounding access to essential technological inputs and by encouraging adjustments in sourcing and production commitments. Handley and Limão, 2015, establish that uncertainty can influence investment decisions where firms incur substantial entry costs. Bown, 2020, identifies the importance of specialized technological

dependencies in semiconductor production, while Antràs and de Gortari, 2020, demonstrate how changes in trade costs can influence production network organization. Together, these mechanisms suggest that accumulating restrictions may coincide with changes in export performance.

The expected relationship is negative because cumulative restrictions may increase the constraints facing internationally integrated producers. However, the association may be weakened by substitution, adaptation, or changes in the composition of exports. Moreover, cumulative event counts increase with calendar time and therefore cannot distinguish regulatory accumulation from other contemporaneous developments without additional identifying information. The proposed hypothesis is consequently an exploratory association that can be evaluated separately from the policy timing and event occurrence hypotheses.

H3: A higher cumulative count of documented semiconductor export control events is negatively associated with China's high technology exports as a percentage of manufactured exports.

2.5 Conceptual Framework and Empirical Alignment:

The conceptual framework links three observed dimensions of semiconductor export control policy to China's high technology export share. Policy timing identifies the regulatory period beginning in 2019, event occurrence distinguishes years containing documented interventions, and cumulative implementation measures the recorded accumulation of interventions. The dependent variable is the annual percentage of manufactured exports classified as high technology exports.

These relationships represent theoretical expectations evaluated through observed annual associations. The three policy indicators are derived from the same limited chronology and should not be interpreted as independent policy shocks. Their high temporal overlap also limits the feasibility of estimating separate effects within a single regression. Accordingly, each hypothesis can be evaluated through a distinct descriptive comparison or parsimonious association model, with uncertainty and the limited number of post restriction observations explicitly acknowledged.

The United States merchandise export value index provides contextual information about broader export developments but does not constitute a valid semiconductor specific control or a direct measure of China's technological adjustment. The analytical framework therefore retains China's observed high technology export share as the principal outcome. The hypotheses can be examined with the available annual observations, although the short policy period limits statistical precision and prevents reliable causal attribution. Neither acceptance nor rejection of these hypotheses would establish innovation relocation across global semiconductor production networks.

3. Data:

This analysis uses annual export indicators and documented semiconductor export control events covering 2010 to 2021 to examine associations between regulatory changes and export performance. Data provenance, sample construction, variable measurement, and analytical limitations are established using the observations available in the research dataset.

3.1 Data Sources, Population, and Sample Construction:

The empirical setting comprises China and the United States, with annual observations covering 2010 to 2021. Two indicators originate from the World Bank World Development Indicators: China's high technology exports as a percentage of manufactured exports, identified by TX.VAL.TECH.MF.ZS, and the United States merchandise export value index, identified by TX.VAL.MRCH.XD.WD. The first measures the composition of manufactured exports, while the second measures changes in merchandise export values relative to the 2015 base year. Both indicators are annual macroeconomic measures rather than direct observations of semiconductor production or innovation relocation. The World Bank provides the underlying statistical definitions, while the supplied dataset records values transcribed from IndexBox displays attributed to World Development Indicators.

The policy chronology identifies three regulatory developments: restrictions targeting Huawei in 2019, expansion of the foreign direct product rule affecting Huawei in 2020, and the addition of SMIC to the Entity List in 2020. These events establish the timing of selected restrictions but do not quantify their economic intensity. The chronology is retrospective and does not constitute an independently measured firm exposure dataset. The resulting empirical structure combines two separate country level annual series with a calendar year policy chronology. It is not a firm panel, bilateral trade panel, or semiconductor innovation dataset.

The accessible sampling frame comprises 12 calendar years for each of the two export indicators, generating 24 potential country indicator year observations. The supplied workbook contains 22 nonmissing export observations, including 10 observations for China's high technology export share and 12 observations for the United States merchandise export index. China's values are unavailable for 2010 and 2011. These unavailable observations remain missing rather than being reconstructed through interpolation.

Table 1: Construction of the Available Annual Dataset

Stage	Units	Observations	Reason or Rule
Initial annual indicator frame	2 country indicator series	24	Two annual series across 2010 to 2021

Unavailable China observations	1 affected series	2	Missing values for 2010 and 2011
Retained export observations	2 series	22	Nonmissing reported values
China outcome series	1 series	10	Annual outcome observations for 2012 to 2021
United States contextual series	1 series	12	Annual observations for 2010 to 2021
Documented policy chronology	3 events	3	One event in 2019 and two in 2020
Available China outcome and policy timing alignment	1 series	10	Calendar year matching for 2012 to 2021

The target population concerns semiconductor production networks affected by international technology restrictions. However, the accessible sampling frame contains aggregate export indicators rather than the firm, patent, investment, or bilateral semiconductor trade observations needed to represent that population directly. Consequently, the 10 annual China observations define the available outcome series, not a representative sample of global semiconductor producers. The short post restriction period also limits the information available for distinguishing regulatory effects from contemporaneous economic changes.

3.2 Data Integration, Cleaning, and Quality Assurance:

Data integration uses calendar year as the common identifier connecting the export indicators and documented regulatory events. Each export series contains one potential observation per country and year. The policy chronology is recorded separately because multiple regulatory events may occur within the same calendar year. Annual policy indicators can therefore be constructed without multiplying export observations when more than one event occurs in a year.

The two export indicators retain their original measurement units. China's high technology export share is expressed as a percentage of manufactured exports, whereas the United States export value index uses 2015 as its reference year. No currency conversion, inflation adjustment, or cross series normalization is required for their separate descriptive interpretation. The export share represents an annual proportion, not an export growth rate, while the index represents relative export value rather than a monetary amount.

Missing values are identifiable for China's export share in 2010 and 2011. These observations are not coded as zero because unavailable data do not establish the absence of exports. No imputed values appear in the supplied observations. The recorded export shares lie within the permissible percentage range, and the United States index contains positive values. However, the workbook does not document an independent cross source reconciliation, formal outlier screening, historical revision audit, or duplicate record validation. These procedures cannot therefore be presented as completed quality assurance tests.

The source documentation identifies World Development Indicators as the original statistical provider and IndexBox as the immediate source of the transcribed numerical observations. This distinction matters because the displayed values are rounded, and the workbook does not preserve the exact statistical release used for extraction. Similarly, the policy chronology uses a retrospective institutional source. The dataset therefore supports historical comparisons but does not establish that each observation reflects the information available to economic agents at the time of the corresponding policy decision.

3.3 Variable Measurement, Construction, and Validation:

The principal outcome is China's high technology exports as a percentage of manufactured exports. It measures the relative importance of high technology goods within manufactured exports and provides an aggregate indicator of export composition. It does not distinguish semiconductors from other high technology products. The United States merchandise export value index supplies an additional indicator of international export conditions but is not a semiconductor specific outcome or a validated counterfactual for China.

Export control policy timing is represented by calendar year indicators identifying the periods beginning in 2019 and 2020. These variables distinguish periods before and after documented regulatory developments. Their values reflect the timing of policy events rather than observed exposure, enforcement intensity, or changes in firms' technological capabilities. The documented events also permit construction of annual event occurrence and cumulative event count indicators. These constructions depend on the three events recorded in the available chronology and should not be interpreted as a complete census of export control measures.

Table 2: Variable Dictionary

Variable or Indicator	Analytical Role	Definition and Construction	Source and Identifier	Unit and Frequency	Transformation and Direction	Missing Value Rule	Coverage and Limitation
China high technology export share	Principal outcome	High technology exports divided by manufactured exports, expressed as a percentage	World Bank, TX.VAL.TECH.MF.ZS	Percentage, annual	Higher values indicate a greater high technology share	Missing observations retained as unavailable	2012 to 2021, not semiconductor specific

United States merchandise export value index	Contextual indicator	Merchandise export value relative to the 2015 base	World Bank, TX.VAL.MRCH.XD.WD	Index, annual	Higher values indicate a higher indexed export value	No missing values in supplied series	2010 to 2021, all merchandise
Policy period beginning in 2019	Policy timing predictor	One for 2019 to 2021 and zero for preceding years	Researcher coded from policy chronology	Binary, annual	One identifies the later policy period	Not applicable to missing export outcomes	Measures timing, not exposure
Policy period beginning in 2020	Policy timing predictor	One for 2020 to 2021 and zero for preceding years	Researcher coded from policy chronology	Binary, annual	One identifies the later regulatory period	Not applicable to missing export outcomes	Overlaps with the 2019 period indicator
Annual documented event occurrence	Event predictor	One when at least one of the three recorded events occurred during the year	Documented policy chronology	Binary, annual	One indicates a recorded policy event year	Zero denotes no event in the recorded chronology	Does not represent all possible restrictions
Cumulative documented event count	Implementation predictor	Running total of the three recorded events through each calendar year	Documented policy chronology	Count, annual	Higher values indicate more recorded events to date	Zero before the first recorded event	Not a measure of policy intensity

The observed China export share contains 10 valid annual values, with a mean of 30.761 percent, standard deviation of 0.615 percentage points, median of 30.840 percent, and a range from 29.700 to 31.590 percent. The United States merchandise export value index contains 12 observations, with a mean of 102.575, standard deviation of 8.383, median of 102.900, and a range from 85.100 to 116.800.

Table 3: Descriptive Statistics of Observed Export Indicators

Indicator	Valid N	Mean	SD	Median	Minimum	Maximum
China high technology export share	10	30.761	0.615	30.840	29.700	31.590
United States merchandise export value index	12	102.575	8.383	102.900	85.100	116.800

The descriptive statistics are calculated from the numerical observations in the supplied workbook. The standard deviations use the sample denominator. The relatively narrow observed range of China's high technology export share indicates limited aggregate variation, although it does not establish stability in semiconductor production or innovation location. No reliability coefficients, factor models, or latent variable validation results are reported because the measures are observed macroeconomic indicators and researcher coded policy variables rather than multi-item survey constructs.

3.4 Analytical Framework, Identification, and Reproducibility:

This analysis adopts an exploratory associational framework to examine whether China's high technology export share differs across documented semiconductor export control periods. The available annual observations provide variation in export composition and policy timing, but they do not establish firm level exposure or an untreated comparison group. The empirical interpretation therefore concerns temporal associations rather than identified causal effects.

The principal analytical comparison separates the period from 2012 to 2018 from the period from 2019 to 2021. The 2020 policy indicator provides a narrower temporal distinction, while annual event occurrence and cumulative event counts describe alternative representations of the documented regulatory chronology. These indicators are strongly related by construction and should not be treated as independent sources of regulatory variation. Their interpretation is further constrained by the small number of annual observations following the first documented restriction.

The available dataset permits descriptive comparisons of export shares across policy periods and examination of associations between annual export outcomes and recorded regulatory timing. However, the supplied workbook does not contain estimated regression coefficients, standard errors, significance tests, model diagnostics, or robustness results. Accordingly, no regression specification is presented as implemented, and no hypothesis is classified as supported or rejected. The distinction between observed associations and causal effects follows established concerns about policy uncertainty, trade adjustment, and the geographical organization of production networks identified by Handley and Limão, 2015, Handley and Limão, 2017, Amiti et al., 2019, Fajgelbaum et al., 2020, and Antràs and de Gortari, 2020.

The principal identification challenge is that semiconductor restrictions coincide with other economic developments capable of influencing aggregate exports. These include changes in global demand, production conditions, trade relationships, and the composition of manufactured exports. With one national outcome series and a limited number of post restriction observations, the available data cannot separate these influences

reliably. The United States merchandise export index provides descriptive context but does not eliminate these confounding factors or establish a valid comparison economy.

Reproducibility is supported by the supplied annual observations, World Development Indicators series identifiers, policy event chronology, and variable definitions. The documented sources allow the export measures and policy indicators to be traced to their respective origins. Nevertheless, the workbook does not establish a frozen source release, complete extraction history, independent source reconciliation, or executable estimation code. These limitations restrict independent replication of any inferential analysis beyond the available observations.

The resulting empirical evidence is suitable for examining aggregate export composition during documented regulatory periods. It does not directly measure semiconductor patent relocation, geographical redistribution of research activities, changes in semiconductor production capacity, or the reorganization of firm level innovation networks. Consequently, the available indicators cannot validate the central innovation relocation mechanism. Any statistical association between policy timing and aggregate exports must remain distinct from evidence of technological relocation.

4. Methods:

4.1 Research Design and Identification Strategy:

The study adopts an exploratory annual time-series design to examine associations between documented semiconductor export control developments and China's high technology export share. The unit of analysis is the calendar year. The estimation sample comprises ten annual observations covering 2012 to 2021. Sample construction and measurement definitions are presented in Tables 1 and 2 of Section 3.

The analysis evaluates three temporal relationships: differences between the periods preceding and beginning in 2019, differences between years with and without recorded interventions, and the linear association with accumulated interventions. Useful variation arises from annual changes in export composition and the timing of the documented regulatory actions.

The estimates represent unadjusted temporal associations. The design does not separate regulatory developments from concurrent changes in global demand, trade conditions, or production activity. This distinction follows Angrist and Pischke's (2010) emphasis on research design as the basis for credible causal interpretation. The United States merchandise export value index provides descriptive context but does not constitute an untreated comparison group or enter the regression models.

4.2 Model Specification and Measurement Alignment:

The three hypotheses are evaluated using separate linear regressions:

$$Y_t = \alpha_j + \beta_j X_{jt} + \varepsilon_{jt}, \qquad j \in \{1,2,3\}.$$

Here, Y_t denotes China's high technology exports as a percentage of manufactured exports in calendar year t. The index jidentifies the specification, $\alpha_j$is the intercept, $\beta_j$is the slope coefficient, $X_{jt}$is the corresponding policy indicator, and $\varepsilon_{jt}$is the regression disturbance.

In the first specification, X_{1t} equals zero from 2012 to 2018 and one from 2019 to 2021. The coefficient estimates the difference in mean export shares between these periods. In the second specification, X_{2t}equals one in 2019 and 2020 and zero in the remaining observed years. Its coefficient estimates the difference between event-year and nonevent-year means. Because the comparison category includes 2021, zero indicates no newly recorded intervention rather than the absence of continuing restrictions.

In the third specification, X_{3t}equals zero from 2012 to 2018, one in 2019, and three in 2020 and 2021. Its coefficient estimates the linear association between the cumulative count and export composition. This construction imposes a constant slope across the observed count values and measures accumulated events rather than regulatory severity.

Each specification contains an intercept and one contemporaneous predictor. The indicators are estimated separately because they represent overlapping aspects of the same chronology. All models use the same ten observations. The first two coefficients are expressed in percentage points; the third is expressed in percentage points per additional recorded intervention.

4.3 Data Processing, Estimation, and Inference:

Calendar year provides the identifier for aligning the outcome and policy chronology. The unavailable China observations for 2010 and 2011 are excluded without interpolation or replacement by zero. The retained outcome values preserve their supplied scale and numerical precision. Processing proceeds from annual alignment and indicator construction to descriptive comparisons and separate regression estimation.

The first comparison contains seven observations preceding 2019 and three observations from 2019 onward. The event-year comparison contains two observations with recorded interventions and eight without a newly recorded intervention. The cumulative classification contains seven observations at zero, one at one, and two at three.

Ordinary least squares estimates each model by minimizing squared residuals. The slope estimator is:

$$\hat{\beta}_j = \frac{\sum_{t\in T}(X_{jt} - \overline{X}_j)(Y_t - \overline{Y})}{\sum_{t\in T}(X_{jt} - \overline{X}_j)^2}.$$

Here, T denotes the retained years, $\overline{X}_j$ is the sample mean of the predictor in specification j, and $\overline{Y}$ is the sample mean of the outcome. The intercept is $\hat{\alpha}_j = \overline{Y} - \hat{\beta}_j\overline{X}_j$. Each observation receives equal weight.

The reported uncertainty corresponds to conventional ordinary least squares inference. The slope standard error is:

$$SE(\hat{\beta}_j) = \sqrt{\frac{\sum_{t\in T}\hat{\varepsilon}_{jt}^2/(n-2)}{\sum_{t\in T}(X_{jt} - \overline{X}_j)^2}}.$$

Here, $\hat{\varepsilon}_{jt}$ denotes the fitted residual, $n = 10$, and the residual degrees of freedom equal eight. Two-sided tests evaluate the null hypothesis $\beta_j = 0$ using a Student'streference distribution with eight degrees of freedom. The 95% confidence intervals use the corresponding critical value of approximately 2.306.

Conventional standard errors assume constant disturbance variance and no serial correlation. Exact small-sample inference additionally requires normally distributed disturbances under the specified model. These assumptions concern regression errors rather than the distribution of observed export shares. The resulting uncertainty is model-based, not uncertainty generated by randomized policy assignment. Abadie et al. (2020) explain why regression uncertainty must be interpreted in relation to the underlying sampling and assignment framework.

4.4 Analytical Assessment and Interpretive Scope:

Assessment considers coefficient direction, magnitude, confidence intervals, and model fit. For the binary specifications, the slope equals the corresponding difference in group means, providing an algebraic basis for checking consistency between descriptive and regression results. The cumulative specification is interpreted alongside mean outcomes at the observed count values.

Using a common estimation sample ensures that differences across specifications reflect predictor construction rather than changes in observation coverage. Nevertheless, the models evaluate distinct temporal contrasts and do not provide independent replications of a single regulatory effect. Interpretation therefore considers the magnitude and uncertainty of each association rather than treating agreement in statistical significance as validation.

The reported confidence intervals retain the assumptions of conventional inference. The short series and limited observations following the first intervention constrain precision, while concurrent economic developments restrict causal interpretation. An imprecise coefficient does not establish the absence of an economically meaningful relationship.

The annual observations, documented chronology, coding definitions, and Equations 1-3 specify the numerical analysis. Together, these elements support replication of the reported temporal comparisons and regression calculations. The methodological contribution lies in aligning alternative policy representations with a clearly bounded aggregate outcome.

5. Findings:

This analysis examines the empirical relationships between semiconductor export control policy timing, documented regulatory events, cumulative policy interventions, and China's high technology export performance. Three hypotheses are evaluated using annual observations covering 2012 to 2021, with estimates interpreted alongside established evidence on international trade restrictions, policy uncertainty, and global production networks. The findings distinguish observed statistical associations from causal effects and assess whether the available evidence supports the proposed theoretical expectations.

5.1 Sample Characteristics and Descriptive Findings:

The empirical analysis draws on 10 annual observations of China's high technology exports as a percentage of manufactured exports and 12 annual observations of the United States merchandise export value index. The indicators originate from World Bank World Development Indicators series TX.VAL.TECH.MF.ZS and TX.VAL.MRCH.XD.WD, respectively. China's observations cover 2012 to 2021, while the United States series covers 2010 to 2021. The analysis retains the original measurement scales and excludes unavailable observations without interpolation.

The distinction between export composition and export value is central to interpreting the findings. High technology export shares measure the relative contribution of technology intensive products to manufactured exports, whereas export value indices measure changes in aggregate export values. These indicators cannot independently identify the geographical relocation of semiconductor innovation. Antràs and de Gortari, 2020, demonstrate that global value chains depend on the geographical organization of sequential production, while Bown, 2020, identifies specialized technological dependencies within the semiconductor industry. Consequently, aggregate export performance provides contextual evidence about production networks but does not directly measure the redistribution of semiconductor research or manufacturing capabilities.

Table 1: Descriptive Statistics of Annual Export Indicators

Indicator	N	Mean	SD	Median	Minimum	Maximum
China high technology export share, percent	10	30.761	0.615	30.840	29.700	31.590
United States merchandise export value index	12	102.575	8.383	102.900	85.100	116.800

China's average high technology export share was 30.761 percent, with a standard deviation of 0.615 percentage points. The difference between the minimum and maximum observations was 1.890 percentage points, indicating limited variation in aggregate export composition across the sample. However, relatively stable aggregate shares do not establish stability in individual technology industries. Amiti et al., 2019, show that trade restrictions can generate substantial supply chain adjustments, while Fajgelbaum et al., 2020, demonstrate that trade policy interventions can change trade flows and economic welfare. These findings establish the relevance of examining trade responses but do not imply that aggregate high technology export shares necessarily decline following semiconductor restrictions.

The policy chronology records one regulatory event in 2019 and two additional events in 2020. Seven observations precede the first documented intervention, and three observations fall within the subsequent policy period. This temporal distribution limits the precision of comparisons and creates substantial overlap among the policy indicators. Handley and Limão, 2017, establish that trade policy uncertainty can influence export participation and investment decisions, while Pierce and Schott, 2016, demonstrate that changes in trade policy can produce heterogeneous industry responses. These mechanisms imply that aggregate export indicators may conceal substantial differences across affected firms and production activities.

5.2 Export Control Policy Timing and High Technology Export Performance:

The first hypothesis predicts a negative association between the semiconductor export control period beginning in 2019 and China's high technology export share. The comparison separates seven annual observations from 2012 to 2018 and three observations from 2019 to 2021. The estimated relationship is an unadjusted difference in annual means, equivalent to an ordinary least squares regression containing an intercept and a binary policy period indicator.

Table 2: High Technology Export Performance Across Policy Periods

Period	Observations	Mean Export Share, Percent	Standard Deviation
2012 to 2018	7	30.756	0.688
2019 to 2021	3	30.773	0.532
Difference in means		+0.018 pp	

The observed increase of 0.018 percentage points contradicts the negative direction predicted by H1. Its magnitude is also small relative to the annual variation in export composition. The estimated coefficient is positive at 0.0176 percentage points, with a standard error of 0.4501 and a 95 percent confidence interval extending from negative 1.0202 to positive 1.0555 percentage points. The associated p value is 0.970, indicating that the available sample does not provide statistically distinguishable evidence of a change in the mean export share.

This result differs from the negative trade responses documented in studies of protectionist measures. Fajgelbaum et al., 2020, identify reductions in international trade associated with tariff interventions, while Amiti et al., 2019, document adjustments in supply chain relationships following increased trade barriers. However, these studies examine different policy instruments and outcomes. Their results do not establish that semiconductor export controls must reduce the percentage of manufactured exports classified as high technology products.

The absence of a detectable negative association is also compatible with adjustment mechanisms within international production networks. Antràs and de Gortari, 2020, show that trade costs influence the organization of geographically fragmented production. Handley and Limão, 2017, demonstrate that uncertainty can affect trade decisions through investment and market participation. These mechanisms permit changes in sourcing, product composition, and production arrangements without requiring an immediate decline in aggregate export shares.

The estimated association is positive but economically small and statistically imprecise. The evidence does not establish that semiconductor export controls increased export performance or that their effects were absent. It establishes that the available annual observations do not exhibit the predicted negative difference in aggregate export composition.

5.3 Documented Export Control Events and High Technology Export Performance:

The second hypothesis examines whether years containing documented semiconductor export control events are negatively associated with China's high technology export share. The event indicator identifies 2019 and 2020, while the remaining eight observations form the comparison group. This classification measures the occurrence of recorded regulatory interventions rather than their enforcement intensity, technological coverage, or direct effects on affected enterprises.

Table 3: Export Performance by Documented Regulatory Event Occurrence

Classification	Observations	Mean Export Share, Percent	Standard Deviation
Years without a recorded event	8	30.689	0.664
Years containing recorded events	2	31.050	0.325
Difference in means		+0.361 pp	

The average export share was 31.050 percent during recorded event years, compared with 30.689 percent during other years. The positive difference of 0.361 percentage points contrasts with the negative association predicted by H2. The corresponding regression coefficient is 0.3613, with a standard error of 0.4996 and a 95 percent confidence interval extending from negative 0.7908 to positive 1.5133 percentage points. The p value of 0.490 indicates that the estimated association is statistically imprecise.

The positive point estimate should not be interpreted as evidence that regulatory restrictions improved technological competitiveness. Bown, 2020, explains that semiconductor export restrictions operate through specialized technological inputs and supply chain dependencies. Their consequences may therefore differ across firms, production stages, and geographical locations. Aggregate export shares cannot distinguish these mechanisms because they combine semiconductor related products with other high technology categories.

The findings also require distinction between policy occurrence and policy exposure. Pierce and Schott, 2016, demonstrate that industries respond differently to trade policy changes according to their exposure. Amiti et al., 2019, establish that restrictions can alter supply chain relationships and imported input availability. These studies support the importance of differentiated responses, but the present event indicator does not measure the degree to which individual semiconductor producers were affected.

Furthermore, the comparison group includes 2021, a year following the documented interventions. Consequently, the event year indicator does not distinguish the absence of a new intervention from the absence of continuing regulatory restrictions. Handley and Limão, 2015, establish that policy uncertainty can influence investment decisions beyond the immediate announcement of a policy change. This mechanism reinforces the need to interpret event year comparisons as temporal associations rather than isolated treatment effects.

H2 is not supported. The estimated relationship is positive, but its confidence interval includes both negative and positive associations. The available observations cannot establish whether documented regulatory events independently changed China's high technology export composition.

5.4 Cumulative Export Control Implementation and High Technology Export Performance:

The third hypothesis predicts a negative association between the cumulative number of documented semiconductor export control interventions and China's high technology export share. The cumulative indicator records zero events before 2019, one event in 2019, and three events in 2020 and 2021. This construction measures the accumulation of recorded policy actions rather than the intensity of enforcement or the economic exposure of semiconductor producers.

Table 4: High Technology Export Performance by Cumulative Regulatory Events

Cumulative Event Count	Observation Period	N	Mean Export Share, Percent
0	2012 to 2018	7	30.756
1	2019	1	30.820
3	2020 to 2021	2	30.750

The observed means do not exhibit a consistent downward relationship with cumulative regulatory events. The mean export share increased from 30.756 percent before the recorded interventions to 30.820 percent following the first event, before declining to 30.750 percent when the cumulative count reached three. The differences are small relative to the observed annual variation and provide no clear evidence of progressive deterioration in aggregate export composition.

The estimated ordinary least squares coefficient is negative at 0.0005 percentage points per additional recorded event, with a standard error of 0.1737. The 95 percent confidence interval extends from negative 0.4011 to positive 0.4001 percentage points, while the p value is 0.998. The coefficient is effectively zero at the precision supported by the available observations.

The result does not establish that accumulating restrictions have no economic consequences. Bown, 2020, identifies specialized technological dependencies through which semiconductor restrictions may constrain particular production activities. Antràs and de Gortari, 2020, demonstrate that production networks respond to trade costs through changes in geographical organization. These mechanisms can generate adjustments that remain invisible in aggregate export composition, particularly when the affected products represent only part of the measured export category.

The cumulative indicator also increases with calendar time, making it difficult to separate regulatory accumulation from contemporaneous economic developments. Handley and Limão, 2017, show that trade policy uncertainty influences economic decisions, while Fajgelbaum et al., 2020, demonstrate that trade restrictions can

generate effects through several interconnected channels. Consequently, the absence of a detectable aggregate relationship does not rule out adjustments in investment, intermediate input sourcing, or production location.

The observed association is negligible and statistically imprecise. The evidence does not demonstrate a progressive decline in China's aggregate high technology export share as the number of documented regulatory interventions increases.

5.5 Consolidated Hypothesis Testing and Empirical Interpretation:

The consolidated analysis evaluates the three proposed relationships using separate ordinary least squares regressions. Each specification includes 10 annual observations and one regulatory indicator. The estimates represent unadjusted associations and are not interpreted as causal effects because the available dataset does not establish independent policy exposure, an untreated comparison group, or sufficient variation to isolate contemporaneous economic influences.

Table 5: Consolidated Regression Results and Hypothesis Decisions

Statistic	H1 Policy Timing	H2 Event Occurrence	H3 Cumulative Events
Coefficient	+0.0176	+0.3613	−0.0005
Standard error	0.4501	0.4996	0.1737
Lower 95% confidence limit	−1.0202	−0.7908	−0.4011
Upper 95% confidence limit	+1.0555	+1.5133	+0.4001
p value	0.970	0.490	0.998
R squared	0.0002	0.0613	0.0000
Observations	10	10	10

The results reveal three empirical patterns. First, the estimated association between the policy period beginning in 2019 and China's high technology export share is positive but negligible. Second, years containing documented regulatory interventions exhibit a higher average export share, although the estimated difference is statistically imprecise. Third, cumulative regulatory events show virtually no linear association with the outcome. None of the three estimated relationships provides statistically distinguishable evidence of the predicted negative association.

These findings differ from the reductions in trade flows identified by Fajgelbaum et al., 2020, and the supply chain adjustments documented by Amiti et al., 2019. However, those investigations evaluate different policy measures and economic outcomes. The contrast does not establish conflicting causal evidence because the present analysis examines aggregate export composition rather than semiconductor specific trade flows, production values, or firm level exposure.

The distinction is theoretically important. Antràs and de Gortari, 2020, explain how the geographical distribution of production activities responds to trade costs, while Bown, 2020, identifies the dependence of semiconductor production on specialized technological capabilities. Both mechanisms permit changes within production networks without requiring an equivalent movement in aggregate national export shares. Therefore, the observed stability of China's high technology export composition cannot establish stability in the location of semiconductor innovation.

The results also differ from evidence linking policy uncertainty to export investment and market participation. Handley and Limão, 2015, demonstrate that uncertainty influences investment where firms face substantial entry costs, while Handley and Limão, 2017, identify the importance of reduced trade policy uncertainty for export expansion. Pierce and Schott, 2016, further show that changes in trade policy can generate heterogeneous industrial adjustments. These findings indicate that responses may occur through channels that the available aggregate outcome does not measure.

The principal empirical limitation concerns statistical identification. The analysis contains only three annual observations following the first documented regulatory intervention. Moreover, the three policy indicators derive from the same chronology and share substantial temporal variation. Their separate coefficients cannot be interpreted as independent regulatory effects. The wide confidence intervals further indicate that the available sample cannot exclude economically meaningful positive or negative associations.

6. Discussion:

The central finding challenges the assumption that semiconductor export restrictions necessarily produce an immediate deterioration in aggregate high technology export performance. The regression results in Table 5 indicate that the policy period coefficient is positive but negligible, at 0.0176 percentage points, while the event occurrence coefficient is positive at 0.3613 percentage points. Neither association is statistically significant, and all three hypotheses remain unsupported. These findings do not contradict the established economic importance of trade restrictions. Rather, they reveal a distinction between restrictions targeting technologically specialized production networks and outcomes measured through broad national export categories. Baldwin and Venables, 2013, demonstrate that international production fragmentation creates interdependence across production stages, while Johnson and Noguera, 2012, establish that gross trade

indicators can differ substantially from the underlying distribution of value added. The contribution of this analysis lies in demonstrating the empirical importance of that measurement distinction: aggregate export composition does not provide sufficient evidence to infer whether targeted semiconductor restrictions have altered innovation location. This result redirects attention from national export shares toward the specific production stages, technological inputs, and geographical relationships through which regulatory interventions operate.

The interpretation of regulatory mechanisms requires separating plausible transmission channels from empirically identified mediation. Table 5 reports unadjusted associations and does not contain mediator coefficients, indirect effects, or changes in coefficients following mediator inclusion. Consequently, the analysis cannot establish whether technological substitution, supply chain reconfiguration, or investment relocation mediated the relationship between export controls and export performance. Nevertheless, the absence of a measurable decline in the aggregate outcome is consistent with several competing adjustment processes. Timmer et al., 2014, establish that value creation within global production networks is distributed across activities with different technological and skill requirements. This implies that changes in specialized production activities need not translate proportionately into national export shares. Gereffi, 2020, further demonstrates that production network responses to regulatory and supply disruptions depend on governance arrangements, supplier relationships, and institutional coordination. The theoretical implication is that export composition and technological adjustment should be treated as distinct outcomes rather than successive stages of an empirically established causal pathway.

The comparison across policy indicators provides a further insight into the limitations of aggregate regulatory measurement. Table 5 shows that the event occurrence indicator has a larger positive coefficient than the policy period indicator, while the cumulative event coefficient is approximately zero. These differences do not establish pathway dominance because the indicators have different units, represent overlapping policy developments, and were estimated in separate specifications. Instead, the results demonstrate that the apparent direction and magnitude of regulatory associations depend on how policy exposure is operationalized. Johnson and Noguera, 2012, show that gross trade measures can conceal the geographical distribution of value creation, while Baldwin and Venables, 2013, establish that the organization of fragmented production depends on technological sequencing and coordination costs. The theoretical contribution is therefore a more precise distinction between regulatory event counts, export performance, and the underlying organization of production. None of these measures can substitute for direct evidence of innovation relocation.

The principal structural challenge revealed by the analysis is the mismatch between the geographical and sectoral specificity of semiconductor restrictions and the breadth of the available economic indicators. The policy chronology identifies interventions affecting particular firms and technological relationships, whereas the dependent variable aggregates high technology exports across industries. This difference creates a measurement problem that cannot be resolved by statistical significance testing. The limited number of observations following the first documented intervention further restricts the ability to distinguish regulatory developments from contemporaneous changes in global demand and production conditions. The evidence therefore does not establish that regulatory restrictions were ineffective, that firms successfully substituted restricted technologies, or that semiconductor innovation remained geographically unchanged. Rather, it demonstrates why national export composition is an insufficient empirical basis for evaluating those outcomes. This distinction is important because policy assessments based exclusively on aggregate export shares may overlook changes occurring within specialized production networks.

The international relevance of these findings concerns the interpretation of trade policy outcomes across economies with different positions in global value chains. The near zero association between cumulative regulatory events and China's high technology export share does not imply that comparable restrictions would produce equivalent outcomes in other economies. Timmer et al., 2014, identify differences in the activities performed by advanced and emerging economies within global production networks, while Gereffi, 2020, demonstrates that institutional coordination and supply chain organization influence responses to international disruptions. Johnson and Noguera, 2012, further establish that conventional trade measures can conceal important differences in production sharing. These findings suggest that countries specializing in semiconductor design, fabrication, equipment, or assembly may experience different adjustments even when aggregate export indicators remain relatively stable. The contribution to international debate is therefore methodological and conceptual: the absence of a detectable aggregate export response should not be interpreted as evidence that targeted technological restrictions have failed to alter production network relationships.

The implications are most immediate for the evaluation of semiconductor export control policies and the design of empirical monitoring systems. Table 5 provides insufficient evidence to conclude that the documented restrictions reduced China's aggregate high technology export share, and it offers no direct estimate of innovation relocation. Policymakers should therefore avoid treating aggregate export shares as sufficient indicators of regulatory effectiveness. A more informative assessment would distinguish semiconductor trade flows, technological input dependencies, patent ownership, research activity, and changes in production

location. The theoretical extension is to treat regulatory exposure, production network adjustment, and innovation geography as separate constructs requiring distinct observations and identification strategies. Baldwin and Venables, 2013, provide a basis for examining how production sequencing influences geographical adjustment, while Gereffi, 2020, highlights the importance of institutional and supply chain governance. Future empirical research can investigate whether restrictions change the geographical distribution of semiconductor research and production without producing proportional changes in aggregate exports. The present findings establish the need for that distinction, but do not determine the magnitude or direction of such relocation.

7. Conclusion and Implications:

Targeted technological restrictions demand more precise evaluation than national export indicators alone can provide. Across three alternative representations of the documented interventions, the analysis finds no statistically distinguishable decline in China's aggregate export composition. This convergence qualifies expectations of an immediate aggregate deterioration, while leaving adjustments within specialized production networks undetermined. The core contribution is an empirical distinction between the specificity of regulatory intervention and the breadth of the outcome used to assess it. This distinction sharpens production network theory by showing why expectations about disrupted technological access require evidence at the production stages where constraints operate. For managers, the findings support assessing supplier dependencies and technological access separately from national trade trends when allocating resources and managing disruption risks. For policymakers, they imply that aggregate export stability provides insufficient grounds for judging targeted restrictions ineffective. Evaluation systems should connect regulatory objectives to corresponding sectoral and organizational evidence. Operationally, firms can strengthen monitoring by distinguishing restricted inputs, affected transactions, and changes in supplier availability. Such monitoring could support better continuity planning and more proportionate compliance decisions. The broader social relevance lies in improving the evidence informing interventions that affect interconnected producers and their customers, without assuming that aggregate stability establishes technological resilience.

The short annual series creates opportunities for extending observation periods and examining delayed adjustment. More detailed semiconductor trade, firm investment, and patent data would allow researchers to distinguish commercial responses from changes in innovation location. Linking individual regulatory measures to firm exposure could improve measurement beyond event timing and counts. Cross-country comparisons could test whether responses differ across design, fabrication, equipment, and assembly specializations. Stronger identification strategies with defensible comparison groups could separate regulatory effects from concurrent economic changes. Future research could also examine whether technological substitutability and supplier concentration condition these relationships, extending the analysis across different production environments.

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