Technology Rivalry and Resilience Under Trade Disruptions: The Case of Semiconductor Foundries

Weiting Miao

The University of Hong Kong

19th China Economics Summer Institute (CUHK)

August 2026

Motivation

- Rising concerns about trade disruptions
  - Policy-driven restrictions (e.g., U.S. export controls on advanced chips)
  - Geopolitical tensions affecting major semiconductor production hubs
  - Shipping disruptions (e.g., COVID-19 port closures, Suez Canal blockage)

Motivation

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- Recent surge in industrial policies in the semiconductor industry, e.g., US CHIPS and Science Act (2022)
  - 25% investment subsidy $\Rightarrow$ Local supply resilience
  - Investment restrictions in mainland China (CN) $\Rightarrow$ Technology leadership

Research Questions

How do industrial policies interact with trade disruption risks in global oligopolistic industries to shape:

- Firms' innovation and capacity location decisions
- Cross-country technology races and local consumer welfare

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Challenges in estimating policy effects

- Policy impacts not yet observable
- Technological changes take time

$\Rightarrow$ New quantitative framework & novel micro-level data

  - Characterize firm decisions & policy evaluation & optimal policy

This Paper

1. **New facts:** Provide data insights on industry features, especially technology dynamics, in semiconductor foundries

2. **Model:** Build a dynamic oligopoly model of innovation and global capacity choice under trade-disruption risk and industrial policy

3. **Estimation:** Estimate the model using micro-level data from the foundry industry

4. **Policy:** Quantify the impacts of the U.S. CHIPS Act, which includes *capacity investment subsidies* and *investment restrictions*

Relation to Literature

Industrial & Trade Policies: Brander & Spencer (1985), Eaton & Grossman (1986), Maggi (1996), Barwick, Kalouptsidi, & Zahur (2021), Lashkaripour & Lugovskyy (2023), Bartelme et al. (2024), Juhasz & Lane (2024), ...

Innovation Dynamics in Oligopolistic Industries: Aghion et al. (2001), Goettler & Gordon (2011), Igami & Uetake (2020)...

Supply Chain Disruption and Resilience: Leibovici & Santacreu (2020), Castro-Vincenzi (2022), Grossman, Helpman, & Lhuillier (2023), Galdin (2024)...

Semiconductor Industry: Irwin & Klenow (1994), Irwin & Klenow (1996), Hatch & Mowery (1998), Flanmm (2019), Goldberg et al. (2024), Zhuo & Tiew (2025)...

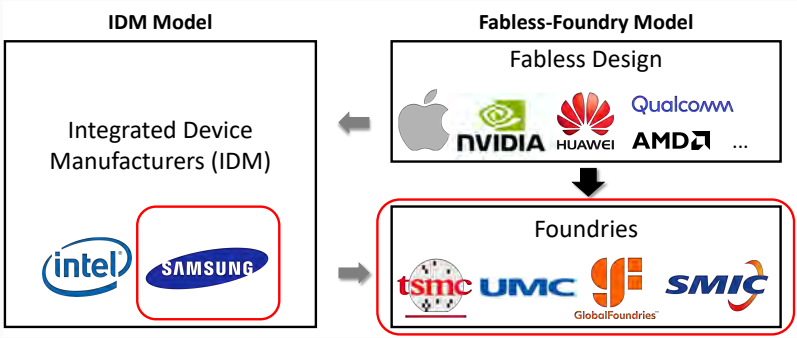
Main Contribution

- A new quantitative model + comprehensive industry data
- Structurally analyzes how industrial policies interact with trade disruption risks in shaping consumer welfare + technology competition

Roadmap of Talk

- Industry Features
- Quantitative Model
- Estimation
- Counterfactual Analysis
  - Unilateral Capacity Investment Subsidies
  - Guardrail Restrictions
- Conclusion

Institutional Background



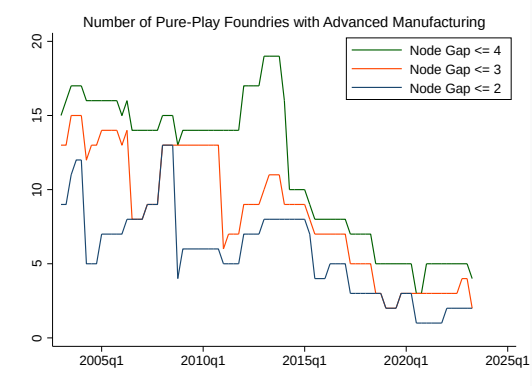
- Focus on foundries for advanced logic ICs
- Mainly used in smartphones, PCs, and high performance computing platforms
- Identify technology vintage by process node (e.g., 3nm, 5nm, 7nm)

Supply Demand Imbalance Across Regions

Data

- Pure Play Foundry Market Tracker from Omdia
  - Quarterly data from 2003Q1 to 2023Q3
  - Capacity, utilization, shipment, and revenue by firm and technology node
  - Focus on pure-play foundries, limited information on Samsung foundry
- 300mm Fab Outlook to 2026 from SEMI
  - Quarterly data from 2015Q1 to 2026Q4 (including prediction)
  - Location, capacity, technology node, construction and equipment costs for each 300mm fab production line
  - Include IDMs like Intel and Samsung
- Other complementary data
  - Firm quarterly reports: revenue, COGS, and R&D costs
  - Industry analysis data from: IC Knowledge, BCG and SIA
  - Downstream shipment data

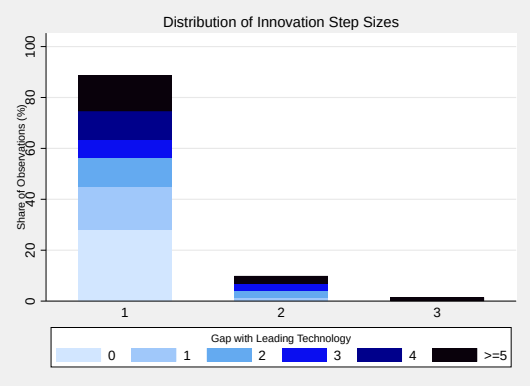
Decreasing Number in Leading-Edge Manufacturers Over Time



Source: Omdia data and author's calculation

- Highly concentrated and continues to intensify Include IDM

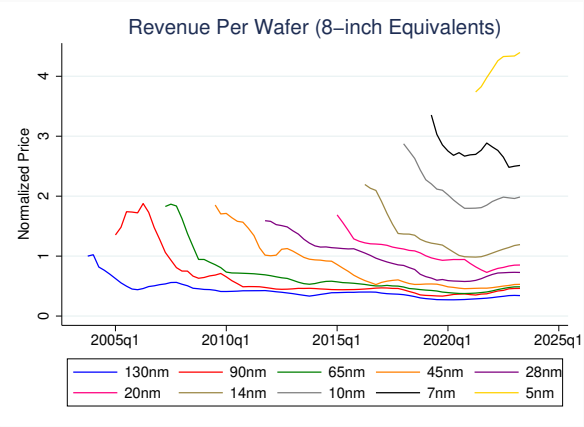
Incremental Innovation



Source: Omdia data and author's calculation

- Leapfrogging is rare and mostly happens in mature nodes
- No new firms directly competing in advanced nodes

Frontier Firms Gain Higher Profits



- Price drops rapidly after introduction

Source: Omdia data and author's calculation

Frontier Firms Gain Higher Profits

	Unit Investment Cost			
	(1)	(2)	(3)	(4)
Time Trend	0.0002	0.0006	0.0016	0.0004
	(0.0007)	(0.0006)	(0.0012)	(0.0010)
Log(Capacity)		-0.0253*	-0.0186	-0.0079
		(0.0132)	(0.0107)	(0.0128)
Constant	0.1779***	0.4347***	0.3509**	0.2554*
	(0.0131)	(0.1366)	(0.1202)	(0.1274)
Technology Node Fixed Effects	Yes	Yes	Yes	Yes
Firm Fixed Effects	No	No	Yes	No
Country Fixed Effects	No	No	No	Yes
N	107	107	97	106
R^2	0.9038	0.9082	0.9233	0.9227

Source: SEMI data and author's calculation

- Price drops rapidly after introduction
- Investment cost of fixed nodes doesn't decrease significantly over time

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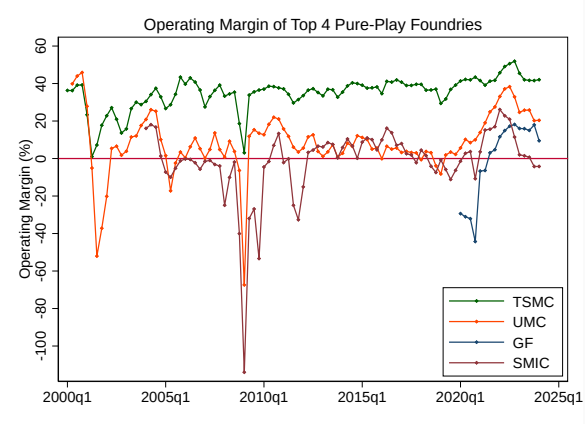
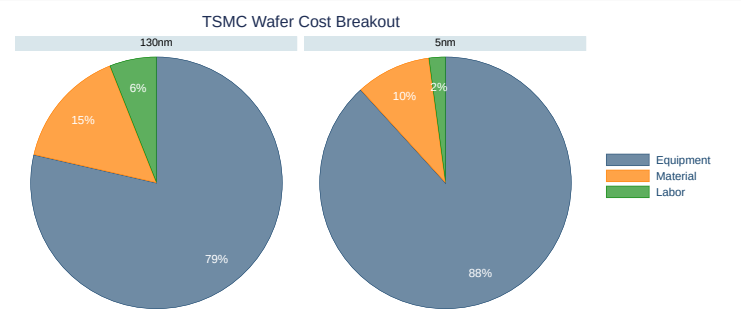


- Price drops rapidly after introduction
- Investment cost of fixed nodes doesn't decrease significantly over time
- Frontier firms gain high profits

Source: Firms' quarterly reports and author's calculation

High R&D Intensity & Equipment Cost Dominates

- High R&D intensity: $\sim$ 10% of sales
- Equipment costs account for the majority of wafer cost



Source: IC Knowledge Strategic Cost Model and author's calculation

Industry Features Summary

	Industry Features	Model Assumption
Market Structure	Limited number of firms	Oligopoly competition
Nature of Innovation	Leapfrogging is rare	Step-by-step innovation
	Declining margins for latecomer	Far-behind firms opt out of advanced tech
Cost Structure	High R&D Intensity	Focus on R&D and capacity decisions
	Equipment cost dominates	Capacity investment subsidies as the policy tool

Roadmap of Talk

Industry Features

Quantitative Model

Estimation

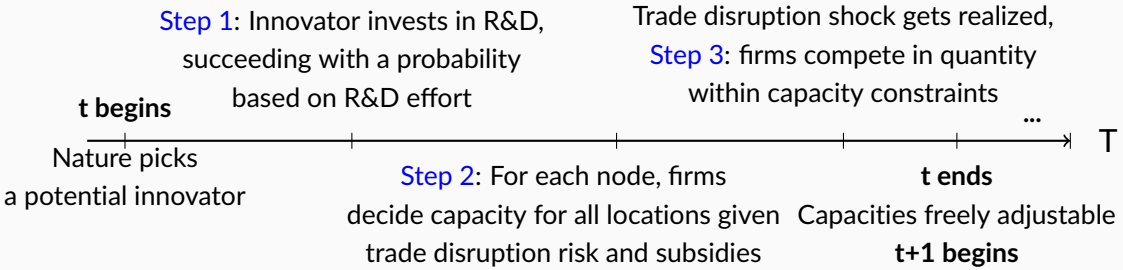
Counterfactual Analysis

- Unilateral Capacity Investment Subsidies
- Guardrail Restrictions

Conclusion

A dynamic oligopoly model of innovation and multi-location production

- Technology ladder from generations 1 to $\bar{N}$, firms can produce multiple vintages



- Trade disruption $\Rightarrow$ can only serve customers within local capacity

Step 3: Optimal Shipment Decisions

- The expected profit given capacity and trade disruption risk ψ is (abstract from node n and time t)

$$\pi_i(\mathbf{C}_i, \mathbf{C}_{-i}, \psi) = \max_{q_{i,int}, \{q_{im}\}_{m=1}^{M}} (1-\psi) \underbrace{\pi_{i,int}(q_{i,int}, q_{-i,int})}_{\text{unified global market}} + \psi \underbrace{\sum_m \pi_{im}(q_{im}, q_{-im})}_{\text{segmented local markets}}$$

$$\text{s.t. } q_{i,int} \leq C_{i,int} = \sum_m C_{im}, \; q_{im} \leq C_{im} \; \forall m$$

- $\mathbf{C}_i$: vector of firm i's capacities across all locations
- C_{im}, q_{im}: i's capacity/shipment quantity in market m
- $q_{i,int}, C_{i,int}$: i's global capacity/shipment quantity

- With shipment unit cost $= 0$ and price elasticity > 1, firms use full capacity

Capacity Installation Problem

- Given the unit cost of capacity at each location κ_{im}, firms install the optimal capacity at each location

$$\max_{C_{im} \geq 0} \pi_i(\mathbf{C}_i, \mathbf{C}_{-i}, \psi) - \sum_m \kappa_{im} C_{im}$$

- κ_{im} depends on the investment subsidies

$$\kappa_{im} = \delta_{im} \frac{w_m}{\nu_i} (1 - s_m)$$

  - δ_{im}: foreign cost shifter
  - w_m: fundamental cost at production location, ν_i: firm-level productivity
  - s_m: investment subsidy rate

Step 2: Optimal Capacity Installation

$$(1-\psi)\left(\underbrace{\frac{\partial P_{int}}{\partial Q_{int}}\sum_{m} C^*_{im} + P_{int}}_{\text{same across all locations}}\right) + \psi\left(\underbrace{\frac{\partial P_m}{\partial Q_m} C^*_{im}}_{\text{price effect}} + \underbrace{P_m}_{\text{quantity effect}}\right) = \kappa_{im}\ \forall i, m$$

- When $\psi = 0$: concentrate capacity in the most efficient location
- When $\psi > 0$: diversify capacity
- When $1 > \psi > 0$: $s_m \uparrow \implies \kappa_{im} \downarrow \implies C^*_{im} \uparrow \implies C^*_{im'} \downarrow, \forall m' \neq m$

TSMC's Production Expansion

Innovator's R&D Investment

$$V_{it}(S_t) = \pi_{it}(S_t) + \max_{d \geq 0} \left\{ -c_{i,d}(S_t)d + \beta \left[\begin{array}{c} \rho(d)\,\tilde{V}_{it}^{success}(S_{t+1} \mid S_t) \\ +(1-\rho(d))\,\tilde{V}_{it}^{fail}(S_{t+1} \mid S_t) \end{array} \right] \right\}$$

State variables: S_t

- $\bar{n}_t \leq \bar{N}$: the frontier technology
- $\Delta n_{it} \in \{0, 1, 2, \text{exit}\}$: the lag between firm i's leading technology and $\bar{n}_t$, $\forall i$
- $q_t \leq \bar{q}$: age of the frontier technology; $\{D_{nt}\}_{t=0}^{\infty}, \forall n$: other demand shifters
- $\{s_{nmt}\}_{t=0}^{\infty}, \forall n, m$: trajectories of local subsidies

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Innovation unit cost

- $c_{i,d}(S_t) = c_0(1+g^c)^{(\bar{n}_t - \Delta n_{it})\gamma^{1(\Delta n_{it}>0)}}$
- $\gamma < 1$, capturing across-firm technology spillover

R&D Details

Step 1: Optimal R&D

- FOC implies optimal R&D level, conditioned on it being positive

$$c_{i,d}(S_t) = \beta \rho'(d_i^*) \underbrace{\left[\tilde{V}_{it}^{success}(S_{t+1} \mid S_t) - \tilde{V}_{it}^{fail}(S_{t+1} \mid S_t) \right]}_{\Lambda_{it}^{gap}(S_t)}$$

- $s_{nm} \uparrow \implies \Lambda_{it}^{gap}(S_t) \uparrow \implies d_i^* \uparrow$

Industry Equilibrium | Non-innovator's Value | Backward Induction | Two-Firm Illustration

Firm Decision Margins

- **Capacity investment across locations**
  - *Costs:* shaped by local fundamentals and subsidies
  - *Returns:* market access subject to trade-disruption risk

Firm Decision Margins

- **Capacity investment across locations**
  - *Costs:* shaped by local fundamentals and subsidies
  - *Returns:* market access subject to trade-disruption risk
- **R&D investment**
  - *Costs:* depend on technology spillovers
  - *Benefits:* profits from current technology and option value of future upgrades

Market Inefficiency on Optimal Subsidy

- Inefficiencies
  - Oligopoly competition $\Longrightarrow$ market power distortion $\Longrightarrow$ inefficiently small capacity
  - Followers have lower R&D cost $\Longrightarrow$ technology externalities $\Longrightarrow$ inefficiently low R&D

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- Without trade disruption
  - Benefits leak abroad but local taxpayers pay all policy costs $\Longrightarrow$ low optimal subsidy rate

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- Without trade disruption
  - Benefits leak abroad but local taxpayers pay all policy costs $\Longrightarrow$ low optimal subsidy rate
- With trade disruption
  - Firms internalize the risk but still subject to inefficiencies
  - Trade disruption probability $\uparrow$ $\Longrightarrow$ benefit and cost are more closely aligned $\Longrightarrow$ optimal subsidy rate $\uparrow$

Technology Competition: Integrated vs. Separated Markets

- Far-behind firms have weak incentives to innovate in an integrated market
  - Low price for new generation: leaders already compress markups
  - Low option value: low chance of becoming the leader
  - Subsidies have limited impact: also spur rivals to innovate to avoid being overtaken

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  - Subsidies have limited impact: also spur rivals to innovate to avoid being overtaken
- In separated markets with FDI banned, globally lagging but locally leading firms have strong R&D incentives
  - Local leaders can capture high markups on new generations and the option value of future leadership
  - Subsidies are much more effective for these firms

Roadmap of Talk

Industry Features

Quantitative Model

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Estimation Roadmap

Assume no trade disruption risk during the sample period

Estimation Steps

Step	Data	Method
Demand	Price & quantity by technology Downstream shipment by location	IV regression Estimated α_D & model structure
Capacity Cost	Equipment cost by technology Firm capacity/revenue share	Log Regression First-order condition
R&D Cost	TSMC R&D cost trend Technology upgrading history	Log Regression Maximum likelihood

Estimation Results Highlights

- US and CN: 25% and 22% of global demand
- TSMC: 50%+ more productive than competitors
- Lagging firms: 22% of R&D unit costs of leaders

Calibrated Parameters

Demand Estimation

- Focus on advanced chips

$$\log Q_{nt} = \alpha_0 + \alpha_p \log P_{nt} + D'_{nt}\alpha_D + \epsilon_{nt}$$

- Demand shifters
  - Technology node (proxy for transistor density), frontier technology dummy, next-to-frontier technology dummy, node age
  - Log worldwide PC shipments, log worldwide smartphone and tablet shipments
- Price instruments
  - Prices of legacy chips (500nm or 350nm)
  - Share similar materials and target different downstream markets

Demand Estimation Results

	Log shipment			
	(1)	(2)	(3)	(4)
	OLS	OLS	IV	IV
Log price	-1.308***	-0.784***	-1.488***	-1.686***
	(0.394)	(0.186)	(0.413)	(0.457)
Node	0.065	0.120**	0.281***	0.325***
	(0.119)	(0.057)	(0.096)	(0.106)
Log PC shipment	0.858*	0.365	0.538*	0.586*
	(0.442)	(0.250)	(0.292)	(0.317)
Log mobile shipment	0.648***	0.353***	0.223***	0.186**
	(0.155)	(0.071)	(0.081)	(0.085)
Frontier node		0.344**	0.666***	0.757***
		(0.173)	(0.249)	(0.264)
Next-to-frontier node		0.176	0.405**	0.469**
		(0.143)	(0.185)	(0.196)
Node Age Fixed Effects	No	Yes	Yes	Yes
N	163	163	163	163
Adjusted R^2	0.518	0.836	0.819	0.808
First stage results				
Log price for 500nm wafer			1.024***	
			(0.165)	
Log price for 350nm wafer				0.899***
				(0.222)
F-value			166.24	159.67

Age Effects | Local Market Size

Capacity Cost

- Without trade disruption, firm's capacity share depends on $\kappa_{inm} = \frac{w_{nm}}{\nu_i}$

$$C_{inm} \propto \left(\frac{\alpha_P \sum_i \kappa_{inm}}{1 + \alpha_P N_n} - \kappa_{inm} \right)$$

Parameter	Functional Form	Value	Source
Capacity unit cost	$w_{nm} = w_{0,l}(1 + g^w)^n$	$w_{0,CN} = w_{0,RoW} = 0.925 w_{0,US}$ $g^w = 25.8\%$	BCG and SIA report Unit investment cost growth
Firm-level productivity	ν_i	TSMC: 1; Others: 1/1.57	Firm capacity/sales share

Trends in Equipment and R&D Costs

R&D Cost

- The likelihood function in each period is

$$l_t(a_t \mid S_t; \theta) = \sum_i \hat{p}_{pick,it} \left[\rho\left(d_{it}^*(S_t)\right)\right]^{a_{it}} \left[1 - \rho\left(d_{it}^*(S_t)\right)\right]^{1-a_{it}}$$

- The log-likelihood function is

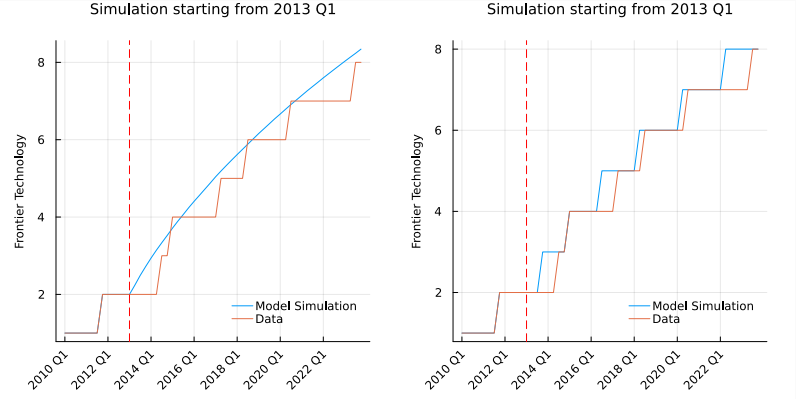
$$\mathcal{L}(\theta) = \sum_{t=1}^{\hat{T}} \ln\left[l_t(a_t \mid S_t; \theta)\right]$$

Parameter	Functional Form	Value	Source
R&D unit cost	$c_0(1+g^c)^n \gamma^{1(\Delta n_{it}>0)}$	$g^c = 28.8\%$	TSMC R&D cost trend
		$c_0/10^6 = 3.2$ [1.5, 3.5]	MLE
		$\gamma = 22\%$ [7%, 92%]	MLE

- R&D cost as a share of profit: 23.3% in the model vs. 18.5% in the data

Model Fit

- Frontier technology trajectory: model vs. data Different Simulation Starting Period



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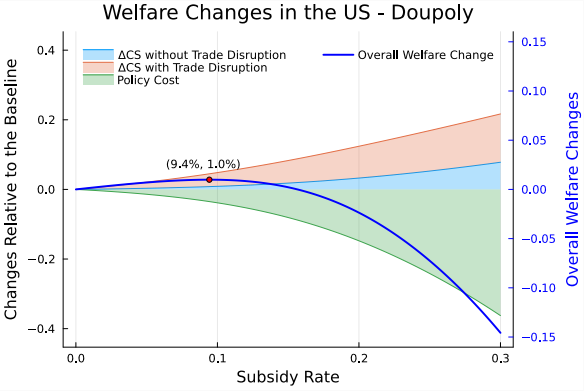
Counterfactual Analysis Roadmap: Capacity Investment Subsidies

Motivated by the US CHIPS Act

- Unilateral Investment Subsidies in the US
  - Two firms: TSMC and Samsung
  - Capacity investment subsidies for fabs built in the US
  - Compare consumer surplus and policy costs
- Investment Restrictions in mainland China

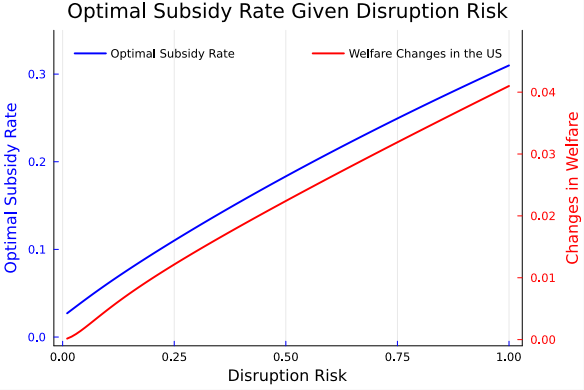
Static Gains in the US



Baseline case: 2 incumbents, $\delta = 1.0$ (foreign cost shifter), $\psi = 0.2$ (trade disruption risk)

- Capacity investment subsidies reduce prices, at a policy cost, with or without trade disruption

Static Gains in the US



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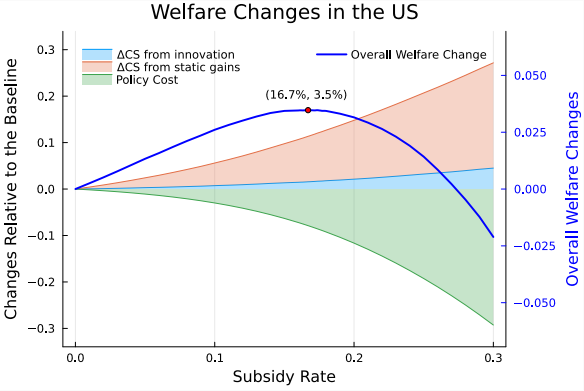
Monopoly Case | Foreign Cost Shifter δ | Static Gains in Other Locations

- Capacity investment subsidies reduce prices, at a policy cost, with or without trade disruption
- Optimal subsidy rate increases with disruption risk

Dynamic Gains in the US



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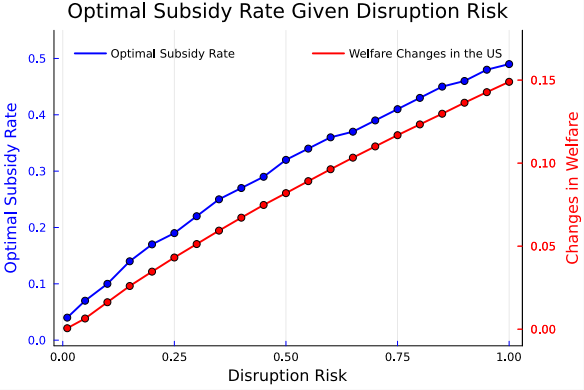
- Dynamic innovation gains further justify the subsidy, but the main benefits are static

Dynamic Gains in the US

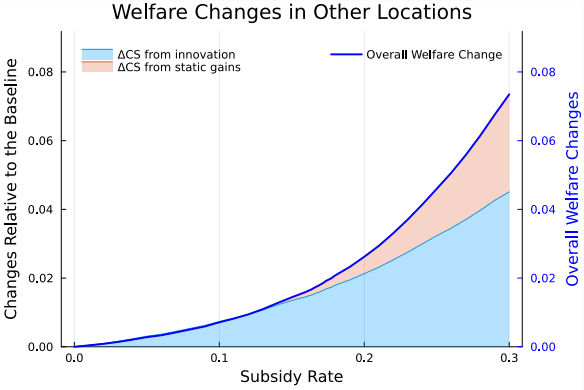


Setting: $\delta = 1.0$

Frontier Technology with and without Subsidies | No Disruption Risk Case

- Dynamic innovation gains further justify the subsidy, but the main benefits are static
- Lower optimal subsidy rate and smaller welfare gains when trade disruption risk is low

Welfare Implication in Other Locations



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- Improve instead of harm welfare in other locations

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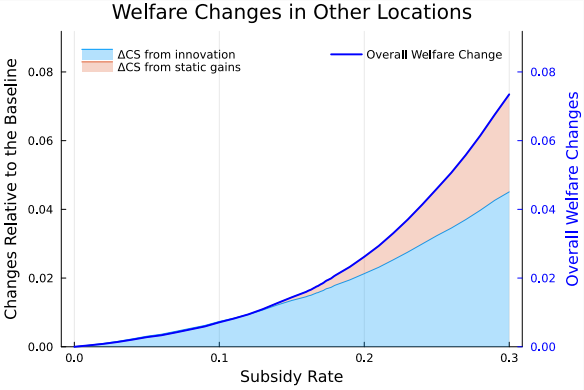

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- Improve instead of harm welfare in other locations
- The majority of welfare gains comes from the innovation channel

Counterfactual Analysis Roadmap: Guardrail Restrictions

- Unilateral Investment Subsidies in the US
- Investment Restrictions in mainland China
  - Three firms: TSMC, Samsung, and SMIC (national champion)
  - TSMC and Samsung cannot expand capacity in CN
  - Compare tech trajectories with/without restrictions

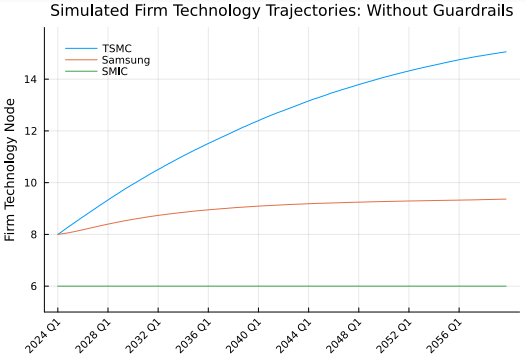
R&D Incentives under Guardrail Restrictions

Optimal R&D effort

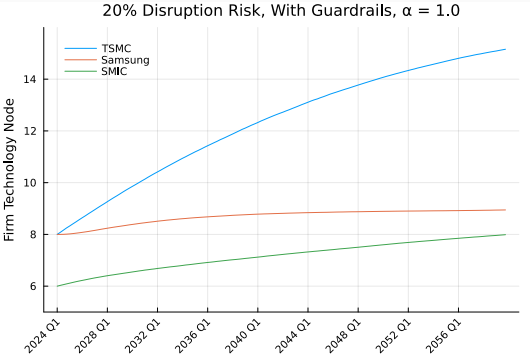
$$d^*(S_t) = \max\{0, \sqrt{\beta \frac{\Lambda^{gap}(S_t)}{c_d(S_t)}} - 1\}$$

- $\Lambda_{gap}(S_t)$: expected value gain from technology upgrading
  - Secure the domestic market demand for CN firms during trade disruptions
  - $\Delta\Lambda^{gap}(S_t) \uparrow$ as disruption risks $\psi \uparrow$
- $c_d(S_t)$: unit cost of R&D - $c_0(1 + g^c)^n \gamma^{1(\Delta n_{it} > 0)}$
  - Higher unit cost when CN firms are followers
  - $\gamma \to \alpha\gamma$ with the spillover reduction factor $\alpha \geq 1$

20% Trade Disruption Risk



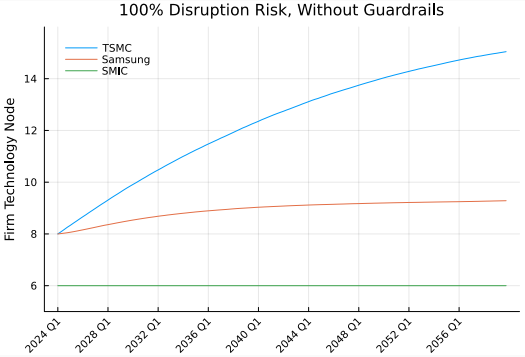
Without Guardrails: $\psi = 20\%$



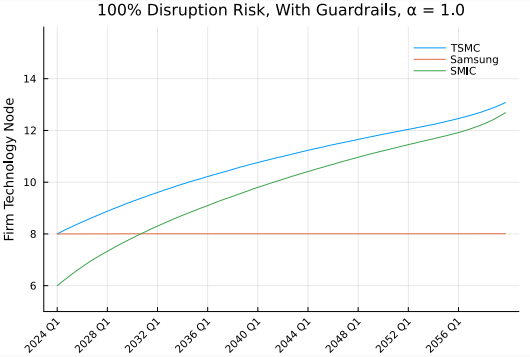
With Guardrails: $\psi = 20\%, \alpha = 1.0$

- Market demand securing is weak when disruption risk is low

100% Trade Disruption Risk

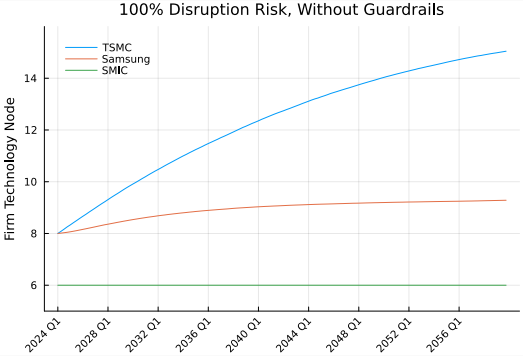


Without Guardrails: $\psi = 100\%$

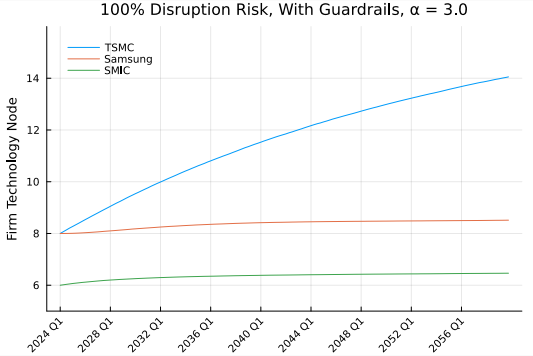


With Guardrails: $\psi = 100\%, \alpha = 1.0$

100% Trade Disruption Risk



Without Guardrails: $\psi = 100\%$



With Guardrails: $\psi = 100\%, \alpha = 3.0$

- Blocking SMIC's technological catch-up under guardrails requires a threefold reduction in spillovers, i.e., $\lambda : 22\% \rightarrow 66\%$

Roadmap of Talk

- Industry Features
- Quantitative Model
- Estimation
- Counterfactual Analysis
  - Unilateral Capacity Investment Subsidies
  - Guardrail Restrictions
- Conclusion

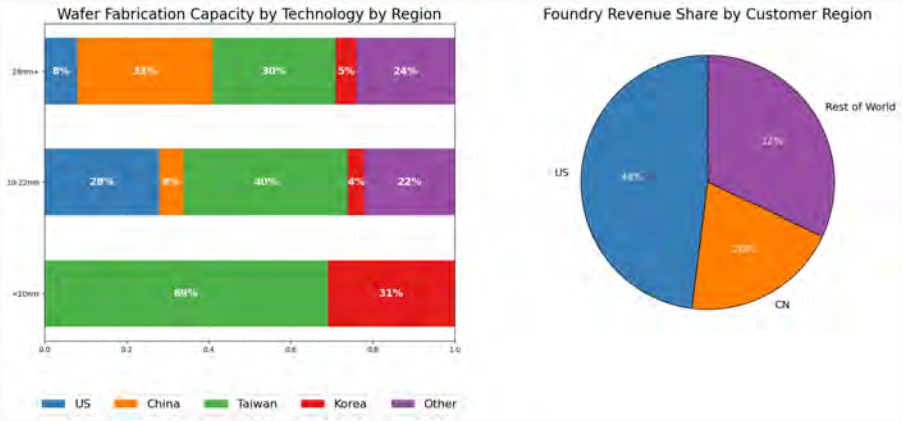
Conclusion

- A dynamic oligopoly model with step-by-step innovation, multi-location production, trade disruption risks, and industrial policies
- Impacts of US CHIPS Act
  - Trade disruption risk $\uparrow \Longrightarrow$ optimal capacity investment subsidies $\uparrow$
  - Investment restrictions in CN might $\uparrow$ CN firms' innovation when interacting with export controls

Roadmap of Talk

Additional Material

Supply Demand Imbalance

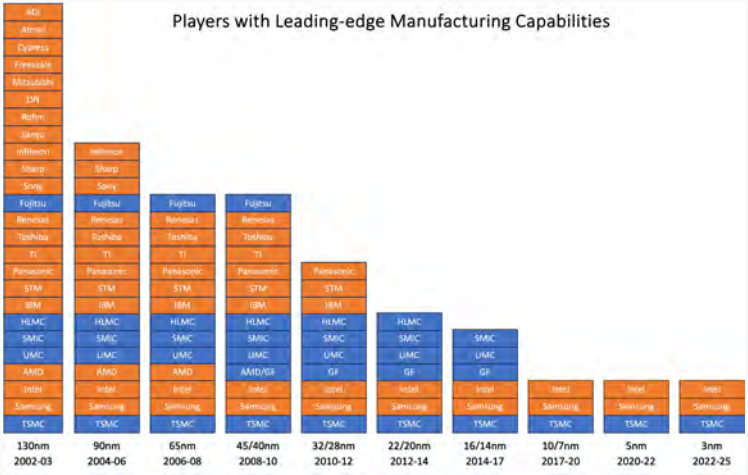


Source: BCG; Omdia data in 2023 Q4 and author's calculation

- Notable imbalance between foundry capacity and demand across locations

Back

Industry Evolution including IDMs



Back

Trade Disruption Shock Examples

- Export controls / Sanctions
- Pandemic crises leading to restrictions on the movement of goods
- Risks causing disruptions in shipping and logistics

Back

Microfoundation of the Demand Curve

- Consumers demand goods from multiple sectors with preferences

$$U_m = \Pi_s (c_m^s)^{\beta^s} \text{ where } \sum_s \beta^s = 1$$

- Each sector requires a specific generation of chips and a homogeneous and freely tradable numeraire good

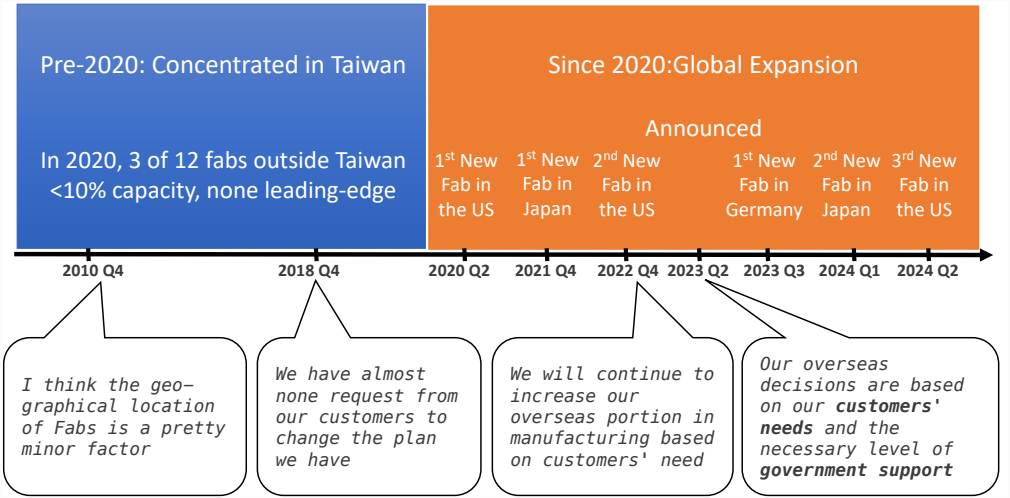
$$c_m^s = q_0 + \exp\left(\frac{\alpha_0^s}{\alpha_p}\right) \frac{{q_c^s}^{1-\frac{1}{\alpha_p}}}{1-\frac{1}{\alpha_p}}$$

- The demand for a specific generation of chip is given by

$$\log(q_c^s) = \alpha_0^s - \alpha_p \log(p_c^s)$$

Back

TSMC's Production Expansion



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Innovator's R&D Investment Details

Bellman Equation

- $V_{it}(S_t)$: innovator's value
- $W_{it}^{j}(S_t)$: non-innovator's value when j is picked as the innovator
- $\Lambda_{it}(S_t)$: expected value before knowing the innovator

$$V_{it}(S_t) = \pi_{it}(S_t) + \max_{d \geq 0} \left\{ -c_{i,d}(S_t)d + \beta \begin{bmatrix} \rho(d)[\Lambda_{it+1}(S_{t+1} \mid S_t, a_{it} = 1) \\ +1(\bar{n}_{t+1} > \bar{n}_t)\pi_{it}^{n=2}(S_t)/(1-\beta)] \\ +(1-\rho(d))\Lambda_{it+1}(S_{t+1} \mid S_t, a_{it} = 0) \end{bmatrix} \right\}$$

- d: innovation effort; $\rho(d) = \frac{d}{1+d}$: probability of successful R&D; $a_{it} = 1$ if the R&D is successful
- $\pi_{it}^{n=2}(S_t)$: profit from a node two generations behind the frontier Back

Non-Innovator's Value and Ex-ante Value

- Non-innovator's value when j is picked as the innovator

$$W_{it}^{j}(S_t) = \pi_{it}(S_t) + \beta \left[\begin{array}{c} \rho(d_j^*(S_t))[\Lambda_{it+1}(S_{t+1} \mid S_t, a_{jt} = 1) \\ +1(\bar{n}_{t+1} > \bar{n}_t)\pi_{it}^{n=2}(S_t)/(1-\beta)] \\ + \left[1 - \rho(d_j^*(S_t))\right] \Lambda_{it+1}(S_{t+1} \mid S_t, a_{jt} = 0) \end{array} \right]$$

- Expected value before knowing the innovator

$$\Lambda_{it}(S_t) = p_{pick} \left[V_{it}(S_t) + \sum_{j \neq i} W_{it}^{j}(S_t) \right]$$

Back

Industry Equilibrium

A sequential industry equilibrium is a set of functions $V_{it}(S_t), W_{it}(S_t), \Lambda_{it}(S_t), d^*_{it}(S_t), C^*_{inmt}(S_t), q^*_{inmt}(\mathbf{C}_{nmt}, \mathbf{1}(\Psi_t < \psi)), P_{nmt}(\mathbf{q}^*_{nmt})$ such that for each firm i and period $t \leq T$

- $V_{it}(S_t), W_{it}(S_t), \Lambda_{it}(S_t)$ satisfy the firms' Bellman equations;
- $d^*_i(S_t)$ solves the selected innovator's optimization problem;
- $C^*_{inmt}(S_t)$ determines the incumbent firm's capacity allocation across locations m and technology nodes n;
- $q^*_{inmt}(\mathbf{C}_{nm}, \mathbf{1}(\Psi_t < \psi))$ maximizes the firm's flow profit given the realization of trade disruption risks and capacity constraints $\mathbf{C}_{nm}$ across all firms and locations;
- $P_{nmt}(\mathbf{q}^*_{nmt})$ ensures product market clearing.

Back

Backward Induction

- Assume the terminal values associated with a firm's states and the corresponding industry states $\Lambda_{iT}(S_T)$
- At $T-1$, the picked innovator makes the dynamic decision to maximize

$$\max_{d\geq 0}\left\{-c_{i,d}(S_{T-1})d+\beta\left[\begin{array}{c}\rho(d)[\Lambda_{iT}(S_T\mid S_{T-1},a_{i,T-1}=1)\\+1(\bar{n}_T>\bar{n}_{T-1})\pi^{n=2}_{i,T-1}(S_{T-1})/(1-\beta)]\\+(1-\rho(d))\Lambda_{iT}(S_T\mid S_{T-1},a_{i,T-1}=0)\end{array}\right]\right\}$$

- Solve this iteratively until the first period

Back

Two-Firm Model Setup

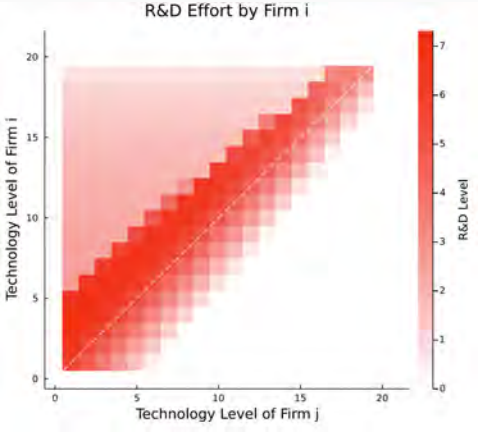
Goals

- Understand firms' R&D patterns considering their technology status and response to subsidies
- Examine how the effectiveness of subsidies in fostering technology leadership is affected by firms' relative technology status

Setup

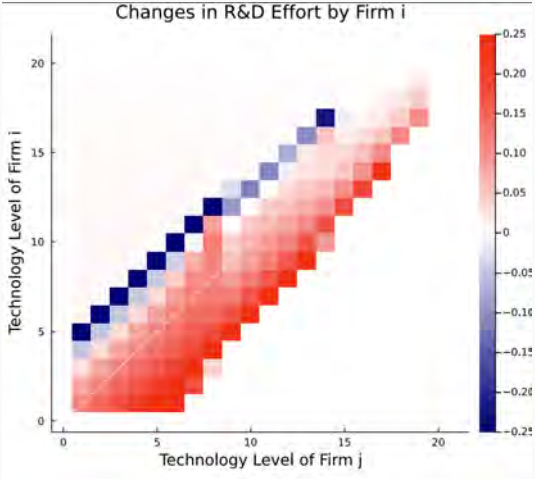
- No trade disruption risk
- Consider 2 firms subject to different investment subsidy rate τ
- Only the leading firm makes a positive profit in monopoly markets

Optimal R&D Investment Pattern



- Highest innovation when neck-and-neck
- Substantially lagging firms lose incentive to innovate
  - No leapfrogging
  - R&D must be a multi-period effort to catch up

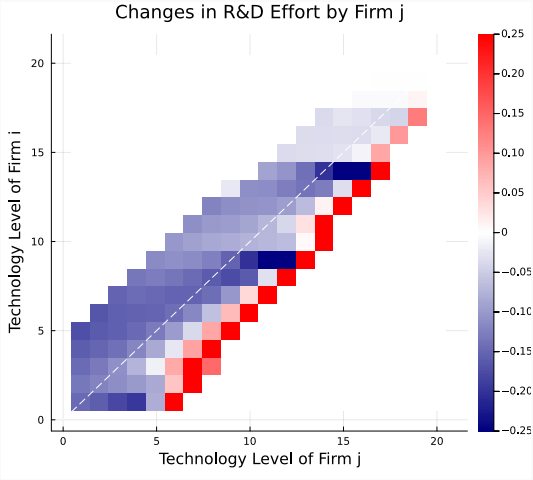
Effects of Subsidies to *i* on R&D Investment - Subsidized Firm



- No response when technology gap is too large
- Increase R&D in most cases as subsidies cover part of the cost
- Reduce R&D when leading in certain regions as R&D subsidy to leading firm further deters laggards

Back to Full Model | Effects on the Rival | Technology Upgrading Dynamics | Industrial Policy Timing

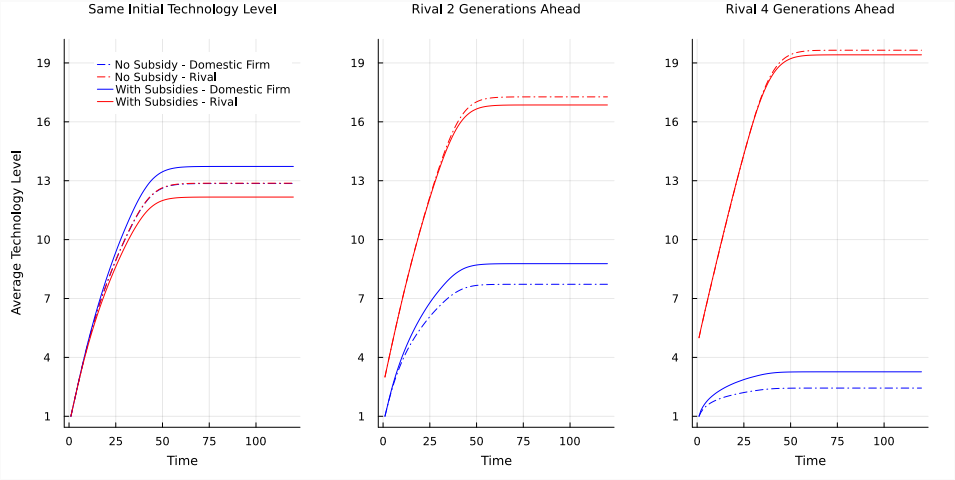
Effects of Subsidies to *i* on R&D Investment - Rival



- No response when technology gap is too large
- Cut R&D when the subsidized firm leads or closely trails
- Rise R&D to prevent the subsidized firm from catching up when has a significant technological lead

Back

Technology Upgrading Dynamics



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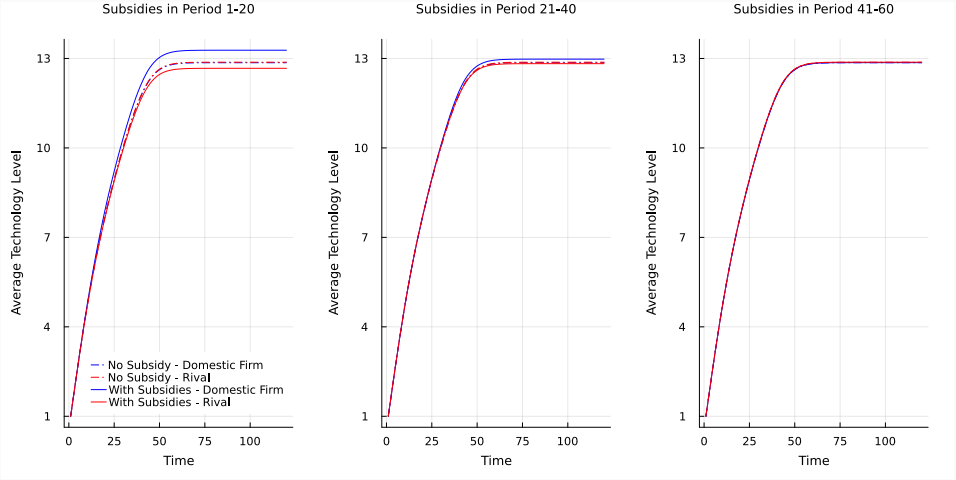
Timing's Influence on Industrial Policy Success



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Calibrated Parameters

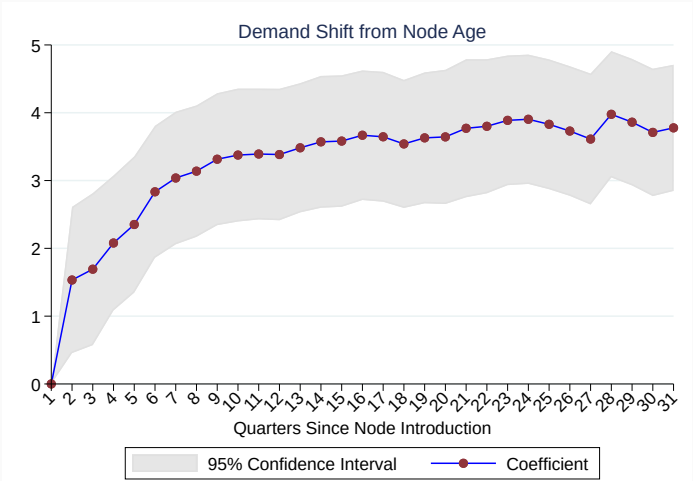
Assume no trade disruption risk during the sample period

Calibrated Parameters

Parameter	Meaning	Value	Source
β	Discount factor	$0.9^{1/4}$	Quarterly rate
$\bar{N}$	Technology limit	16	ASML Roadmap
T	Final period	$2059Q4$	Sensitivity analysis (2045Q4)
ψ	Trade disruption risk	$[0, 1]$	Set as 0 in calibration
δ	Foreign cost shifter	$[1, 2]$	Only relevant in counterfactual

Back

Age Effects on Demand



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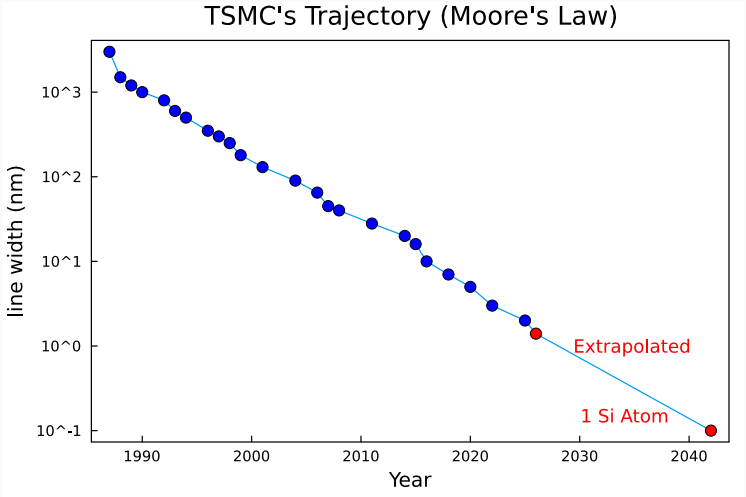
Parameterization, Calibration, and Estimation Results

Parameter	Functional Form	Value	Source
Discount factor		$\beta = 0.9^{1/4}$	Quarterly rate
Technology limit		$\bar{N} = 16$	Sensitivity analysis (11)
Final period		$T = 2059Q4$	Sensitivity analysis (2045Q4)
Trade disruption risk		$\psi \in [0, 1]$	Set as 0 in calibration
Foreign cost shifter		$\delta \in [1, 2]$	Only relevant in counterfactual
Market Share		$M_{US} = 25\%, M_{CN} = 22\%$	Downstream demand &
		$M_{ROW} = 53\%$	Estimated demand shifter coefficient
Firm-level productivity	ν_i	$\nu_{TSMC} = 1, \nu_{others} = 1/1.57$	Firm capacity share
Capacity unit cost	$\frac{w_{0,I}}{\nu_i}(1+g^w)^n(1-s_i)$	$w_{0,US} = 1, w_{0,CN} = w_{0,RoW} = 0.925$	BCG and SIA report
		$g^w = 25.8\%$	Unit investment cost growth
R&D unit cost	$c_0(1+g^c)^n\gamma^{1(\Delta n_it>0)}$	$c_0/10^6 = 3.2$ [1.5, 3.5]	MLE
		$g^c = 28.8\%$	TSMC R&D cost trend
		$\gamma = 22\%$ [7%, 92%]	MLE

Moore's Law | Market Size Definition | Trends in Equipment and R&D Costs | Firm R&D Cost Comparison | Back

Moore’s Law Extrapolation



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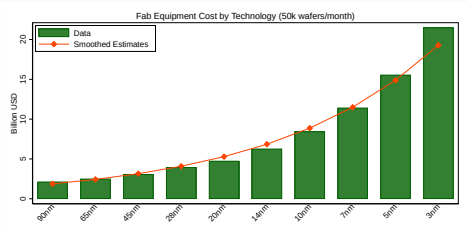
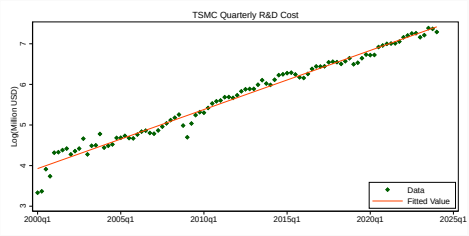
Trends in Equipment and R&D Costs



Source: SMIC prospectus and author's calculation

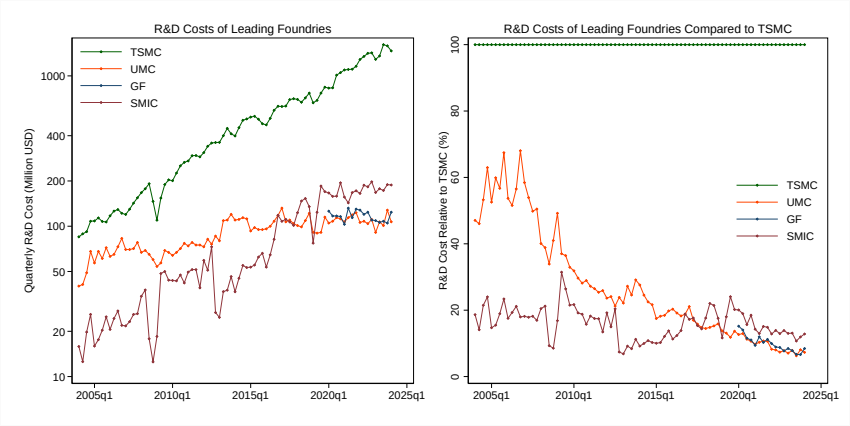


Source: TSMC's quarterly reports and author's calculation

- Both investment costs and R&D expenditures increases exponentially with advancing technology nodes

Back

R&D Costs of Leading Foundries



Source: Firms' quarterly reports and author's calculation

Back

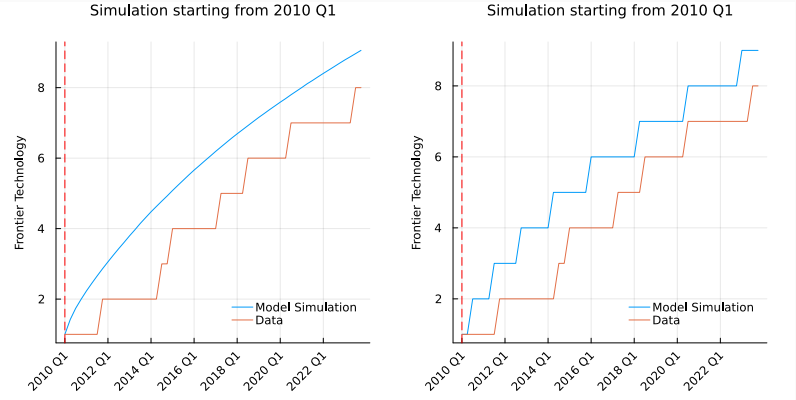
Market Size

- Define market size based on downstream demand for smartphones, tablets, and PCs
- From the demand estimation: $N_m \propto Q_{PC,m}^{\alpha_D^{PC}} Q_{mobile,m}^{\alpha_D^{mobile}}$
- Estimated market size shares: US 25.2%, CN 22.2%, RoW 52.6%

Back

Model Fit - Frontier technology trajectory

- Frontier technology trajectory: model vs. data



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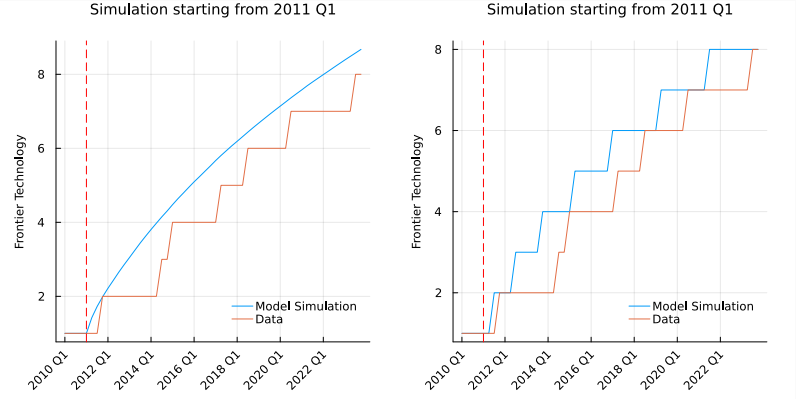
Model Fit - Frontier technology trajectory

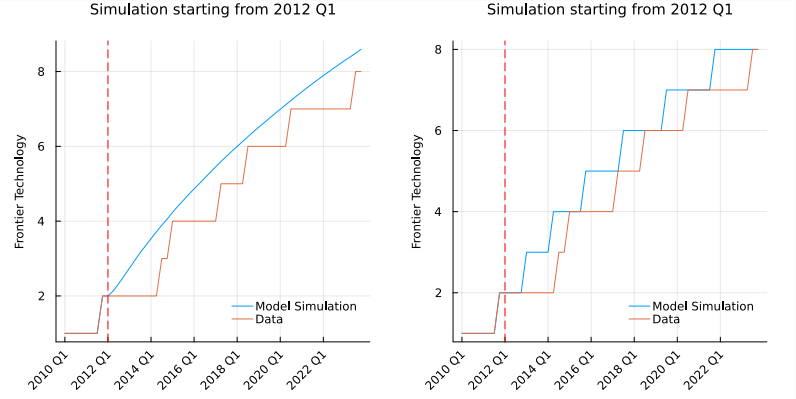
- Frontier technology trajectory: model vs. data



Back

Model Fit - Frontier technology trajectory

- Frontier technology trajectory: model vs. data



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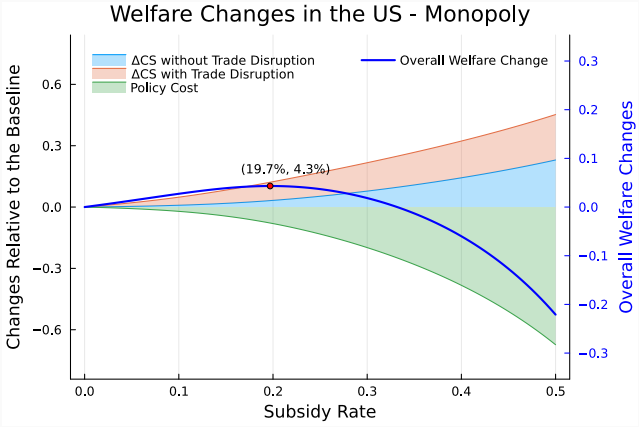
Static Gains in the US: Monopoly Case



Monopoly case: $\delta = 1.0, \psi = 0.2$

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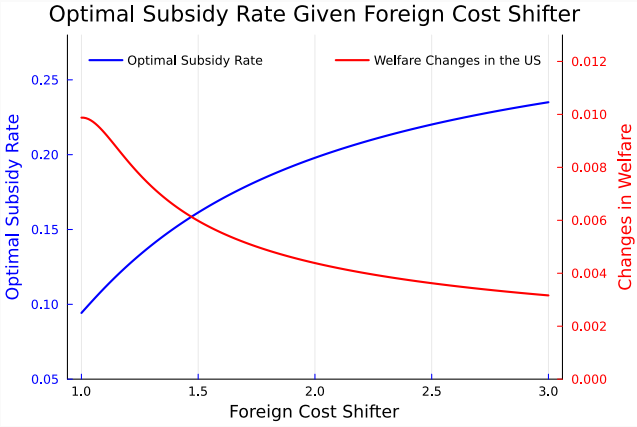
Static Gains in the US: The Role of δ



Setting: 2 incumbents, $\psi = 0.2$

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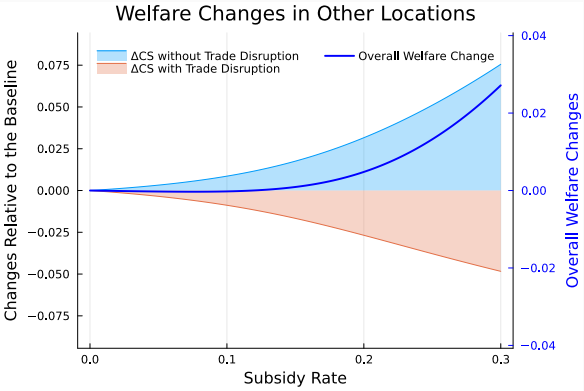
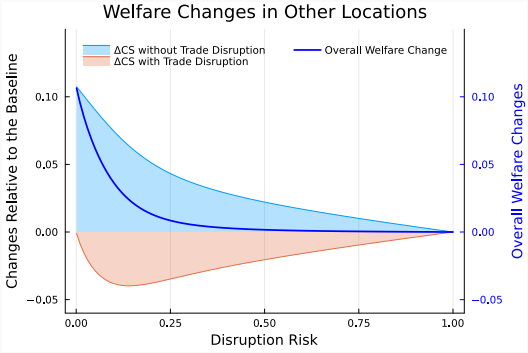
Static Gains in Other Locations



Baseline case: 2 incumbents, $\delta = 1.0, \psi = 0.2$

- US subsidies shift capacity to the US, raising prices elsewhere during trade disruptions but lowering global prices without disruption

Static Gains in Other Locations

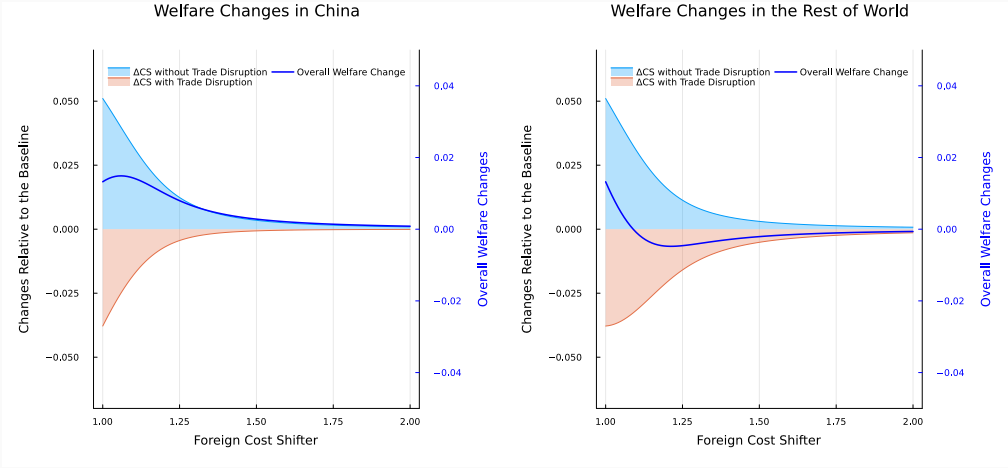


Setting: 2 incumbents, $\delta = 1.0$, $s_{US} = 25\%$

Foreign Cost Shifter δ Back

- US subsidies shift capacity to the US, raising prices elsewhere during trade disruptions but lowering global prices without disruption
- Other locations benefit less from US subsidies as trade disruption risk rises

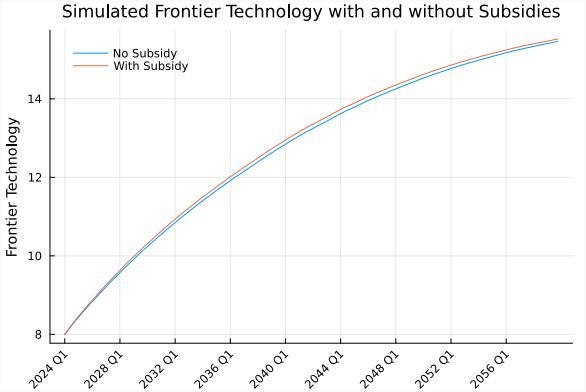
Static Gains in Other Locations: The Role of δ



Setting: 2 incumbents, $\psi = 0.2$, $s_{US} = 25\%$

Back

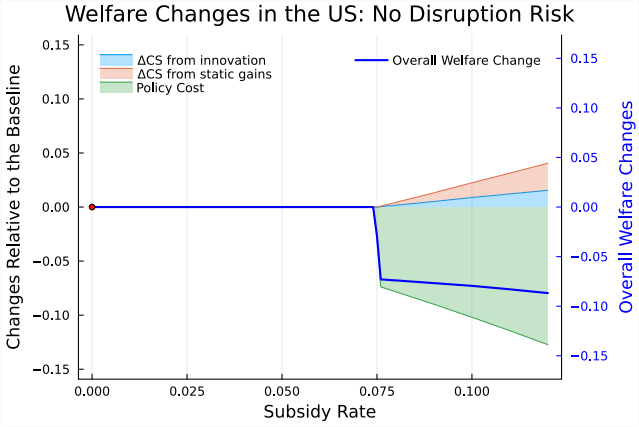
Gains from Faster Technology Upgrades



Baseline case: $\delta = 1.0, \psi = 0.2, s_{US} = 17\%$

Back

Dynamic Gains in the US: No Disruption Risk



Setting: $\delta = 1.0, \psi = 0.0$

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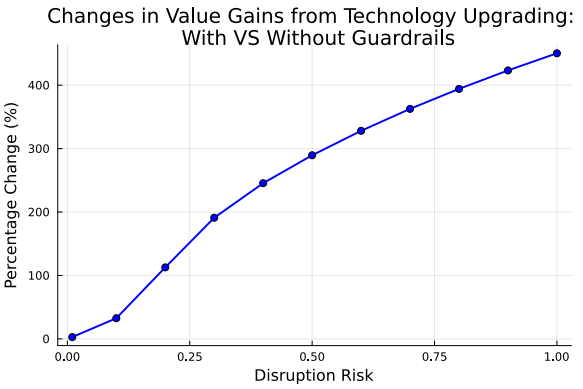
Minimum α for Effective Guardrails



Note: Changes in Λ_{gap} for SMIC in 2024Q2 with and without guardrails, $s_{US} = 25\%, \delta = 1.0$

- To curb CN firm's innovation: $\uparrow$ disruption risks $\Longrightarrow$ $\uparrow$ spillover blocking
- Export controls and the Huawei ban $\uparrow$ disruption risks in CN

Back