Investment-Goods Market Power and Capital Accumulation

Slides

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Motivation

- Post-2020 recovery and inflation dynamics
  - Dependence of economy on semiconductors
  - Necessary inputs in equipment and durable goods
    Automotive, healthcare, telecommunications, ...
  - Produced by concentrated industry List PPI
    With capacity constraint
  - Ambitious policy responses (e.g., CHIPS Act 2022)
    $52.7 billion in federal subsidies
- Several investment-goods industries are concentrated
  Commercial aircraft & ships, EV, construction and mining machinery

How does investment-goods market power shape macro dynamics?

This Paper: Model

Macro model with market power in investment goods

- Demand (Domestic economy)
  - Capital accumulation in open economy
  - The investment Euler equation pins down dynamic demand for investment goods
- Supply (Foreign firms)
  - "Large" (i.e., non-atomistic) foreign firms produce input required in investment

    Internalize effect on prices through investment Euler
  - Dynamic oligopoly with endogenous markups

    Generalized Euler equation generates state-dependent markups

$\rightarrow$ State-dependent investment friction in domestic economy

This Paper: Quantitative Application

- Semiconductor manufacturing industry in post-2020 recovery PPI
- High concentration (TSMC + Samsung dominant role) List
- Investment-demand shock in the presence of steep marginal cost
- Decomposition of price changes: marginal cost vs. markup
- Counterfactual analyses: changes in marginal cost, changes in market structure (CHIPS Act)

Related Literature

- Market Power in Macro (Focus: market power in dynamic inputs)
  - De Loecker/Eeckhout/Unger (2020), Mongey (2021), Berger/Herkenhoff/Mongey (2022), Wang/Werning (2022) Edmond/Midrigan/Xu (2023), Villa (2023)
- Investment Frictions (Focus: the supply side of investment)
  - Cooper/Haltiwanger (2006), Khan/Thomas (2008), Buera/Shin (2013)
- Intern. Trade & Macro (Focus: imports of inv. goods from "large" firms)
  - Ghironi/Melitz (2005), Hsieh/Klenow (2007), Atkeson/Burstein (2008), Lanteri/Medina/Tan (2023)
- Oligopoly & Durable Goods (Focus: macro implications)
  - Coase (1972), Maskin/Tirole (2001), Esteban/Shum (2007), Goettler/Gordon (2011)

Outline

- Model environment
  - Demand & assembly
  - First best (perfect competition among suppliers)
  - Suppliers dynamic oligopoly
    1. Without commitment (Markov-perfect equilibrium)
    2. With commitment (competing Ramsey planners)
- Quantitative analysis
  - Transitional dynamics of capital accumulation
  - Application: post-2020 recovery and semiconductors

Model

Capital Accumulation in Open Economy

- Det. model (for now), time discrete and infinite $t = 0, 1, ..$
- Rep. household in domestic economy max $\sum_{t=0}^{\infty} \beta^t u(C_t)$
- Budget: $C_t + P_t^I I_t + B_t = W_t L + R_t^K K_{t-1} + RB_{t-1} + D_t$
- Economy is "small" in the sense that R is exogenous
  - Focus on endogenous P_t^I
- Capital accumulation $K_t = (1-\delta)K_{t-1} + I_t$
- Representative firm with technology $Y_t = F(K_{t-1}, L)$

Investment Euler Equation

1. Household optimality conditions $\left(\mathcal{M} \equiv \beta \frac{u_c(C_{t+1})}{u_c(C_t)}\right)$

$$\begin{aligned} 1 &= \mathcal{M}R \\ P_t^I &= \mathcal{M}\left(R_{t+1}^K + (1-\delta)P_{t+1}^I\right) \end{aligned}$$

2. Firm optimality conditions

$$\begin{aligned} f_k(K_{t-1}) \equiv F_K(K_{t-1}, L) &= R_t^K \\ F_L(K_{t-1}, L) &= W_t \end{aligned}$$

Investment Euler equation

$$P_t^I = R^{-1}\left(f_k(K_t) + (1-\delta)P_{t+1}^I\right)$$

Investment Assembly and Production

Assembly: investment is Leontief aggregator of...

(i) imported oligopolistic input Q_t & (ii) competitive output X_t

$$I_t = \min\left\{\frac{Q_t}{\theta}, \frac{X_t}{1-\theta}\right\}$$

Optimality and perfect competition with free entry in assembly

1. $\frac{Q_t}{\theta} = \frac{X_t}{1-\theta}$
2. Price index $P_t^I = \theta P_t + (1-\theta)\cdot 1$

Production: $N \geqslant 1$ "large" foreign producers of imported input

- Cost function $c(q_{j,t})$, $c_q > 0$, $c_{qq} > 0$ (capacity constraints)
- Static profit $\pi_{j,t} \equiv P_t q_{j,t} - c(q_{j,t})$
- Objective function $\sum_{t=0}^{\infty} R^{-t}\pi_{j,t}$

First Best

Investment Euler, price index, and market clearing

1. $P_t^I = R^{-1}\left(f_k(K_t) + (1-\delta)P_{t+1}^I\right)$
2. $P_t^I = \theta P_t + (1-\theta)\cdot 1$
3. $\sum_{j=1}^N q_{j,t} = Q_t = \theta I_t$

FIRST-BEST ALLOCATION

Perfect competition or planner that operates technology to max utility in domestic economy (symmetry is an equilibrium outcome)

$$P_t = c_q(q_t) = c_q\left(\frac{\theta I_t}{N}\right)$$

Dynamic Oligopoly - Markov Perfect Equilibrium

GENERIC OLIGOPOLIST PROBLEM WITH NO COMMITMENT

Given other players strategies $q_{-}(K)$ and future policy function $P(K')$, an oligopolist best response is given by

$$\max_{P,q,K'} \quad P \cdot q - c(q) + R^{-1} V(K')$$

subject to...

1. Investment Euler: $P^I = R^{-1}\left(f_k(K') + (1-\delta)P^I(K')\right)$
2. Price index: $P^I = \theta P + (1-\theta) \cdot 1$
3. Capital accumulation: $K' = (1-\delta)K + I$
4. Market clearing: $(N-1)q_{-}(K) + q = Q = \theta I$

Generalized Euler Equation

With symmetry

1. $q(K) = q_{-}(K) = \frac{\theta I(K)}{N}$
2. $V(K)$ is maximum value

Generalized Euler Equation (GEE) & Envelope

$$\theta P - \theta c_q(q) + qR^{-1}\left(\theta^{-1} f_{kk}(K') + (1-\delta) P_k(K')\right) + R^{-1} V_k(K') = 0$$

$$V_k(K') = -\theta \left(1 - \delta + \left(\frac{N-1}{N}\right) I_k(K')\right)\left(P(K') - c_q\left(\frac{\theta I(K')}{N}\right)\right)$$

This is a GEE because the derivatives of the future equilibrium investment and price functions $I_k(K')$ and $P_k(K')$ appear

- How can we interpret this (ugly) GEE?

Dynamic and Static Markup

- Inverse price elasticity of investment

$$\eta \equiv -\frac{Q}{P}\frac{dP}{dQ} = -\frac{Q}{P}\theta^{-1}R^{-1}\left(\theta^{-1}f_{kk}(K') + (1-\delta)P_k(K')\right)$$

- GEE can be expressed as a dynamic markup rule

$$P = \underbrace{\frac{N}{N-\eta}}_{\text{Dynamic Markup}} \cdot \underbrace{\left(c_q(q) - R^{-1}\theta^{-1}V_k(K')\right)}_{\text{Dynamic Marginal Cost}}$$

- Part of the marginal cost is the foregone future markup
- Dynamic markup rate $\mu^D \equiv \frac{\eta}{N-\eta}$
- $\mu^S \equiv \frac{P-c_q(q)}{c_q(q)} = \mu^D\left(1 - \frac{NR^{-1}\theta^{-1}V_k(K')}{\eta c_q(q)}\right)$ See figure

Commitment to Future Production I

- Same model but different commitment technology
- At $t = 0$, each investment-good producer commits to an infinite sequence of production levels $\{q_t\}_{t=0}^{\infty}$ taking as given a sequence of competitors' productions $\{q_{-,t}\}_{t=0}^{\infty}$
- We then impose symmetry across investment-goods producers in equilibrium

Commitment to Future Production II

The oligopolist's maximization problem is

$$\max_{\{P_t,q_t,K_t\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} R^{-t}\left(P_t q_t - c\left(q_t\right)\right)$$

subject to sequences of demand schedule (or "implementability constraint" in Ramsey-optimal policy)

$$P_t = R^{-1}\left(\theta^{-1} f_k(K_t) + (1-\delta)P_{t+1}\right) - \kappa \quad \text{(Inv. Euler+Price Index)}$$

for $t = 0, 1, ..,$ with multiplier $R^{-t}\gamma_t$, and the law of motion

$$K_t = (1-\delta)K_{t-1} + \underbrace{\theta^{-1}\left((N-1)q_{-,t} + q_t\right)}_{I_t} \quad \text{(K L.o.M.+M.C.)}$$

which we use to substitute away q_t See all constraints and κ

Commitment to Future Production III

Optimality conditions w.r.t. P_t and K_t:

$$q_t - \gamma_t + \gamma_{t-1}(1-\delta) = 0$$

$$\theta P_t - \theta c_q(q_t) + \gamma_t R^{-1}\theta^{-1} f_{kk}(K_t) - R^{-1}\theta(1-\delta)\left(P_{t+1} - c_q(q_{t+1})\right) = 0$$

- State variable γ_{t-1} enforces collusion with past self: high current price allows high past price
- In this formulation, we assume that investment-goods producers cannot collude because of coordination costs
- In the paper, we also analyze collusion with rival producers

Quantitative Analysis

Calibration Strategy

Quantitative analysis of role of semiconductors for post-2020 US recovery All parameter values

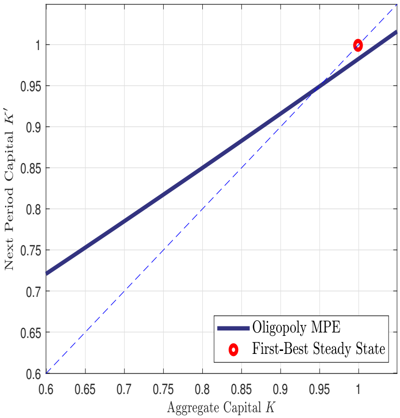
- Interpret capital as US stock of machinery and equip. (α, δ)
- Interpret oligopoly industry as semiconductor suppliers

We calibrate 4 non-standard parameters (θ, N, c_1, and c_2):

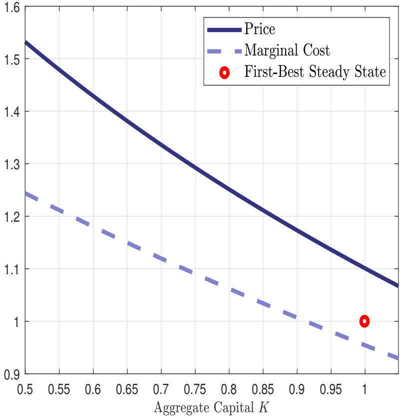
1. θ to match post-2020 pass-through of semiconductors PPI (+20%) to equipment PPI (+7%) Details PPI
2. $N = 3$, high concentration (TSMC+Samsung+Others) List
3. $c(q) = c_1 q + .5 c_2 q^2$ to match pre-2020 profitability from ORBIS data Details

Policy Fun.s & Transition Paths

Capital Accumulation and Prices



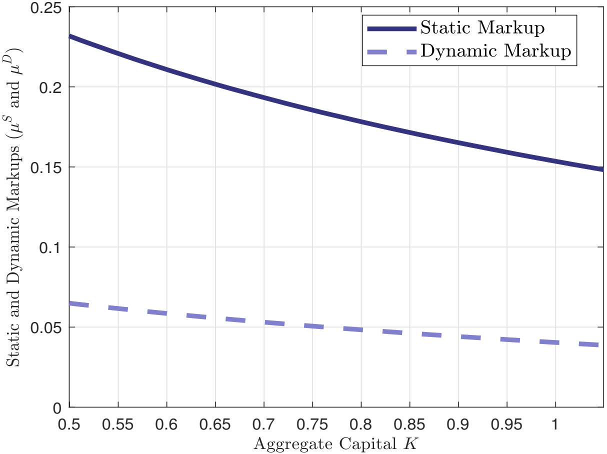
(a) Capital Accumulation



(b) Price and Marginal Cost

Less competition dampens capital accumulation

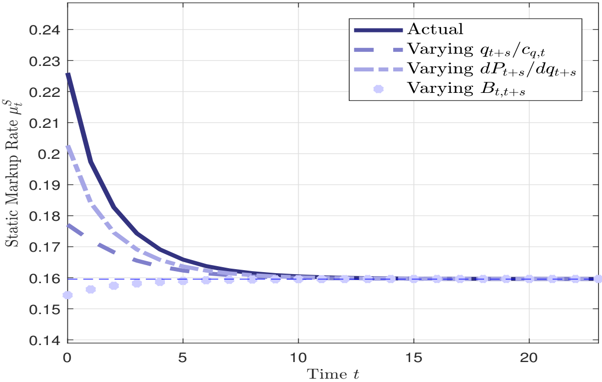
Markups



Static markup covers MC from competition with future $(1-\delta)K$

See formula

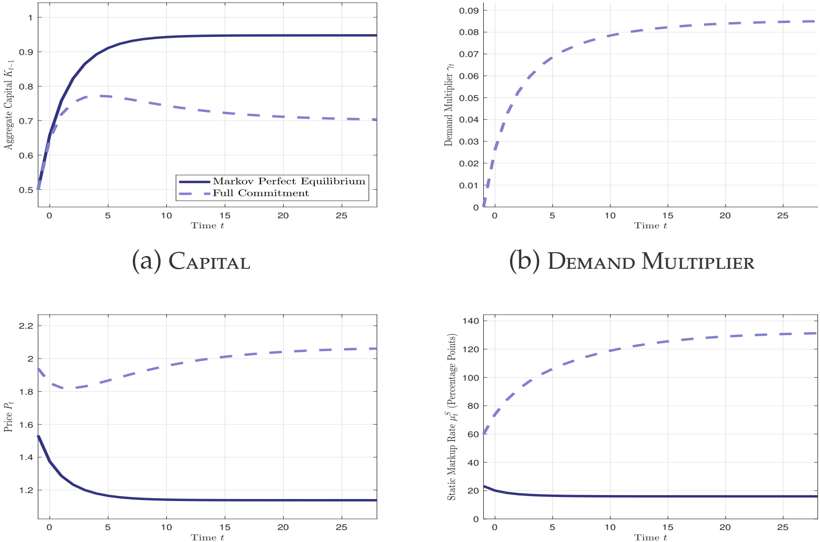
MPE Markup Decomposition over Transition to S.S.



$$\mu_t^S = \frac{P_t - c_q(q_t)}{c_q(q_t)} = -\sum_{s=0}^{\infty} \overbrace{B_{t,t+s}}^{\text{Discount}} \cdot \underbrace{\frac{q_{t+s}}{c_q(q_t)}}_{\text{Quantity}} \cdot \overbrace{\frac{dP_{t+s}}{dQ_{t+s}}}^{\text{Demand Derivative}}$$

FC Markup Decomposition

Role of Commitment: Transition to S.S.



(a) Capital (b) Demand Multiplier

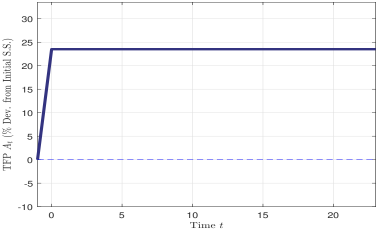
(c) Price (d) Static Markup

Role of c_2 and δ

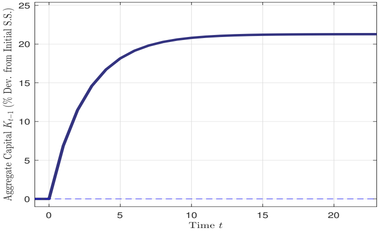
- A higher c_2 leads to larger distortions due to market power
  - Higher c_2 (or a capacity constraint) ensures that it is not optimal for producers to scale up production quickly
  - This force sustains higher markups and an effective price discrimination across periods
- We also find that capacity constraints increase markups
- A higher δ (lower durability) implies
  - less competition between current and future production
  - and affects the level of investment demand, potentially increasing the volume of production
- A higher $\delta \implies$ a slightly higher S.S. markup rate

Demand VS Supply Shock

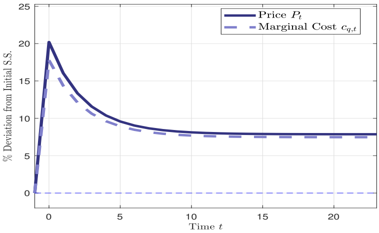
Demand Shock (TFP to match 20% $\uparrow$ in P_t post-2020)



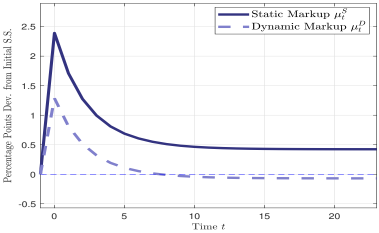
(a) TFP



(b) Capital

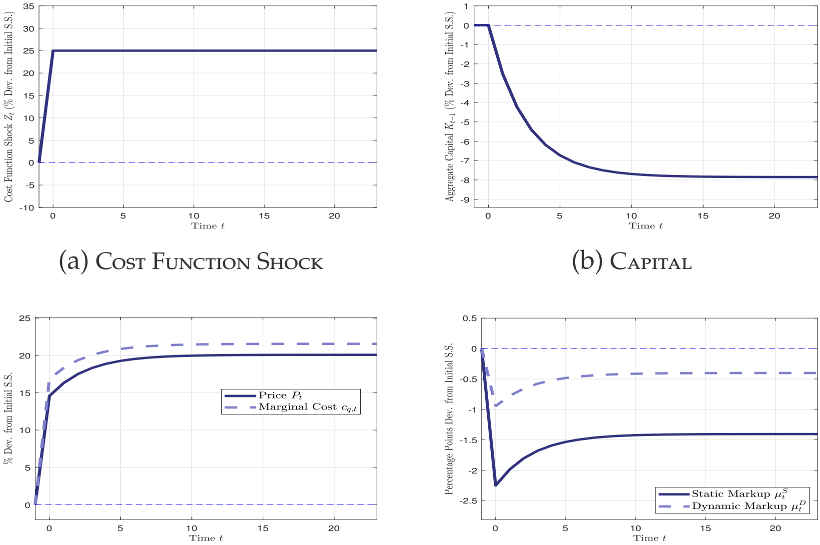


(c) Price and Marginal Cost



(d) Markups

Supply Shock ($Z_t c(q_{j,t})$ with $Z_t \uparrow$ to match previous $P_t \uparrow$)



(a) Cost Function Shock

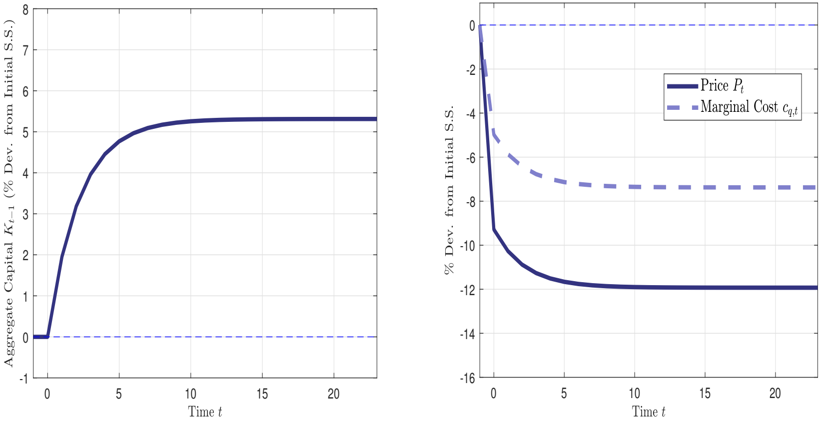
(b) Capital

(c) Price and Marginal Cost

(d) Markups

Change in Market Structure or Relax Capacity Constraints?

Change in Market Structure: from N = 3 to N = 4 (MPE)

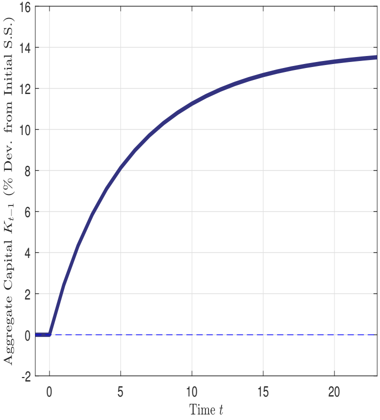


(a) Capital

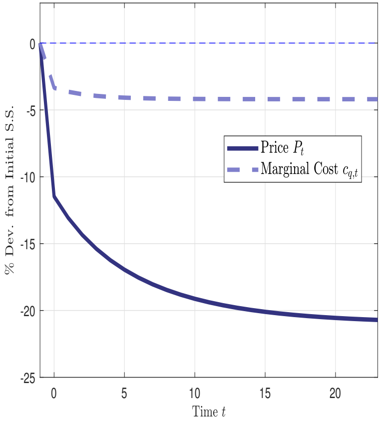
(b) Price and Marginal Cost

Aggr. capacity expansion interacts with rising competition

Change in Market Structure: from N = 3 to N = 4 (FC)



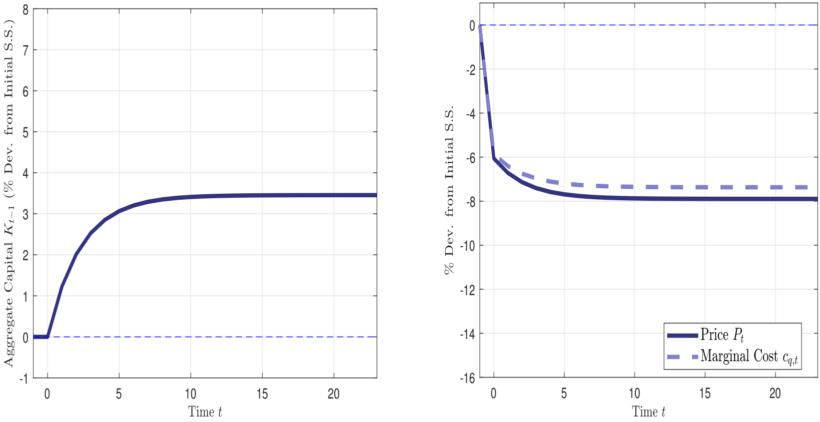
(a) Capital



(b) Price and Marginal Cost

Even more interaction effect under FC

Relaxing Capacity Constraints: $c_2 \downarrow$ (MPE)



(a) Capital (b) Price and Marginal Cost

Given same c_q decline, no endogenous markups compression

Extension: Stochastic Model

Stochastic Model with Demand and Supply Shocks

We assume A_t and Z_t follow a VAR(1). We calibrate 5 parameters to match 5 targets in the data.

	Parameter	Symbol	Value
TFP Stochastic Process	Autocorrelation	ρ_A	0.850
	Standard Deviation	σ_A	0.018
Cost Level Stochastic Process	Autocorrelation	ρ_Z	0.575
	Standard Deviation	σ_Z	0.085
Correlation	Correlation	$\frac{\sigma_{A,Z}}{\sigma_A \sigma_Z}$	-0.290

Parameter	Data	Model(MPE)
log(GDP) Autocorrelation	0.09	0.136
log(GDP) Standard Deviation	0.010	0.014
Equipment Price Autocorrelation	0.028	0.024
Equipment Price Standard Deviation	0.015	0.022
log(GDP)-Equipment Price Correlation	0.008	0.002

RBC Model with Oligopolistic Investment Production

	FB	MPE	FC
Mean I	0.134	0.128	0.098
Mean P	0.990	1.136	1.702
Mean Markup	0	0.160	0.908
St. Dev. I/St. Dev. Y	18.306	6.694	21.484
St. Dev. P	0.025	0.037	0.025
St. Dev. Markup	0	0.008	0.074
Corr. Y and I	0.135	0.482	0.184
Corr. Y and P	-0.15	0.007	0.383
Corr. Y and Markup	0	0.275	0.272

Low St. Dev. Markup over P (MPE) confirms that, in response to demand shocks, marginal costs play a major role

Constrained Efficiency: Problem

- We formulate and solve a constrained planning problem with FC that chooses an infinite sequence of production levels and prices
  - A first step toward a macro theory of optimal industrial policy in durable-good industries with market power
- We consider a benevolent planner that operates N investment-goods producers to maximize welfare in the domestic economy, subject to
  - The participation constraint, i.e. investment-goods producers must achieve a minimum level of profits
  - The capital accumulation and the investment Euler equations
  - There are no lump-sum transfers between domestic economy and foreign firms

Constrained Efficiency: Results

- The planner balances the need
  - to deliver profits through markups
  - with the incentive to increase welfare by increasing production and thus reducing investment prices
- We find that
  - In the short run, the planner increases levels of production and reduces prices, leading to capital accumulation and high output in the domestic economy
    (as in the policy intervention to expand capacity)
  - In the long run, the accumulation in the multipliers on past investment Eulers advises the planner to increase prices to deliver profits to producers, ensuring their participation

Conclusion

- Propose a new model with endogenous dynamic markups in the global production of investment goods
- Less competition dampens K accumulation

  In MPE markups decrease in K → microfounded K "adjustment cost"

  In FC markups increase in K → long-term rent extraction
- Post-2020 recovery: what drives price increase?
  - Demand. Both P and Q increased. Despite market power, increase in P driven by increase in c_q (capacity constraints)
- How to effectively expand global capacity?
  1. Market power is policy relevant
  2. ↑ N more effectively stimulates K accumulation

     Aggregate capacity expansion interacts with rising competition
  3. ↑ N even more effective under FC

Thank You

Parameter Values

	Parameter	Symbol	Value
Investment Demand	Discount Factor	β	0.96
	Depreciation	δ	0.1354
	Capital Share	α	0.0645
	Oligopolistic Capital Share	θ	0.366
	Total Factor Productivity	A	2.743
Investment Supply	Number of Producers	N	3
	Marginal Cost (Intercept)	c_1	0.6369
	Marginal Cost (Slope)	c_2	22

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θ Calibration Details

We calibrate the share of imported investment goods θ in total investment using US data on investment-goods prices as follows

1. Deflate the Producer Price Index of semiconductors and the Producer Price Index of machinery and equipment using the GDP deflator
2. We fit a linear trend in both series during 2012-2019. We then match the pass-through of the cumulative increase in the real price of semiconductors to the real price of machinery and equipment during 2019-2023
3. Relative to trend, we observe a 20% increase in the real price of semiconductors and a 7% increase in the real price of machinery and equipment

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List and Market Share of Seminconductors Manufacturer

Company	Segment	Market Share
Taiwan Semiconductors Manufacturing Company (TSMC)	Foundry	59% (2022Q4)
Samsung	Foundry	13% (2022Q4)
UMC, GlobalFoundries, SMIC	Foundry	<10%
Samsung	Vendor	15.5% (2019)
Intel	Vendor	14% (2019)
SK Hynix	Vendor	7% (2019)
Others	Vendor	<5% (2019)

Sources: CounterPoint Research (Foundry); Statista (Vendors)

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c_1, c_2 Calibration Details

1. We assume that the cost function to produce investment goods is quadratic: $c(q) = c_1 q + \frac{c_2}{2} q^2$
2. Given a calibrated value for the slope of the marginal cost c_2, we set the intercept c_1 to normalize the marginal cost of investment to one in the first-best steady state
3. We calibrate c_2 so that the ratio of profits to sales in steady state closely matches the ratio of operating income to sales in balance-sheet data for the major semiconductor manufacturers.
   - Specifically, using ORBIS data on TSMC and Samsung, we obtain a ratio of approximately 30%.

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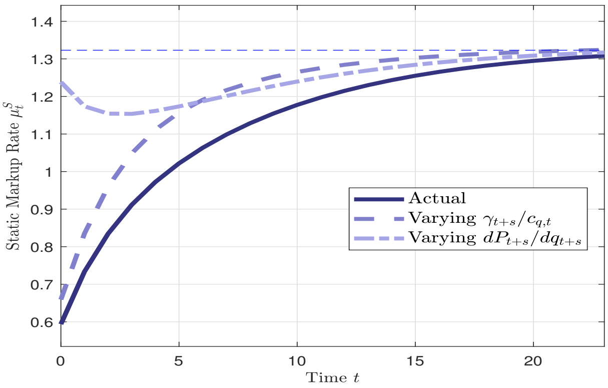
FC Constraints

FC subject to sequences for $\forall t$

1. Investment Euler: $P^I_t = R^{-1}\left(f_k(K_t) + (1-\delta)P^I_{t+1}\right)$
2. Price index: $P^I_t = \theta P_t + 1 - \theta$
3. Capital accumulation: $K_t = (1-\delta)K_{t-1} + I_t$
4. Market clearing: $(N-1)q_-(K_t) + q_t = Q_t = \theta I_t$

The constant $\kappa \equiv \theta^{-1}(1-\theta)\left(1 - R^{-1}(1-\delta)\right)$. Back

FC Markup Decomposition over Transition to SS



$$P_t - c_q(q_t) = -\sum_{s=0}^{\infty} \overbrace{R^{-s}(1-\delta)^s}^{\text{Discount}} \cdot \underbrace{\gamma_{t+s}}_{\text{Multiplier}} \cdot \overbrace{\frac{dP_{t+s}}{dQ_{t+s}}}^{\text{Demand Derivative}}$$

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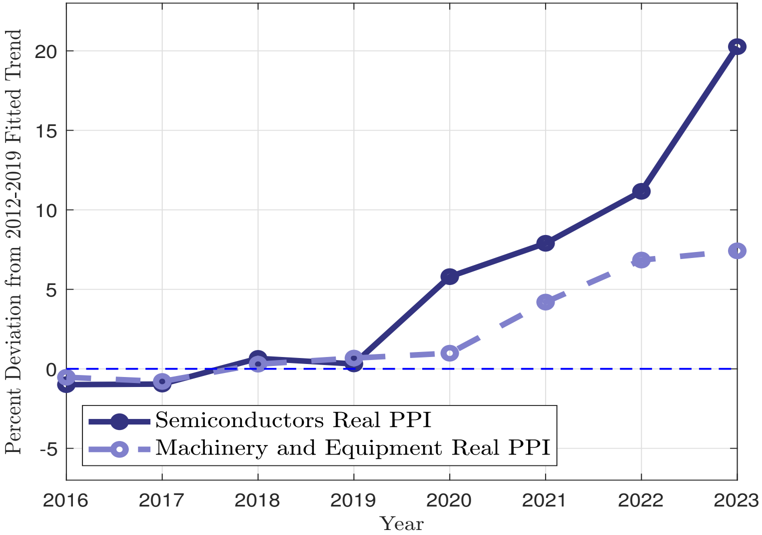
Semicondunductor and Machinery & Equipment PPI



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