Constrained-Efficient Capital Reallocation

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Search and Matching in Macro and Finance (SaMMF)
Virtual Seminar Series

June 7, 2021

Motivation

- Financial frictions (specifically, collateral constraints) distort
  - level of aggregate investment
  - (re)allocation of capital across firms
- Analyze efficiency of capital allocation **subject to** financial frictions
- **Is resale price of capital (collateral) "too high" or "too low"?**

This Paper

- Efficiency analysis in equilibrium model with
  - (macro) investment and capital reallocation
  - (heterogeneity) heterogeneous firms facing idiosyncratic shocks
  - (finance) collateral constraints

- Two types of pecuniary externalities through resale price of capital
  - Collateral externality
    - Higher collateral value facilitates new investment
  - Distributive externality
    - More constrained buy old capital from less constrained
    - Lower price of old capital facilitates purchases of old capital

- Insight: **Distributive externality dominates collateral externality**
  - New investment has positive externality: reduces price of old capital
  - Facilitates reallocation of old capital to more constrained firms
  - Both analytical and quantitative results

Related Literature

- Capital Reallocation
  - Eisfeldt/Rampini (2006, 2007); Lanteri (2018); Rampini (2019); Ma/Murfin/Pratt (2019); Gavazza/Lanteri (forthcoming)
- Pecuniary Externalities
  - Lorenzoni (2008); Dávila/Hong/Krusell/Ríos-Rull (2012); Dávila/Korinek (2018); Bianchi/Mendoza (2018); Itskhoki/Moll (2019); Jeanne/Korinek (2019)
- Financial Frictions and Misallocation
  - Kiyotaki/Moore (1997); Buera/Kaboski/Shin (2011); Midrigan/Xu (2014); Moll (2014)

Outline

(1) Stylized Model: Analytical Results

(2) Quantitative Analysis

(1) Stylized Model

Capital Reallocation and Pecuniary Externalities

Roadmap

- Environment
- First Best
- Competitive Equilibrium with Financial Frictions
- Constrained Efficiency
  - Distributive externality > collateral externality in comp. eqm.
  - Sustaining First Best
- Three Generalizations
- Essential Role of Heterogeneity and Reallocation

Environment

- Time is discrete and horizon infinite
- Infinitely-lived representative household
  - Linear preferences
$$\sum_{t=0}^{\infty} \beta^t C_t$$
- Continuum of firms born at each date t; live for two dates
  - Owned by representative household
  - Each firm draws initial net worth w
    - $w \in W \equiv [w_{min}, w_{max}]$ with distribution $\pi(w)$ (mass 1)
  - Invest at t, produce output at $t + 1$
  - Maximize present value of dividends (net of financing costs)

Capital Goods and Technology

- Capital goods
  - Last for two periods (so "new" and "old")
  - New capital produced using output with linear technology at cost 1
  - (Standard) one period time to build
  - New and old capital perfect substitutes in production
- Firm production

$$y_t(w) = f\left(k^N_{t-1}(w) + k^O_{t-1}(w)\right)$$

with $f_k > 0$ and $f_{kk} < 0$

- Resource constraint (frictionless economy)

$$\int y_t(w) d\pi(w) = C_t + \int k^N_t(w) d\pi(w)$$

- Evolution of aggregate old capital

$$\int k^N_{t-1}(w) d\pi(w) = \int k^O_t(w) d\pi(w)$$

First Best

Social planner maximizes household utility subject to resource constraints

- First-Best allocation satisfies

$$1 = \beta\left(f_k(k_t^{FB}) + q_{t+1}^{FB}\right)$$

$$q_t^{FB} = \beta f_k(k_t^{FB})$$

- Steady state

$$q^{FB} = \frac{1}{1+\beta} \qquad k^{FB} = f_k^{-1}\left(\frac{1}{\beta(1+\beta)}\right)$$

- Allocation of new vs. old capital at firm level is indeterminate

Financial Frictions

- Collateral constraint

$$\theta q_{t+1} k_t^N \geq \beta^{-1} b_t$$

  with $\theta \in [0, 1)$

- Cost of equity issuance $\phi(-d)$
  - increasing and convex for $d < 0$
  - zero otherwise

Competitive Equilibrium with Financial Frictions

- New firm's problem at time t in competitive equilibrium

$$\max_{\{d_{0t}, d_{1,t+1}, b_t, k_t^N, k_t^O\} \in \mathbb{R}^3 \times \mathbb{R}_+^2} d_{0t} - \phi(-d_{0t}) + \beta d_{1,t+1}$$

subject to budget constraints of new firm at t and old firm at $t+1$

$$\begin{aligned} w_{0t} + b_t &= d_{0t} + k_t^N + q_t k_t^O \\ f(k_t^N + k_t^O) + q_{t+1} k_t^N &= d_{1,t+1} + \beta^{-1} b_t \end{aligned}$$

and collateral constraint

$$\theta q_{t+1} k_t^N \geq \beta^{-1} b_t$$

Firm Optimality

- Firms maximize present value of dividends net of cost ϕ subject to
  - budget constraints
  - collateral constraint $(\beta\lambda_t)$
  - non-negativity constraints on k_t^N, k_t^O $(\underline{\nu}_t^N, \underline{\nu}_t^O)$
- First-order conditions w.r.t. k_t^N, k_t^O, b_t

$$
\begin{aligned}
1+\phi_{d,t} &= \beta\left(f_k(k_t)+q_{t+1}\right)+\beta\theta\lambda_t q_{t+1}+\underline{\nu}_t^N \\
q_t(1+\phi_{d,t}) &= \beta f_k(k_t)+\underline{\nu}_t^O \\
1+\phi_{d,t} &= 1+\lambda_t
\end{aligned}
$$

- Marginal value of net worth $1+\phi_{d,t}$

Stationary Competitive Equilibrium

- Definition: Stationary Competitive Equilibrium
  - Policy functions $d_0(w)$, $d_1(w)$, $k^N(w)$, $k^O(w)$, and $b(w)$
  - Price of old capital q

  such that

  - Individual optimality
  - Goods market clearing (including costs of equity issuance)

$$\int y(w)d\pi(w) = C + \int k^N(w)d\pi(w) + \int \phi(d_0(w))d\pi(w)$$

  - Capital goods market clearing

$$\int k^O(w)d\pi(w) = \int k^N(w)d\pi(w)$$

Characterization

Proposition 1

Stationary competitive equilibrium is characterized as follows

(i) *New capital has higher down payment than old capital, but (weakly) lower user cost from perspective of unconstrained firm*

(ii) *Price of old capital exceeds price in frictionless economy:* $q \geq q^{FB}$

(iii) *If* $q > q^{FB}$*, thresholds* $\underline{w}_N < \overline{w}_O < \overline{w}$ *such that*

- *firms with* $w \leq \underline{w}_N$ *invest only in old capital*
- *firms with* $w \in (\underline{w}_N, \overline{w}_O)$ *invest* $\underline{k}$*; invest in both new & old capital*
- *firms with* $w \geq \overline{w}_O$ *invest only in new capital*
- *firms with* $w > \overline{w}$ *pay dividends and invest* $\overline{k} > k^{FB} > \underline{k}$

Choice between New and Old Capital

- New and old capital differ in terms of
  - down payments $\wp_N$ and $\wp_O$

$$\wp_N \equiv 1 - \beta\theta q > \wp_O \equiv q$$

  - user cost (for unconstrained firm)

$$u_N \equiv 1 - \beta q \leq u_O \equiv q$$

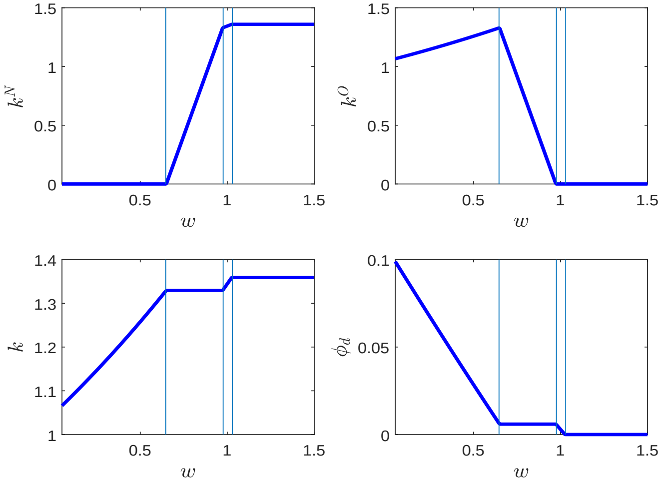
- Investment Euler equations for new and old capital

$$u_N(w) \equiv u_N + \phi_d \wp_N \quad \geq \quad \beta f_k(k)$$

$$u_O(w) \equiv u_O + \phi_d \wp_O \quad \geq \quad \beta f_k(k)$$

- Sufficiently (un)constrained firms invest in old (new) capital

Policy Functions



Parameters

Constrained-Efficient Allocation

- Planner chooses allocations and price to maximize household utility subject to
  - technological constraints

  and
  - individual budget and financial constraints
  - market clearing condition for old capital (η_t)

- First-order conditions w.r.t. k_t^N, k_t^O, b_t

$$
\begin{aligned}
1+\phi_{d,t} &= \beta\left(f_k\left(k_t\right)+q_{t+1}\right)+\beta\theta\lambda_t q_{t+1}+\underline{\nu}_t^N+\beta\eta_{t+1} \\
q_t\left(1+\phi_{d,t}\right) &= \beta f_k\left(k_t\right)+\underline{\nu}_t^O-\eta_t \\
1+\phi_{d,t} &= 1+\lambda_t
\end{aligned}
$$

Lagrangian

Constrained-Efficient Price

- First-order condition w.r.t. price q_t

$$\int k_t^O(w)\left(1+\phi_{d,t}(w)\right)d\pi(w) = \int k_{t-1}^N(w)\left(1+\theta\lambda_{t-1}(w)\right)d\pi(w)$$

or

$$\int k_t^O(w)\left(1+\phi_{d,t}(w)\right)d\pi(w) - \int k_{t-1}^N(w)d\pi(w)$$
$$= \theta \int k_{t-1}^N(w)\lambda_{t-1}(w)d\pi(w)$$

- Using market clearing for capital goods ($\int k_t^O d\pi = \int k_{t-1}^N d\pi$)

$$\int k_t^O(w)\phi_{d,t}(w)d\pi(w) = \theta \int k_{t-1}^N(w)\lambda_{t-1}(w)d\pi(w)$$

- Two types of pecuniary externalities
  - Distributive externality: $k_t^O \phi_{d,t}$
  - Collateral externality: $\theta k_{t-1}^N \lambda_{t-1}$

Externalities in Competitive Equilibrium

Proposition 2

In stationary competitive equilibrium

- *Distributive externality is larger than collateral externality*

$$\int k^O(w)\phi_d(w)d\pi(w) > \theta \int k^N(w)\lambda(w)d\pi(w)$$

- Competitive-equilibrium price of old capital is **higher** than constrained-efficient one

- Intuition: (recall $\lambda(w) = \phi_d(w)$)
  - cov. between mrg. value of net worth and old capital investment

  exceeds
  - cov. between mrg. value of net worth and new capital investment

Constrained-Efficient Allocation: Sustaining First Best

Stationary constrained-efficient allocation achieves First-Best welfare

$$q^* = \frac{w_{min}}{k^{FB}} < q^{FB} \leq q$$

- Price of old capital is low enough that
  - even firms with net worth w_{min} achieve scale k^{FB}
  - without issuing equity: $\phi_d = \lambda = 0$ for all w

Constrained-Efficient Allocation: Implementation

- Competitive equilibrium with taxes $\tau_t^N(w)$, $\tau_t^O(w)$

$$\tau^N = -\beta\eta = -\beta(q^{FB} - q^*) < 0$$

$$\tau^O = \frac{\eta}{q^*} = \frac{q^{FB}}{q^*} - 1 > 0$$

  - Tax rates independent of net worth w

- Taxes rebated lump-sum so as to respect each budget constraint

- Under additional restriction $\tau_t^O(w) = 0$, we show $\tau_t^N(w) < 0$

Tax implementation | Implementation ($\tau^O = 0$)

Three Generalizations

Sign of inefficiency obtains in three generalizations of the model:

- Risk-averse entrepreneurs (Proposition 3) Risk-averse entrepreneurs
  - $u(c_{0t}) + \beta u(c_{1,t+1})$, $u_c > 0$, $u_{cc} < 0$
- Heterogeneity in productivity (Proposition 4) Heterogeneity in productivity
  - $y_t(w) = s\, f\left(k_{t-1}(w)\right)$
  - $\frac{\partial \phi_d(w,s)}{\partial s} \geq 0$
- Long-lived firms and capital (Proposition 5)

Long-Lived Firms and Capital

- Stochastic firm life cycle
  - Probability of firm death ρ
  - Net worth is endogenous state variable
- Long-lived capital
  - Fraction δ^N of new capital becomes old
  - Fraction δ^O of old capital is destroyed
  - Both new and old capital serve as collateral
- Stylized model is special case: $\rho = \delta^N = \delta^O = 1$

Proposition 5

In stationary competitive equilibrium

- *Distributive externality is larger than collateral externality*

Essential Role of Heterogeneity and Reallocation

- Distributive externality hinges on reallocation in equilibrium
  - Stationary equilibrium with reallocation

- Representative entrepreneur in steady state – Kiyotaki/Moore (1997)
  - Assets in fixed supply (land)
  - Entrepreneur has constant amount of land in steady state
  - Misallocation, but no reallocation
  - Change in price of land has no effect on budget constraints
  - Only collateral externality

- Our result obtains with assets in fixed supply and OLG firms
  - Heterogeneity between young and old firms
  - Reallocation of land from old to young firms
  - Distributive externality dominates collateral externality

(2) Quantitative Analysis

Quantitative Model

We generalize assumptions as follows:

- Stochastic life cycle (prob. of death ρ)
- Long-lived capital (δ^N, δ^O)
- Persistent idiosyncratic productivity shocks s
- New and old capital imperfect substitutes in production

$$y = s\ f\left(g(k^N, k^O)\right)$$

where g CES aggregator

- Scrappage value of old capital $\underline{q} \geq 0$

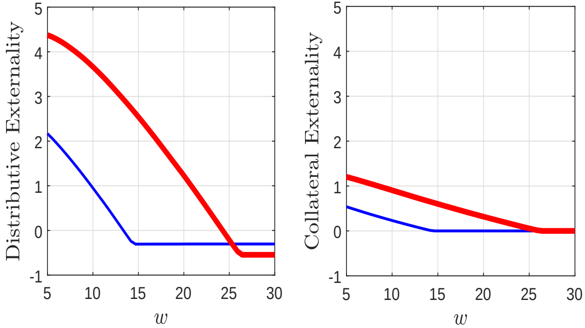
Calibration Strategy

- Technology and shocks
  - Evidence on investment and reallocation dynamics of US firms (Khan/Thomas, 2013; Lanteri, 2018)
- Financial frictions
  - Estimates of financing costs from corporate-finance literature (Hennessy/Whited, 2007; Catherine/Chaney/Huang/Sraer/Thesmar, 2020; Li/Whited/Wu, 2016)
- Capital reallocation
  - Joint distribution of firm age and capital age (Ma/Murfin/Pratt, 2020)

Parameter Values

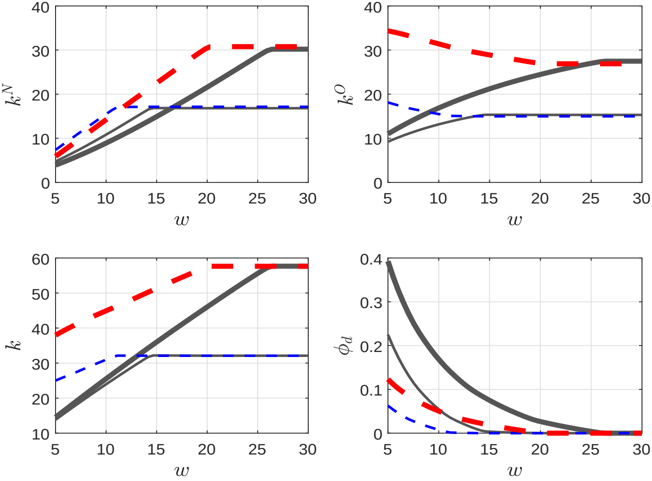
Cross Section of Externalities

$|\text{Distributive externality}| \approx \mathbf{2.3} \times |\text{Collateral externality}|$



Thick red: High productivity. Thin blue: low productivity.

Constrained-Efficient Reallocation



Solid: Competitive Equilibrium. Dashed: Constrained Efficient.

Implementation

Aggregate Outcomes

Variable	Comp. Eqm.	Constr. Eff.	Constr. Eff. ($\tau^O = 0$)
Output	0.899	0.973	0.921
Investment	0.857	0.962	0.893
Consumption	0.933	0.983	0.943
Price q	1.010	0.184	0.987
Average tax τ^N	0	-8.6%	-0.6%
Average tax τ^O	0	103.8%	n.a.

- Allocations and price expressed as fractions of First-Best value

Additional Analyses and Robustness

- Transition dynamics
  - Compute optimal "simple" policy starting from competitive eqm.
  - Optimal time-invariant τ^N for all firms $\approx -0.3\%$ Figure
- Benchmarking gains from capital reallocation
  - Consider restriction: $\frac{k^O(s^a)}{k^N(s^a)} = \omega$
  - Going from restricted to unrestricted competitive equilibrium
  - Approximately 0.4% consumption gain
- Sensitivity analysis
  - Collateralizability θ, elasticity of substitution ϵ, scrap value $\underline{q}$

Conclusion

- Gains from reallocation of old capital
  - High-MPK firms buy old capital
- **Price of old capital in competitive equilibrium is too high**
  - Distributive externality dominates collateral externality
- New investment today makes old capital less scarce in future
  - Positive externality on constrained firms in future
  - Novel rationale for subsidies on new investment

Extra

Lagrangian for Constrained Efficiency

$$
\begin{aligned}
\mathcal{L} \equiv \sum_{t=0}^{\infty} \beta^t \Bigg\{ \int & \left(d_{0t} - \phi(-d_{0t}) + d_{1t} \right) d\pi \\
& - \int \mu_{0t} \left(d_{0t} - w + k_t^N + q_t k_t^O - b_t \right) d\pi \\
& - \int \mu_{1t} \left(d_{1t} - f\left(k_{t-1}^N + k_{t-1}^O \right) - q_t k_{t-1}^N + \beta^{-1} b_{t-1} \right) d\pi \\
& + \int \lambda_t \left(\beta \theta q_{t+1} k_t^N - b_t \right) d\pi \\
& + \int \underline{\nu}_t^N k_t^N d\pi + \int \underline{\nu}_t^O k_t^O d\pi - \eta_t \left(\int k_t^O d\pi - \int k_{t-1}^N d\pi \right) \Bigg\}
\end{aligned}
$$

Back

Lagrangian for Constrained Efficiency: New Subsidies Only

$$
\begin{aligned}
\mathcal{L} \equiv \sum_{t=0}^{\infty} \beta^t \Bigg\{ & \int \left(d_{0t} - \phi(-d_{0t}) + d_{1t}\right) d\pi \\
& - \int \mu_{0t} \left(d_{0t} - w + k_t^N + q_t k_t^O - b_t\right) d\pi \\
& - \int \mu_{1t} \left(d_{1t} - f\left(k_{t-1}^N + k_{t-1}^O\right) - q_t k_{t-1}^N + \beta^{-1} b_{t-1}\right) d\pi \\
& + \int \lambda_t \left(\beta\theta q_{t+1} k_{t+1}^N - b_t\right) d\pi \\
& + \int \psi_t \left(q_t(1+\phi_{d,t}) - \beta f_k(k_t)\right) d\pi \\
& + \int \underline{\nu}_t^N k_t^N d\pi + \int \underline{\nu}_t^O k_t^O d\pi - \eta_t \left(\int k_t^O d\pi - \int k_{t-1}^N d\pi\right) \Bigg\}
\end{aligned}
$$

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Numerical Example

Table: Parameter Values

		Parameter	Value
Preferences	Discount rate	β	0.96
Net worth	Uniform $\pi(w)$	w_{min}	0.05
		w_{max}	1.5
Technology	Curvature of f	α	0.6
Financial constraints	Collateralizability	θ	0.5
	Cost of equity	ϕ_0	0.1
		ϕ_1	2

- Functional forms: $f(k) = k^{\alpha}$; $\phi(-d) = \phi_0(-d)^{\phi_1}$ for $d < 0$

Back

Covariance Interpretation

Interpretation: covariance between net expenditure and marginal value of net worth

- We show that
$$\mathrm{Cov}(k^O, \phi_d) > \mathrm{Cov}(k^N, \phi_d)$$
- Also, $\mathrm{Cov}(k^N, \phi_d) < 0$
- Typically (and in our example), $\mathrm{Cov}(k^O, \phi_d) > 0$

Implementation

- Competitive equilibrium with
  - proportional taxes on new and old capital $\tau_t^N(w)$, $\tau_t^O(w)$
  - rebated lump-sum to each firm, so as to not to redistribute resources
- Budget constraint

$$w + b_t = d_{0t} + k_t^N(1 + \tau_t^N) + q_t k_t^O(1 + \tau_t^O) - T_t$$

- Lump-sum transfer

$$T_t = \tau_t^N k_t^N + \tau_t^O q_t k_t^O$$

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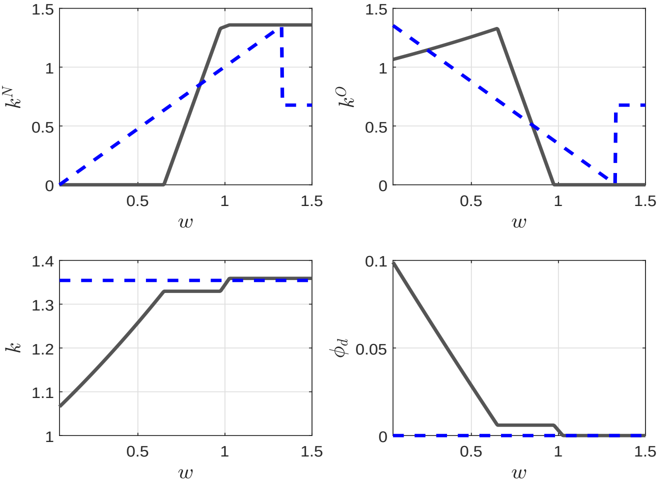
Constrained-Efficient Reallocation



Solid: Competitive Equilibrium. Dashed: Constrained Efficient.

New-Capital Subsidies Only

Introduce additional constraint: old capital cannot be taxed

$$q_t(1+\phi_{d,t}) \geq f_k(k_t)$$

with multiplier ψ_t

Lagrangian Back

Constrained Efficiency: New-Capital Subsidies Only

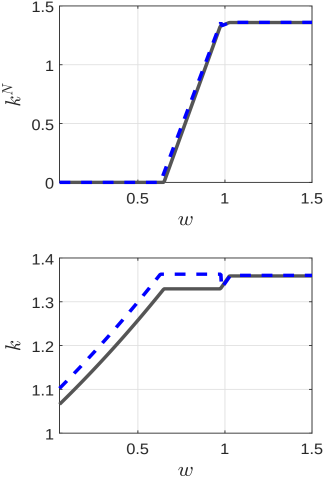
- FOC wrt k^N_{t+1}

$$1 + \phi_{d,t} = \beta\left(f_k(k_t) + q_{t+1}\right) + \beta\theta\lambda_t q_{t+1} + \beta\eta_{t+1} + \psi_t\left(q_t\phi_{dd,t} - \beta f_{kk}(k_t)\right)$$

- FOC wrt q_t

$$\int k^O_t(1 + \phi_{d,t})d\pi = \int k^N_{t-1}(1 + \theta\lambda_{t-1})d\pi + \int \psi_t(1 + \phi_{d,t} + q_t\phi_{dd,t}k^O_t)d\pi$$

Constrained-Eff. Reallocation: New-Capital Subsidies Only



Solid: Competitive Equilibrium. Dashed: Constrained-Efficient.

Back

Risk-Averse Entrepreneurs

- Entrepreneurs maximize $u\left(c_{0t}\right)+\beta u\left(c_{1,t+1}\right)$, $u_c > 0, u_{cc} < 0$

Proposition 6

In stationary competitive equilibrium

- *Distributive externality is larger than collateral externality*

$$\int k^O(w) u_c\left(c_0(w)\right) d\pi(w) > \int k^N(w)\left[u_c\left(c_1(w)\right)+\theta\lambda(w)\right] d\pi(w)$$

Back

Heterogeneity in Productivity

- Joint distribution of net worth w and productivity s, $\pi(w, s)$
- Production $y_t = s\, f(k^N_{t-1} + k^O_{t-1})$
- We show $\frac{\partial \phi_d(w,s)}{\partial s} \geq 0$

Proposition 7

In stationary competitive equilibrium

- *Distributive externality is larger than collateral externality*

$$\int k^O(w, s)\phi_d(w, s) d\pi(w, s) > \theta \int k^N(w, s)\lambda(w, s) d\pi(w, s)$$

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Quantitative Model: Net Worth and Collateral Constraint

- Net worth evolution

$$w_t(s^a) = s_a f(k_{t-1}(s^{a-1})) + (1 - \delta^N(1 - q_t))k^N_{t-1}(s^{a-1}) + q_t(1 - \delta^O)k^O_{t-1}(s^{a-1}) - \beta^{-1}b_{t-1}(s^{a-1})$$

- Collateral constraint

$$\theta \left[(1 - \delta^N(1 - q_{t+1}))k^N_t(s^a) + q_{t+1}(1 - \delta^O)k^O_t(s^a)\right] \geq \beta^{-1}b_t(s^a)$$

Quantitative Model: Market Clearing

- Market clearing for old capital

$$\sum_{a=0}^{\infty} \gamma_a \sum_{s^a} p(s^a) k_t^O(s^a) = \sum_{a=0}^{\infty} \gamma_a \sum_{s^a} p(s^a) \left[\delta^N k_{t-1}^N(s^a) + (1 - \delta^O) k_{t-1}^O(s^a) \right]$$

Quantitative Model: Constrained-Efficient Allocation

- FOC wrt $k_t^N(s^a)$

$$\begin{aligned} 1+\phi_{d,t} &= \\ \beta\mathbb{E}_t &\left[s_{a+1} f_k(k_t) g_{N,t} + (1-\delta^N(1-q_{t+1}))\right](1+(1-\rho)\phi_{d,t+1}) \\ &\qquad + \beta\theta\lambda_t(1-\delta^N(1-q_{t+1})) + \beta\delta^N \eta_{t+1} \end{aligned}$$

- FOC wrt $k_t^O(s^a)$

$$\begin{aligned} q_t(1+\phi_{d,t}) &= \\ \beta\mathbb{E}_t &\left[s_{a+1} f_k(k_t) g_{O,t} + (1-\delta^O) q_{t+1}\right](1+(1-\rho)\phi_{d,t+1}) \\ &\qquad + \beta\theta(1-\delta^O)\lambda_t q_{t+1} - \eta_t + \beta(1-\delta^O)\eta_{t+1} \end{aligned}$$

- FOC wrt $b_t(s^a)$

$$\phi_{d,t} = (1-\rho)\mathbb{E}_t \phi_{d,t+1} + \lambda_t$$

Quantitative Model: Constrained-Efficient Price

- FOC wrt q_t

$$\sum_{a=0}^{\infty} \gamma_a \sum_{s^a} p(s^a) k_t^O (1 + \phi_{d,t}) \geq$$

$$\sum_{a=0}^{\infty} \gamma_a \sum_{s^{a+1}} p(s^{a+1}) \left(\delta^N k_{t-1}^N + (1 - \delta^O) k_{t-1}^O \right) (1 + (1-\rho)\phi_{d,t} + \theta \lambda_{t-1})$$

Back

Solving for Constrained Efficiency

- Guess shadow value of old capital η
  - Guess price q
  - Compute policy functions solving investment FOCs on grid for (w, s)
  - Compute stationary distribution $\pi(w, s)$
  - Check market clearing and update q
- Evaluate externalities (FOC wrt q) and update η

Back

Calibration

	Parameter	Value
Discount rate	β	0.96
Initial net worth	w_0	5
Death probability	ρ	0.1
Curvature of production function	α	0.6
CES elasticity of substitution	ϵ	5
CES new share	ν	0.5
Depreciation new	δ^N	0.2
Depreciation old	δ^O	0.2
Scrap value	$\underline{q}$	0.1
Productivity persistence	χ_s	0.7
Productivity st. dev. of innovations	σ_s	0.12
Collateralizability	θ	0.5
Cost of raising equity	ϕ_0	0.1
	ϕ_1	5

- Functional forms: $f(k) = k^{\alpha}$; $\phi(-d) = \phi_0(-d)^{\phi_1}$ for $d < 0$

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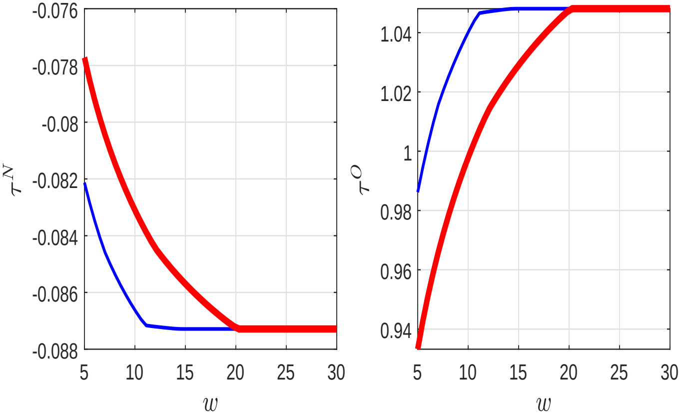
Implementation



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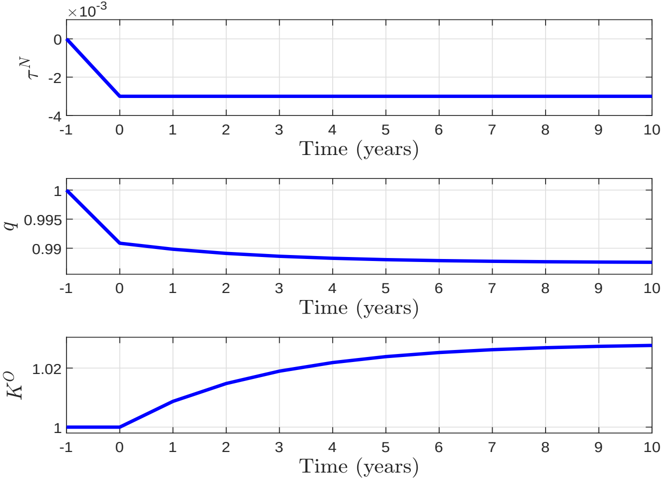
Transition Dynamics



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