Limits to Innovation
Plenary Lecture

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Firm level perspectives on innovation

- *Innovation by firms* — important unmeasured capital stock that contributes to aggregate productivity
  - patents
  - R&D expenditures
  - organization capital
  - new products

- *Innovation Policy* — alters the costs of or incentives to invest in innovation
  - patent policy
  - tax treatment of R&D expenditures
  - market structure
  - entry costs
  - international trade costs
Innovation Policy and Innovation

• *How does innovation policy affect innovation?*

• Large empirical literature documents the responsiveness of firms’ innovative activity to changes in the costs of or incentives to innovate.

• Studies the impact of innovation policy on innovation at the firm or industry level

• Documents at the microeconomic level that innovation is indeed responsive to economic incentives.
Examples of such research

- Recent titles of working papers from the NBER Productivity series
- Half a Century of Public Software Institutions: Open Source as a Solution to Hold-Up Problem
- Business and Financial Method Patents, Innovation, and Policy
- Innovation and Institutional Ownership
- R&D Investment, Exporting, and Productivity Dynamics
- Private Equity and Long-Run Investment: The Case of Innovation
Innovation Policy and Aggregate Productivity

• How does innovation policy affect aggregate productivity?

• What is the impact of a change in innovation policy on aggregate productivity in the long run in general equilibrium?

• How do we aggregate the impact on aggregate productivity of all the changes in individual firm’s innovative investments?

• Does the current empirical literature on innovation policy and innovation by firms help us answer this question?

• Is the elasticity of firms’ investments in innovation to changes in the costs of or incentives to innovate a key parameter in this calculation?

• Today, I argue that for an important baseline case: No.
The Limits to Innovation

- Macroeconomic forces limit the impact of a change in innovation costs on aggregate productivity. To a first order approximation, induced changes in firms’ innovative investments do not affect the answer to the question of how a change in innovation costs impacts aggregate productivity.

- In our model, firms engage in two types of innovation:
  - *Process Innovation* investments to reduce the marginal cost of production of an existing product (can be interpreted as quality).
  - *Product Innovation* Investments to create new products.

- The response of aggregate productivity is pinned down by the direct subsidy to firm profits from the change in innovation costs.

- If process innovation is highly elastic, product innovation simply adjusts to offset that effect on aggregate productivity.
The Limits to Innovation

- Focus on steady-states of a stylized, one sector, closed economy model of innovation by firms
- Impact on aggregate productivity of changes in resource costs of process innovation
- Paper provided focuses on an open economy model — trade costs and innovation
- Ongoing work examines taxes/subsidies, multi-sector models, etc.
- Abstract from spillovers
- Contrast with Quality Ladder type models
Plan for Talk

- Describe Model
  - Define goods and describe production and aggregation
  - Variable Profits and Aggregate Productivity
  - Process Innovation and the value of a variety
  - Product Innovation
  - Free Entry, Equilibrium Process Innovation and Variable Profits
  - The allocation of labor between production and research in steady-state when interest rates are low
  - Solving for aggregate productivity in the steady-state

- What happens to steady-state aggregate productivity when the costs of process innovation change?
  - An envelope condition

- Extensions

- Conclude
Model: Final Goods

- **Final good** produced via a CES aggregate of a continuum of size $N_t$ of intermediate goods. Price of final good normalized to one.

\[ Y_t = \left( \int_0^{N_t} y_{it}^{(\rho-1)/\rho} di \right)^{\rho/(\rho-1)} \]

- Final good consumed $C_t$ and used for investment $X_t$ in innovation

\[ C_t + X_t = Y_t \]

- **Research good** (input into innovation) produced with labor and final good. Price of research good $P_{rt}$

\[ Y_{rt} = L_{rt}^{\lambda} X_t^{(1-\lambda)} \]

- Assume $\rho + \lambda > 2$ to ensure finite production
Model: Intermediate Goods and Productivity

- Monopolistically competitive firms have productivity (or quality) indexed by \( \exp(z) \) and produce intermediate goods using labor.

\[ y_{it} = \exp(z_{it})^{1/(\rho-1)} l_{it} \]

- Productivity: \( N_t \) number of firms/varieties. \( Z_t \) index of \textit{average productivity}

\[ Z_t = \frac{1}{N_t} \int_0^{N_t} \exp(z_{it}) \, di \]

- Index of \textit{Aggregate Productivity} \( N_t Z_t \)
Model: Labor and Entry/Exit

- Labor market clearing production labor $L_{pt}$ and research labor $L_{rt}$

\[ L_{pt} = \int_0^{N_t} l_{it} dt \]

\[ L_{pt} + L_{rt} = 1 \]

- Varieties die at exogenous rate $\delta$. Number of new varieties that enter $M_t$

\[ N_{t+1} = (1 - \delta) (N_t + M_t) \]
Model: Variable Profits

- Facing CES demand, firms charge a fixed markup over marginal cost (wages divided by productivity).

- Variable profits depend on productivity, wages, and the scale of final goods production through a scale factor $\Pi_t$ and the productivity index $\exp(z)$

$$p_i t y_{it} - W_t l_{it} = \Pi_t \exp(z_{it})$$

$$\Pi_t = \rho^{-\rho}(\rho - 1)^{\rho-1} W_t^{1-\rho} Y_t$$

- Key relationship between firm profitability and equilibrium wages and output
Variable Profits and Aggregate Productivity

- Standard aggregation in equilibrium gives final good production and wages

\[ Y_t = (N_t Z_t)^{1/(\rho-1)} L_{pt} \]

\[ W_t = \frac{\rho - 1}{\rho} (N_t Z_t)^{1/(\rho-1)} \]

- Cost minimization in production of research good implies price reflects labor intensity of research good

\[ P_{rt} = \frac{1}{\lambda^\lambda (1 - \lambda)^{(1-\lambda)}} W_t^\lambda \]

- Key equilibrium relationship between firm profitability, aggregate productivity and production labor

\[ \frac{\Pi_t}{P_{rt}} = \kappa \frac{(N_t Z_t)^{(2-\rho-\lambda)/(\rho-1)}}{L_{pt}} \]
Firms invest research good in *process innovation* to increase productivity (or quality) of an existing variety.

Convex cost in terms of research good of raising productivity. Proportional cost of fixed growth in productivity. (Costs scale with $\exp(z)$)

- $D$ cost parameter. $P_r$ relative price of research good.

\[
P_r Dc \left( \exp(g_{zt}) \right) \exp(z_{it})
\]

\[
\exp(z_{it+1}) = \exp(g_{zt}) \exp(z_{it})
\]

In steady-state, Bellman equation for optimal process innovation and value of a variety

\[
V(z) = \max_{g_z} \left[ \Pi - P_r D \exp(g_z) \right] \exp(z) + \beta (1 - \delta) V(z + g_z)
\]
Optimal Process Innovation

- In steady-state, value of variety is growing perpetuity of variable profits less process innovation costs

\[ V(z) = \frac{\exp(z)}{1 - \beta(1 - \delta) \exp(g_z)} \left[ \Pi - P_r Dc(\exp(g_z)) \right] \]

- Scale independent optimal investment in process innovation \( g_z \)

\[ Dc'(\exp(g_z)) = \frac{\beta(1 - \delta)}{1 - \beta(1 - \delta) \exp(g_z)} \left[ \frac{\Pi}{P_r} - Dc(\exp(g_z)) \right] \]

- Process innovation increasing in variable profits less process innovation costs
Product Innovation and Free Entry

- Firms can create a new variety with initial productivity $\bar{z}$ by investing $n_e$ units of research good.

- Steady-state free entry condition

$$P_r n_e = \beta (1 - \delta) V(\bar{z})$$

- Free entry pins down scale of variable profits less process innovation costs

$$n_e = \frac{\beta (1 - \delta) \exp(\bar{z})}{1 - \beta (1 - \delta) \exp(g_z)} \left[ \frac{\Pi}{P_r} - Dc(\exp(g_z)) \right]$$
Free Entry, Equilibrium Process Innovation, Average Productivity and Variable Profits

• Free Entry and first order condition for process innovation gives solution for equilibrium process innovation

\[ Dc'(\exp(g^*_z)) = \frac{n_e}{\exp(\bar{z})} \]

• In steady-state, average productivity determined by process innovation \( g^*_z \)

\[ Z = \delta \frac{\exp(\bar{z})}{1 - (1 - \delta) \exp(g^*_z)} \]

• And free entry also pins down equilibrium variable profits

\[ n_e = \frac{\beta (1 - \delta) \exp(\bar{z})}{1 - \beta (1 - \delta) \exp(g^*_z)} \left[ \frac{\Pi}{P_r} - Dc(\exp(g^*_z)) \right] \]
The Story So Far

- Static profit maximization and aggregation give relationship between the scale of variable profits, aggregate productivity, and the allocation of labor

\[
\frac{\Pi}{P_r} = \kappa (NZ)^{(2-\rho-\lambda)/(\rho-1)} L_p
\]

- Free Entry gives optimal process innovation \( g^*_z \), average productivity \( Z \), and the scale of equilibrium variable profits

\[
n_e = \frac{\beta (1-\delta) \exp(\bar{z})}{1 - \beta (1-\delta) \exp(g^*_z)} \left[ \frac{\Pi}{P_r} - Dc(\exp(g^*_z)) \right]
\]

- Next we solve for \( L_p \). Then these two equations give us the number of firms \( N \) and aggregate productivity \( NZ \) as a function of model parameters
The Allocation of Labor

• Solve for $L_p$ and $L_r$ when the real interest rate is zero ($\beta = 1$)

• Constant markups (CES) implies production wage bill $WL_p$ constant fraction of total variable profits

• Cobb-Douglas production of research good implies research wage bill $WL_r$ constant fraction of total expenditure on research good.

• Zero interest rate ($\beta = 1$) implies no economic profits in steady-state: total variable profits equals total expenditure on research good.

• Thus steady-state allocation of labor fixed with zero interest rate

$$\frac{L_p}{L_r} = \frac{\rho - 1}{\lambda}$$
Aggregate Productivity $NZ$ in Steady-State

- Downward sloping relationship between scale of variable profits and aggregate productivity

\[
\frac{\Pi}{\bar{P}_r} = \kappa (NZ)^{(2-\rho-\lambda)/(\rho-1)} \bar{L}_p
\]

- Free Entry gives optimal process innovation $g_z^*$, average productivity $Z$, and the scale of equilibrium variable profits

\[
\frac{\Pi}{\bar{P}_r} = n_e \frac{1 - (1 - \delta) \exp(g_z^*)}{(1 - \delta) \exp(\bar{z})} + Dc(\exp(g_z^*))
\]
Comparative Statics Across Steady-States: A Change in Process Innovation Costs $D$

- Downward sloping relation between change in scale of variable profits and change in aggregate productivity

\[
\Delta \log \left( \frac{\Pi}{P_r} \right) = \left( \frac{2 - \rho - \lambda}{\rho - 1} \right) \Delta \log (NZ)
\]

- *Envelope condition* — $g^*_z$ optimal — implies first order change in scale of variable profits equals direct impact of change in $D$ on profits holding $g^*_z$ fixed.

\[
\Delta \log \left( \frac{\Pi}{P_r} \right) = \left( \frac{Dc(\exp(g^*_z))}{\Pi/P_r} \right) \Delta \log D
\]

- *Elasticity of process innovation* $g^*_z$ with respect to change in costs $D$ is irrelevant for first order effect on aggregate productivity
Product and Process Innovation Offset

• What happens if process innovation is elastic?

• Change in process innovation determined by differentiating first order condition for $g_z^*$

$$\frac{c''(\exp(g_z^*))\exp(g_z^*)}{c'(\exp(g_z^*))} \Delta g_z^* = \Delta \log D$$

• Average productivity changes, perhaps by a lot.

$$\Delta \log Z = \frac{(1 - \delta) \exp(g_z^*)}{1 - (1 - \delta) \exp(g_z^*)} \Delta g_z^*$$

• But, in steady-state, this has no impact on aggregate productivity. Product innovation $N$ simply adjusts as required to offset this change in average productivity.

• Micro evidence on $\Delta g_z^*$ not relevant for aggregate productivity
What are the Limits to Innovation?

• Baseline case with zero interest rate has fixed allocation of labor

• Research good labor intensive ($\lambda > 0$), and demand elastic ($\rho > 2 - \lambda$) implies increases in aggregate productivity ($NZ$) drive down variable profits denominated in units of the research good ($\Pi/P_r$).

• This effect of increased competition, with free entry, limits equilibrium aggregate productivity

• Envelope condition/optimality of process innovation implies impact of innovation cost changes on equilibrium variable profits determined only by direct effect of cost on profit — same as direct subsidy to profits of operating firms.

• Process innovation only one type of innovation. If it is elastic, product innovation simply adjusts to offset its effect on aggregate productivity.
Extensions I

• Straightforward extension to change in entry cost $n_e$

• Positive interest rates: Economic profits in steady-state. Aggregate allocation of labor changes. Comparative statics need to be computed numerically. Still have offset between process and product innovation, but not longer exact.

• Innovation taxes and subsidies (as opposed to resource costs). Envelope condition no longer holds. "Harberger triangles". Also changes in aggregate allocation of labor.

• Multiple sectors or industries. Limits to sectoral productivity in steady-state still determined by macroeconomic considerations. Elasticity of process innovation at the firm level not relevant for comparative statics.
Extensions II: Endogenous Growth

- Research good not labor intensive \((\lambda = 0)\). “Lab Equipment” model. Endogenous growth through growth in varieties. Answers TBD.

- Spillovers? Lots of possibilities depending on exact specification of the spillover. Average productivity? Total productivity? Number of varieties? Do they affect all types of innovation equally? Need research on precise nature of spillovers.

- Contrast with Quality Ladders Model. No process innovation. Endogenous growth through 100% spillover from average productivity to productivity of entering varieties \((\bar{z})\). No aggregate expansion of varieties as economy grows. Can our framework be extended to encompass this model?
Conclusion

- To evaluate the impact of innovation policy on aggregate productivity, an aggregate, or macroeconomic framework is needed.

- Analogy to public finance study of physical capital taxes — no use for microeconomic studies of elasticity of investment with respect to changes in capital taxes.

- Equivalence of alternative innovation policies. To a first order approximation, any two policies that provide the same direct subsidy to firm profits have the same impact on aggregate productivity.

- Would it be simpler just to subsidize production?