Growth Through Product Creation

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Issues

- We study a GE model of growth driven by innovation.
- Innovation takes the form of inventing new goods.
- Alternative: Quality ladders.

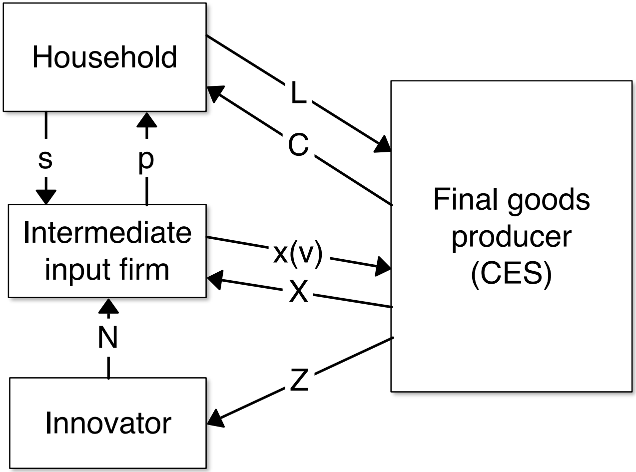
A Model of Product Innovation

Agents:

1. A representative **household** supplies labor to firms
2. **Final** goods firms use labor and intermediate inputs
3. **Intermediate** inputs are produced from final goods
4. **Innovators** create new intermediates from final goods
   receive permanent monopolies

Note: Now that models get more complicated, it really pays off to be pedantic about details.

Model structure



Demographics and Preferences

Demographics:

- A representative household.

Preferences:

$$\int_0^\infty e^{-\rho t} \, \frac{C_t^{1-\theta} - 1}{1-\theta} dt \tag{1}$$

- C: the final good

Technology: Final Goods

Resource constraint:

$$C_t + X_t + Z_t = Y_t$$

Final goods Y are used for

- Z: R&D investment.
- X: Inputs into the production of intermediates x.
- C: consumption

Technology: Final Goods

Production of **final goods** from intermediates and labor:

$$Y_t = (1-\beta)^{-1} \left[\int_0^{N_t} x(v,t)^{1-\beta} \, dv \right] L^\beta \tag{2}$$

This is of the Dixit-Stiglitz form:

Write $\left[\int x^{1-\beta} dv\right]^{\frac{1-\beta}{1-\beta}}$ to see that this is a CES aggregator of x.

Technology: Intermediate Inputs

Each unit of x requires ψ units of Y:

$$X = \psi \int_0^{N_t} x(v,t)\, dv \tag{3}$$

Intermediate inputs fully depreciate in use.

Technology: Innovation

Investing the final good yields a flow of new patents:

$$\dot{N} = \eta Z_t \tag{4}$$

Think of this as the aggregate (deterministic) outcome of the (stochastic) innovation efforts of many firms.

Market arrangements

- Final goods and labor markets are competitive.
- Intermediates are sold by **monopolists** (the innovators).
  - Monopolies are permanent.
  - What the monopolists do with their profits is not clear.
- Free entry into innovation
  - ensures zero present value of profits
- The household owns the innovating firms.
- Asset markets are complicated
  - there is often no need to spell out the details

Notes

Production is cyclical:

- today's Y is used to make X which makes Y
- the alternative: durable X (more complicated)
- implication: the efficient allocation maximizes $Y - X = C + Z$

The only long-lived object is a patent

- this keeps the model simple

Assuming that intermediates are made from final goods fixes marginal costs (and prices)

Solving Each Agent's Problem

Final goods producers

- Maximize period profits by choosing L and $x(v,t)$.
- Normalize the price Y to 1.
- Profits

$$Y_t - w_t L_t - \int_0^{N_t} p^x(v,t)\ x(v,t)\, dv \tag{5}$$

where

$$Y_t = (1-\beta)^{-1} \left[\int_0^{N_t} x(v,t)^{1-\beta}\, dv \right] L^{\beta} \tag{6}$$

Final goods producers

FOCs:

- $\partial Y/\partial x(v) = L^{\beta} x(v)^{-\beta} = p^{x}(v)$
- $\partial Y/\partial L = \beta Y/L = w$

Demand function (cf. the Dixit Stiglitz discussion):

$$x(v,t) = L\, p^{x}(v,t)^{-1/\beta} \tag{7}$$

Solution to the firm's problem: $L_t, x(v,t)$ that satisfy the "2" first-order conditions.

Intermediate input producers

Problem after inventing a variety.

x is produced at constant marginal cost ψ.

Maximize present value of profits

$$V(v,t) = \int_t^\infty e^{-rs} \pi(v,s)\, ds \tag{8}$$

Instantaneous profits are

$$\pi(v,t) = (p^x(v,t) - \psi)\; x(v,t) \tag{9}$$

where $x(v,t) = Lp^x(v,t)^{-1/\beta}$

This is a sequence of static problems

Intermediate input producers

- First order condition (standard monopoly pricing formula):

$$p^x = \psi / (1 - \beta) \tag{10}$$

- Profits are

$$\pi(v,t) = \psi \frac{\beta}{1-\beta} x(v,t) \tag{11}$$

- Solution: A constant p^x.

Household

- The household holds shares of all intermediate input firms.
- Each firm produces a stream of profits.
- New firms issue new shares.
- But: the details don't matter to the household.
- There simply is an asset with rate of return r.
- Euler equation is standard:

$$g(C) = \frac{r - \rho}{\theta} \tag{12}$$

- Invoke Walras' law - so you never have to write down the budget constraint!

Equilibrium

- Objects: $C_t, X_t, Z_t, x(v,t), V(v,t), N_t$ and prices $p^x(v,t), r(t), w(t)$.
- Conditions:
  - "Everybody maximizes." (see above)
  - Markets clear.
    1. Goods: resource constraint.
    2. Shares: omitted b/c I did not write out the household budget constraint.
    3. Intermediates: implicit in notation.
  - Innovation effort satisfies a **free entry** condition: present value of profits equals 0.

Symmetric Equilibrium

We assume (and then show) that all varieties v share the same x, V and p^x.

Intuition:

- p^x: monopoly pricing with a constant elasticity
- x: varieties enter final goods production symmetrically
- V: the age of a variety does not matter
  (no stock of x to build; permanent patents)

Simplifications

Normalize marginal cost $\psi = 1 - \beta$

- so that $p^x = 1$.
- Why can I do that?

Focus on balanced growth paths.

Equilibrium: Characterization

There is an algorithm ...

- The growth rate follows from the Euler equation: $g(C) = (r - \rho)/\theta$.
- We get r from free entry by innovators: present value of profits = cost of creating a variety.

Equilibrium: Characterization

Free entry will determine the interest rate

Spend 1 to obtain η new patents, each valued (initially) at $V(v,t)$

$$\eta V(v,t) = 1 \tag{13}$$

- Then V is constant over time.
- This assumes that innovation takes place.

With balanced growth and constant profits (to be shown):

$$V = \pi/r \tag{14}$$

Profits

With a fixed markup, profits are a multiple of revenues:

$$\begin{aligned} \pi(t) &= \psi \frac{\beta}{1-\beta} x(t) && (15) \\ &= \beta x(t) && (16) \end{aligned}$$

Demand for intermediates:

$$\begin{aligned} x(t) &= L\, p^x(t)^{-1/\beta} \\ &= L \end{aligned}$$

Profits: $\pi = \beta L$.

Free Entry

- Free entry:

$$\eta V = \eta \beta L / r = 1 \tag{17}$$

- This is the closed form solution for r.
- Balanced **growth** rate then follows from the Euler equation.

$$g(C) = \frac{\eta \beta L - \rho}{\theta} \tag{18}$$

Equilibrium: Characterization

Production function for final goods with $x = L$:

$$Y = \frac{N_t L}{1-\beta} \tag{19}$$

Wage (from firm's FOC):

$$w_t = \beta \frac{Y_t}{L_t} = \frac{\beta}{1-\beta} N_t \tag{20}$$

Total expenditure on intermediates:

$$X_t = \psi N_t x_t = (1-\beta) N_t L \tag{21}$$

Summary of Equilibrium

Prices and quantities of intermediate inputs are constant.

- the model is rigged to deliver this
- for tractability

Growth comes from rising N

No Transition Dynamics

The equilibrium looks like an AK model with production function

$$\begin{aligned} Y_t &= \frac{L}{1-\beta} N_t \\ \dot{N}_t &= \eta \; s_z \; Y_t \end{aligned}$$

Intuition:

- Period profits π are constant at βL.
- At any moment we need $\eta V = 1$.
- V is the present value of (constant) profits.
- Constant V is only possible with constant r.
- Intuition: There is a reduced form AK structure.

Scale Effects

$$g(C) = \frac{\eta \beta L - \rho}{\theta}$$

Larger economies (L) grow faster.

Population growth implies exploding income growth (!)

Mechanical reason:

- Innovation technology is linear in goods.
- Larger economy $\rightarrow$ higher Y $\rightarrow$ higher Z $\rightarrow$ faster growth.

We will return to this later.

Pareto Efficient Allocation

Efficiency

Two distortions prevent efficiency of equilibrium:

1. Monopoly pricing.
2. Inefficient innovation due to aggregate demand externality.

Planner's Problem

Solve in two stages:

1. Given N, find optimal static allocation $x(v,t)$.
   - That is: maximize $Y - X$ which is available for consumption and investment.
   - An odd feature of the model: goods are produced from goods without delay.
2. Given the reduced from production function from #1, find optimal Z.

Static Allocation

Given N, choose $x(v,t)$ to maximize $Y - X$:

$$\max (1-\beta)^{-1} L^{\beta} \int_0^{N_t} x(v,t)^{1-\beta} dv - \int_0^{N_t} \psi x(v,t) dv \tag{22}$$

First-order condition

$$L^{\beta} x^{-\beta} = \psi \tag{23}$$

with $\psi = 1-\beta$:

$$x = (1-\beta)^{-1/\beta} \; L \tag{24}$$

The planner's x is larger than the equilibrium x (Intuition?)

Static Allocation

Next: find $Y - X$.

$$X = \psi N x = (1-\beta) N (1-\beta)^{-1/\beta} L \tag{25}$$

Reduced form production function:

$$\begin{aligned} Y_t &= (1-\beta)^{-1} L^{\beta} N [(1-\beta)^{1-1/\beta} L]^{1-\beta} \quad (26) \\ &= (1-\beta)^{-1/\beta} L N_t \quad (27) \end{aligned}$$

Net output

$$\begin{aligned} Y - X &= (1-\beta)^{-1/\beta} LN - (1-\beta)^{1-1/\beta} LN \\ &= (1-\beta)^{-1/\beta} \beta \; L \; N \quad (28) \end{aligned}$$

Planner: Dynamic Optimization

$$\max \int_0^\infty e^{-\rho t} \frac{C_t^{1-\theta} - 1}{1-\theta} dt$$

subject to

$$\begin{aligned} \dot{N} &= \eta Z \\ Y &= (1-\beta)^{-1/\beta} \ \beta \ L \, N = C + Z \end{aligned}$$

Or

$$\begin{aligned} \dot{N} &= A \ N - \eta C && (29) \\ A &= \eta \, (1-\beta)^{-1/\beta} \ \beta \ L && (30) \end{aligned}$$

Hamiltonian

$$H = \frac{C^{1-\theta} - 1}{1-\theta} + \mu \left[AN - \eta C \right] \quad (31)$$

FOC

$$\begin{aligned} \partial H / \partial C &= C^{-\theta} - \mu \eta = 0 \quad (32) \\ \partial H / \partial N &= \rho \mu - \dot{\mu} = \mu A \quad (33) \end{aligned}$$

Optimal growth

The same as in an AK model with

$$A = \eta \left(1-\beta\right)^{-1/\beta} \ \beta \ L \tag{34}$$

we have

$$\dot{C}/C = \frac{A-\rho}{\theta} \tag{35}$$

Comparison with CE

- CE interest rate: $\eta\beta L$.
- Planner's "interest rate:" $(1-\beta)^{-1/\beta}\eta\beta L$.
- The planner chooses faster growth.
- Intuition:
  - CE under-utilizes the fruits of innovation: x is too low.
  - This reduces the value of innovation.

Policy Implications

- One might be tempted to reduce monopoly power.
- A policy that encourages competition (e.g. less patent protection, forcing lower p^x) reduces the static price distortion.
- But it also reduces growth: innovation is less valuable.
- Similar result for shorter patents.
- Policy trades off static efficiency and incentives for innovation.

Reading

- Acemoglu (2009), ch. 13.
- Krusell (2014), ch. 9
- Romer (2011), ch. 3.1-3.4.
- Jones (2005)

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