Knowledge licensing in a Model of R&D-driven Endogenous Growth

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Early growth theory

Solow (1956), one of the seminal papers, discusses how physical capital accumulation can affect short- and long-run growth and welfare

- Solow uses neoclassical framework/production function

$$Y = F(K, AL)$$

where F is homogeneous of degree 1 in capital K and labor L and A is labor augmenting technology.

- Solow also uses the standard capital accumulation rule

$$\dot{K} = I - \delta K$$

where $\delta \in (0,1)$ and $I = sY$ with $s \in (0,1)$

Microeconomics: Homogeneity of degree 1

Homogeneity of degree 1 in K and L is motivated by standard replication argument given that K and L are rival inputs

- Rival goods: whose use by one prevents the use by other
- Replication argument: in order to double output firm needs to hire twice more K and L

Homogeneity of degree 1 supports competitive equilibrium; in equilibrium firms hire K and L and make zero profits

- Euler thoerem: $Y = \frac{\partial F}{\partial K} K + \frac{\partial F}{\partial L} L$

Implication of homogeneity of degree 1

That F is homogenous of degree 1 in K and L implies that the accumulation of K bears decreasing returns

- As capital K increases, the returns to its accumulation decline to zero
- In long-run, output per capita Y/L is constant if A is fixed
    - This is not in line with the observation that many developed countries grow at relatively constant rates (Kaldor stylized facts)
    - A needs to grow in order to have long run growth

Can A grow endogenously a neoclassical model?

In neoclassical framework F is homogenous of degree 1 in K and L

This implies that

- All revenues are spent compensating K and L, and A cannot be compensated
- Therefore, A cannot be accumulated endogenously (by firms/market mechanisms)

Solow (1956) assumes that A grows exogenously

- He acknowledges that this is a significant shortcoming since changes in A involve trade-offs
  - e.g., time and physical resources allocated to research

Early endogenous growth theory - Romer (1986)

Romer (1986) “endogenizes” the accumulation of A assuming that the latter is proportional to the stock of physical capital (per capita)

Romer (1986) assumes that in equilibrium

$$A = \frac{K}{L}$$

- Microeconomics: there are learning-by-doing externalities; workers learn and become more productive as they interact with capital

Early endogenous growth theory - Lucas (1988)

Lucas (1988) interprets AL as human capital H

- "endogenizes" the accumulation of A assuming that the household does it through schooling
- household allocates part of human capital to production ($u_Y H$) and part to schooling ($u_H H$)

$$Y = F(K, u_Y H)$$
$$\dot{H} = \lambda u_H H$$

$$u_Y + u_H \leqslant 1$$

Issues in Romer (1986) and Lucas (1988)

- In Romer (1986) changes in A are semi-endogenous/not driven by (rational) decisions of agents
- In Lucas (1988) it is hard to motivate the linear structure of schooling function
  - human capital is a rival input; constant returns are hard to justify

Romer (1990)

Romer (1990) assumes that private firms' intentional investments in R&D are the driver of long-run growth and welfare

- R&D generates knowledge/ideas that can be used for subsequent innovations
- Knowledge is not rival and is partly non-excludable
  - Non-excludable: there are knowledge spillovers and R&D builds on a pool of knowledge
  - Excludable: firms can use it in order to secure (at least temporary) monopoly position in product market

Microeconomics of Romer (1990)

Final goods sector

$$Y = (u_Y L)^{1-\sigma} \int_0^A x^{\sigma}(i)di$$

where x are intermediate goods

Microeconomics of Romer (1990)

Intermediate/capital goods sector

- intermediate goods producers are price setters
- production of 1 unit of an intermediate good x requires 1 unit of final goods
- intermediate goods producers are infinitely lived
- they maximize their discounted sum of profits (value)

$$\max V = \int_t^{+\infty} \pi(\tau) \exp\left[-\int_0^{\tau} r(s)ds\right] d\tau$$

Microeconomics of Romer (1990)

R&D sector

- “researchers produce blueprints of intermediate goods
- research builds on previous knowledge (which is non-rival good! here it is also non-excludable in R&D)

$$\dot{A} = \lambda A(u_A L)$$

Microeconomics of Romer (1990)

There is free entry into intermediate goods industry

- in order to enter the industry an entrepreneur needs to buy a blueprint
- it borrows the resources for that investment from household at the market interest rate r

Motivation - Non-rivalry and partly excludability

Rivalry of a good is purely technological attribute

- Knowledge is non-rival good because its use by a firm or a person does not preclude its use by another

Excludability depends also on the legal framework and detection mechanisms

Motivation - Interpretation of the assumption

Partly non-excludability: patenting and patent enforcement frameworks and mechanisms for detection of patent infringements are imperfect

- They are weak since firms or researchers can avoid citing or paying license fees for current patents while generating new patents
- They are strong to the extent that firms can maintain exclusive rights on their type of good that is part of the patents

Motivation - Patenting in high-tech industries

In high-tech industries (e.g., ISIC 32) patenting and patent enforcement frameworks and mechanisms for detection of patent infringements seem to be not so imperfect

- In these industries citing, licensing, and establishing consortiums for exchanging patents is common and has played and currently plays significant role for innovation
  - Grindley & Teece (1997), Hagedoorn (1993, 2002), Shapiro (2001), Clark, Piccolo, Stanton & Tyson (2001)
  - e.g., establishment of RCA Corporation patent consortium in the Radio, Television and Communication Equipment industry

Motivation - High-tech industries' contribution to growth

- High-tech industries are the top private R&D performers and have significant contribution to economic growth
  - Helpman (1998), Jorgenson, Ho & Stiroh (2005)

Knowledge licensing and growth Jerbashian (2016)

Jerbashian (2016) models knowledge (patent) licensing between high-tech firms in an endogenous growth framework

- Shows how market concentration, intensity of competition in high-tech industry can matter for innovation in that industry and aggregate performance
- Compares the inference to a setup with knowledge spillovers

The model

- There are N high-tech firms ($N > 1$)
- Firms produce differentiated goods $\{x\}$ and set prices $\{p_x\}$
- Each firm can invest in R&D which improves its knowledge on the production process (or the quality of its x)
- The knowledge of the production process of a high-tech firm is measured by its productivity λ
  - Each firm has its knowledge of the production process
- The production function of a high-tech good x is

$$x = \lambda L_x$$

R&D Processes

- In order to improve its knowledge (increase λ) a high-tech firm needs to hire "researchers" L_r
- Researchers use the current knowledge of the firm in order to create a better one
  - Process innovation: The firm is able to produce more of x
  - Quality upgrade: The firm is able to produce the same amount of higher quality x

Knowledge Licensing (S.1)

S.1: Knowledge licensing

- In this setup, knowledge can be licensed
- Intellectual property regulation facilitates excludability of knowledge and grants bargaining power to the licensors
- If a high-tech firm licenses knowledge from other firms, researchers combine it with the knowledge available in the firm in order to produce new knowledge
- The knowledge of a firm is the only essential knowledge input in the R&D process of the firm

Knowledge Licensing (S.1)

The R&D process of a firm j, $j \in (1, N]$, is given by

$$\dot{\lambda}_j = \xi \left[\sum_{i=1}^{N} (u_{i,j} \lambda_i)^{\alpha} \right] \lambda_j^{1-\alpha} L_{r_j}$$

$$\xi > 0, 1 > \alpha > 0,$$

where $u_{i,j}$ is the share of knowledge of firm i (λ_i) that firm j licenses, and $u_{j,j} \equiv 1$.

Details

Knowledge Spillovers (S.2)

S.2: Knowledge spillovers

- Intellectual property regulation does not enforce excludability and firms cannot maintain secrecy
  - Firms obtain others' knowledge for free/There are knowledge spillovers among high-tech firms
  - In a firm the researchers combine the knowledge that spills over from other firms with the knowledge of their own firm for generating new knowledge

Knowledge Spillovers (S.2)

The R&D process is given by

$$\dot{\lambda}_j = \xi \tilde{\Lambda} \lambda_j^{1-\alpha} L_{r_j}$$

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where I assume that in equilibrium

$$\tilde{\Lambda} = \sum_{i=1}^{N} \lambda_i^{\alpha}$$

The problem of High-tech Firm j

The problem of high-tech firm j is

$$V_j(t) = \max_{p_{x_j}, L_{r_j}, \left\{u_{j,i}, u_{i,j}\right\}_{i=1;(i \neq j)}^{N}} \left\{ \int_{t}^{+\infty} \pi_j\left(\hat{t}\right) \exp\left[- \int_{t}^{\hat{t}} r(s) ds \right] d\hat{t} \right\}$$

$s.t.$

$$\pi_j = p_{x_j} x_j - w\left(L_{x_j} + L_{r_j}\right) + \left[\sum_{i=1, i \neq j}^{N} p_{u_{j,i}\lambda_j}\left(u_{j,i}\lambda_j\right) - \sum_{i=1, i \neq j}^{N} p_{u_{i,j}\lambda_i}\left(u_{i,j}\lambda_i\right) \right],$$

$$x_j, \dot{\lambda}_j, p_{x_j}$$

The Final Goods Sector

Final goods are homogenous Y

- Final goods producers form the demand for high-tech goods

The problem of the representative producer is

$$\pi_Y = \max_{\{x_i\}_{i=1}^N, L_Y} \left\{ Y - \sum_{i=1}^N p_{x_i} x_i - wL_Y \right\}$$

$$s.t.$$

$$Y = X^\sigma L_Y^{1-\sigma}$$

$$X = \left(\sum_{i=1}^N x_i^{\frac{\varepsilon-1}{\varepsilon}} \right)^{\frac{\varepsilon}{\varepsilon-1}}$$

$$1 > \sigma > 0, \varepsilon > 1$$

Households

There is a continuum of identical and infinitely lived households of mass 1

- Each is endowed with a constant amount of labor L

The representative household's optimal problem is

$$U = \max_{C,L} \left\{ \int_0^{+\infty} \frac{C_t^{1-\theta} - 1}{1-\theta} \exp(-\rho t) dt \right\}$$

$$s.t.$$

$$\dot{A} = rA + wL - C$$

$$\theta, \rho > 0$$

Labor demand

Firm j's demand for labor for production and R&D are

$$w = \lambda_j p_{x_j} \left(1 - \frac{1}{e_j}\right)$$
$$w = q_{\lambda_j} \frac{\dot{\lambda}_j}{L_{r_j}}$$

where e_j is the perceived elasticity of substitution Elaborate

Demand for and supply of knowledge, S.1

Firm j's demand for and supply of knowledge are

$$p_{u_{i,j}\lambda_i} = q_{\lambda_j}\xi\alpha\left(\frac{\lambda_j}{u_{i,j}\lambda_i}\right)^{1-\alpha} L_{r_j},\ \forall i \neq j$$
$$u_{j,i} = 1,\ \forall i \neq j$$

Returns on knowledge accumulation, S.1

When there is licensing, high-tech firm's returns on knowledge accumulation are given by

$$\frac{\dot{q}_{\lambda_j}}{q_{\lambda_j}} = r - \left(\frac{e_j^k - 1}{e_j} \frac{p_{x_j}}{q_{\lambda_j}} L_{x_j} + \frac{\partial \dot{\lambda}_j}{\partial \lambda_j} + \sum_{i=1, i \neq j}^{N} \frac{p_{u_{j,i}\lambda_j} u_{j,i}}{q_{\lambda_j}} \right)$$

$$\frac{\partial \dot{\lambda}_j}{\partial \lambda_j} = \xi L_{r_j} \left[1 + (1-\alpha) \sum_{i=1, i \neq j}^{N} \left(\frac{u_{i,j}\lambda_i}{\lambda_j} \right)^{\alpha} \right]$$

When there are spillovers, high-tech firm's returns on knowledge accumulation are given by

$$\frac{\dot{q}_{\lambda_j}}{q_{\lambda_j}} = r - \left(\frac{e_j^k - 1}{e_j} \frac{p_{x_j}}{q_{\lambda_j}} L_{x_j} + \frac{\partial \dot{\lambda}_j}{\partial \lambda_j} \right)$$

$$\frac{\partial \dot{\lambda}_j}{\partial \lambda_j} = (1-\alpha) \frac{\dot{\lambda}_j}{\lambda_j}$$

Growth rates

The growth rates of final output (Y) and productivity (λ) are

$$g_Y = \sigma g_\lambda$$

$$g_\lambda = \frac{\xi DL - \rho}{(\theta - 1)\,\sigma + \alpha I^1_{S.2} + D}$$

where

$$I^1_{S.2} = \begin{cases} 0 \text{ for knowledge licensing (S.1);} \\ 1 \text{ otherwise} \end{cases}$$

Growth rates

D summarizes the effect of competitive pressures on innovation and growth:

$$D = \sigma \frac{e-1}{e-\sigma}$$

$$e = \varepsilon - \frac{\varepsilon - 1}{N}$$

where

$$\frac{\partial D}{\partial N}, \frac{\partial D}{\partial \varepsilon} > 0; \frac{\partial^2 D}{\partial N^2}, \frac{\partial^2 D}{\partial \varepsilon^2} < 0$$
$$\frac{\partial g_\lambda}{\partial D} > 0; \frac{\partial^2 g_\lambda}{\partial D^2} < 0$$

Welfare

Total (consumer) welfare can be expressed as

$$\tilde{U} \quad = \quad -\left[N^{\frac{\sigma}{\varepsilon-1}}\left(NL_x\right)^{\sigma}\left(L_Y\right)^{1-\sigma}\right]^{-(\theta-1)}\frac{1}{(\theta-1)\,\sigma g_\lambda+\rho}.$$

- the term in square brackets increases and g_λ declines with $I^1_{S.2}$
- $\tilde{U}$ declines with $I^1_{S.2}$

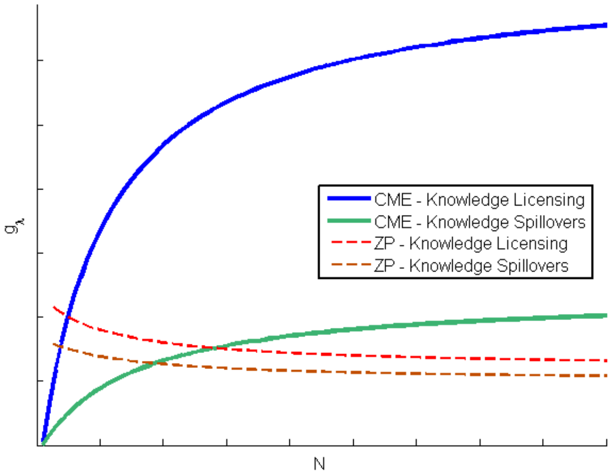
Firm entry: Cost-free entry

- I assume zero entry (exit) costs. In such a case, firms enter (exit) as long as profits net of R&D expenditures are non-negative (negative)
- Zero value/profit condition determines the number of firms given g_λ:

$$\pi = 0 \Leftrightarrow$$

$$g_\lambda = \frac{\rho}{e - 1 - \alpha I^1_{S.2-3} - (\theta - 1)\,\sigma}$$

g_λ and the number of firms



The number of firms

The number of firms is given by the following two expressions

$$e = \varepsilon - \frac{\varepsilon - 1}{N},$$

$$e = \frac{\xi \sigma L \left[1 + \alpha I^{1}_{S.2} + (\theta - 1)\sigma \right]}{\xi \sigma L - \rho}.$$

Innovation and growth do not depend on ε since so does the right-hand side of the second expression

Welfare with cost-free entry

Total (consumer) welfare can be expressed as

$$\tilde{U} \quad = \quad -\left[N^{\frac{\sigma}{\varepsilon-1}}\left(NL_x\right)^{\sigma}\left(L_Y\right)^{1-\sigma}\right]^{-(\theta-1)}\frac{1}{(\theta-1)\,\sigma g_\lambda+\rho}.$$

- $(NL_x)^{\sigma}(L_Y)^{1-\sigma}$ and $N^{\frac{\sigma}{\varepsilon-1}}$ (love-for-variety effect) increase with $I^1_{S.2}$
- g_λ declines with $I^1_{S.2}$
  - $\tilde{U}^{S.1} < \tilde{U}^{S.2}$ for $\alpha \approx 0$
  - $\tilde{U}^{S.1} > \tilde{U}^{S.2}$ if there is no love-for-variety effect

Thank you!

Perceived elasticity of substitution

It can be shown that

$$e_j^B \equiv e_j = \varepsilon - \left[\frac{(\varepsilon - 1)\, p_{x_j}^{1-\varepsilon}}{\sum_{i=1}^{N} p_{x_i}^{1-\varepsilon}} \right]$$

Back to S.1-3

R&D process S.1

This R&D process can be rewritten as

$$\dot{\lambda}_j = \xi \left[\sum_{i=1, i \neq j}^{N} (u_{i,j} \lambda_i)^\alpha + \lambda_j^\alpha \right] \lambda_j^{1-\alpha} L_{r_j}$$

Back to S.1 (2)

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