
Main question:
If one introduces spillovers between two R&D activities (variety expansion and quality improvement), which growth pattern is more likely to emerge: semi-endogenous or endogenous growth?

Motivation:
Previous models of two sector R&D models (Young (1998), Peretto (1998), Aghion and Howitt (1998) Chapter 12, Dinopoulos and Thompson (1998), Y/P/AH/DT) have ignored the role of inter-activity spillovers (i.e. spillovers between variety expanding and quality improving R&D activities).

Grilliches (1995) provides evidence to highlight the importance of R&D spillovers across industries (note: I am not so sure whether this, and also others, can be presented as direct evidence for inter-activity spillovers). The author also provides some anecdotal evidence arguing that “modern technological innovations draw on diverse types of knowledge”. See page C110 for further details.

Using the growth model with spillovers, the author intends to determine the conditions under which endogenous and semi-endogenous growth occurs.

Definitions : (seems to be rather standardized recently)
- **Semi endogenous growth** (Li, 2002 Econ Letters):
  - i. “technological change is endogenous in the sense that it requires real resources
  - ii. long-run growth is exogenous as in the neoclassical growth models.”
- **Endogenous growth**:
  - i. above,
  - ii. growth is endogenous in the sense that policy changes can have permanent effects on the growth rate of the economy.

Model:
- two-sector R&D growth model (in the spirit of the above cited papers)
- variety-expanding R&D and quality-improving R&D
- spillovers between the two R&D activities (the main differentiating feature of the model)
- intertemporal spillovers within each activity also allowed
- eliminates the scale effects property by the standard variety expansion channel.

With this mechanism, the number of varieties grow over time and R&D resources is spread over an increasing number of varieties. Thus, at the balanced growth path, the rate of vertical innovations in the aggregate economy remains constant. The number of varieties also grow at a constant rate. Therefore, the aggregate growth rate in the economy remains free of scale effects.
A basic model in which a fixed portion of labor is allocated to quality and variety R&D conveys the main message of the paper (see pages 111-112). A more comprehensive model which embeds the micro-foundations that determine the allocation of labor across activities is also presented.

Results:
At the balanced growth path of the model, endogenous growth without scale effects takes place if only if two knife-edge conditions regarding spillovers are met. Otherwise, growth turns out to be semi-endogenous. More specifically, in the case, the rate of growth turns out to be a function of the spillover parameters (both within and inter activity spillover parameters) and the population growth rate. These parameters are generally viewed to be exogenous.

Li argues that since endogenous growth takes place only under the knife edge conditions, semi-endogenous growth appears to be more general than previously thought. Li points out that the knife-edge conditions required for endogenous growth are indeed satisfied in the previous two-sector R&D models. Thus, he argues that the previous two-sector R&D models which resurrect the policy effectiveness on growth result are in fact special cases in the context of his model with spillovers.

**Motivation:**
To introduce spillovers in an R&D-based growth model, allowing for technological progress to take place in more than two dimensions. Using this model, the author intends to investigate the implications of balanced growth outcomes for semi endogenous vs. endogenous growth debate. The author seeks to generalize the results of Li (2000) to a multi-dimension R&D setting.

**Model:**
- \( k \)-sector R&D growth model
- one dimension is variety expanding R&D
- the rest of the dimensions are quality improving R&D (example: computers. Their performance can be increased with faster chips, larger memory and hard disks and etc)
- inter-activity spillovers between all \( k \) R&D dimensions
- intertemporal spillover *within* each activity also allowed
- eliminates the scale effects property with the variety expansion channel
- at the balanced growth path, the rate of growth consists of \( k \) components

**Results**
- For one out of \( k \) components of growth to be endogenous, \( k \) knife edge conditions have to be satisfied.
- For all \( k \) components of growth to be endogenous, \( k^2 \) knife-edge conditions have to be satisfied.

**Conclusion**
Li formally shows that as the dimensions of technological progress increases, the number of knife-edge conditions for endogenous growth increases. He views this as a further theoretical argument that strengthens the case for semi-endogenous growth. He discusses some possible extensions such as endogenizing the spillover rate to check whether this claim can be more general.

**Comments:**
The above two papers are useful in that they incorporate spillovers in a more general form. The way scale effects are removed is in the spirit of the variety expansion models of Y/P/AH/DT, so there is not a major innovation in that regards. The generalization and the results are of importance to the extent that inter-activity spillovers matter. I believe that spillovers are important, but I am not sure as to whether or not Li’s results present prima-facial evidence against endogenous growth.

However, the models helped me realize that, after all, the variety expansion channel introduced in Y/P/AH/DT models implies that R&D in variety expansion generates a negative spillover effect on R&D in quality improvement. This is by construction of the
model. If more variety creation takes place, then all other R&D activities will be spread over more sectors, hence the scale effects are removed. So, in general, it seems to me that if there is one R&D sector that creates a negative externality on the other R&D sectors, this may be sufficient to remove scale effects. This helped me to see more clearly that the rent protection mechanism drastically differs from the two-sector R&D growth models. In the RPA model, the R&D difficulty does not arise due to a negative externality from another R&D activity, but is generated directly by the deliberate efforts of incumbent firms.

Motivation:
The author argues that in the growth field, recently there has been too much emphasis on using the knife-edge conditions criteria to evaluate the usefulness of growth models. In his view, this excessive attention, is creating misunderstandings and diverting the focus of research away from important issues. In this review article, Temple attempts to clarify some of the misunderstandings and suggest possible avenues for future research.

Discussion:
Temple argues that balanced growth is, by definition, a very special situation. There is considerable debate as to whether or not such a state can indeed be empirically observed in the real word. Hence, it should not come as a surprise that the balanced growth path of endogenous growth models is characterized by knife-edge conditions. Temple argues that given that balanced growth is a special case, it would be unjust to discriminate between growth models based on their balanced-growth properties.

Temple suggests that instead of worrying about long-run growth, it would be more fruitful to focus on transitional dynamics, level effects and welfare. In the meantime, it would be a mistake, he argues, to dismiss the endogenous growth models just because their existence rely on very stringent parametric conditions. The restrictive assumptions is essentially there to capture the simplest representation of the growth process and thus should be utilized with this in mind. Further, he conjectures that the implications of endogenous vs. semi-endogenous growth models for welfare would not differ much.

Conclusion:
Temple wraps up the paper in the conclusion section with “5 obvious rules” for further research in growth. These results reiterate the main arguments in a very concise and direct fashion.

Comments:
I agree with Temple’s comments in general: that the models are themselves simplified versions of the real world and that they already involve a significant amount of “knife-edge” structuring anyway. So it would not be very counter productive to place excessive focus on the knife-edge conditions concerning the long-run outcomes.
Motivation:
This paper attempts to formalize Schmookler’s (1966) views on technological change in the context of an endogenous growth model. Technological change can be supply driven (i.e., based on cost considerations) or demand driven (i.e., based on usefulness considerations). According to Schmookler, it is the demand-side rather than the supply side that is the key determinant of innovation. In particular, Schmookler argues that demand-side considerations determine the number of problems pursued by researchers and thus ultimately affects the pace of technological progress.

Keely argues that the focus of previous growth models such as Kortum (1997), Romer (1990), Olsson (2000) and etc. were on the supply side rather than the demand side. Hence, these models cannot fully capture the Schmooklerian insight. Keely intends to bridge this gap in the literature by constructing a model that endogenizes the number of problems pursued by the R&D sector.

Side Comment: Keely acknowledges that in the previous models, the price of innovation is endogenously determined and that this, to a certain extent, captures the role of demand-side in affecting technological progress. Her point though is that in the previous models, the demand-side of the innovation process is not fully explored. In particular, she points out that in the previous models, the number of solutions pursued by researchers is mostly taken to be exogenous. This is short of capturing the Schmooklerian view (in Keely’s words) that “the number of problems pursued will be an increasing function of the level of physical capital investment in the sector that will use the solutions, or new technologies”.

Model:
- Very closely follows Romer (1990)
- The major twist comes in the modeling of the innovation process as outlined below.

Innovation Process:
In this model, the rate of innovations $\dot{A}$ is increasing with the number of problems pursued by researchers $H(t)$. The number of problems, in turn, increases with capital investment $K(t)$ and the amount of workers employed in the production of final goods $L_Y(t)$. Hence, $K(t)$ and $L_Y(t)$ are viewed as parameters that capture the degree of usefulness of innovations.

Keely considers three formulations to determine $H(t)$. The only formulation that yields scale-free growth is the third one (p. 289); hence, I limit the discussion to this formulation, which is as follows:

$$H(t) = \Omega \, \dot{K}(t)^\Gamma \, L_Y(t)^{1-\Gamma}, \quad \Gamma < 1$$

(1)
where $\Omega$ and $\Gamma$ are positive parameters.

The rate of innovation at time $t$ is:

$$\dot{A} = H(t)[1 - (1 - v(t)^{L_R(t)})], \quad (2)$$

where $L_R(t)$ shows the amount of labor employed in research, and $v(t)$ represents the probability of successful innovation with respect to a single idea.

Equations (1) and (2) establish a positive feedback from $K$ and $L_Y$ to $\dot{A}$ via $H(t)$. This captures the Schmooklerian insight: usefulness of technology as captured by the level of investment $K$ and the extent of employment in production $L_Y$ affect the number of problems pursued $H(t)$ and thereby exert an influence on the rate of innovation $\dot{A}$.

**Balanced growth path and removal of scale effects:**

The model allows for positive population growth. Keely assumes a particular specification for $v(t)$ (p290-291). With this specification, as research labor $L_R(t)$ increases without bound, it follows that $[1 - (1 - v(t)^{L_R(t)})]$ converges to one. Hence, at steady-state the effect of research labor $L_R$ on probability of successful innovation $v(t)$ is effectively eliminated.

Using the structure of Romer (1990), Keely derives an expression for $\dot{K}$ as

$$\dot{K} = \eta \Psi_0 A(t) L_Y(t)[g_A + l_Y]. \quad (3)$$

where $\eta$ and $\Psi_0$ are constants, $g_A$ represents the rate of growth in technology and $l_Y$ stands for the rate of growth in production labor. Combining (1), (2) and (3), one can derive an expression for the growth rate as:

$$g_A = \frac{\dot{A}}{A} = \frac{H}{A} \frac{\Omega \eta \Psi_0 A(t) L_Y(t)[g_A + g_Y]}{A} \quad \left[ \Omega \eta \Psi_0 (g_A + g_Y) \right]^{\Gamma} \frac{A^\Gamma L_Y}{A}. \quad (4)$$

For $g_A$ to be constant, we need $\dot{L}_Y / L_Y + (\Gamma - 1)\dot{A} / A = 0$. Thus:

$$g_A = \frac{l_Y}{(1 - \Gamma)}, \quad \Gamma < 1.$$  

Notice that this is the same growth rate as found in Jones (1995). Further note that it is the $A^\Gamma$ term with $\Gamma < 1$ in equation (4) that introduces the R&D difficulty notion as in Jones. However, there is a difference between the two papers in the way R&D difficulty is modeled. In Jones (1995), $A^\Gamma$ materializes in an exogenous fashion, whereas in Keely $A^\Gamma$ is introduced by an endogenous mechanism (page 300, par 4). More specifically, the $A^\Gamma$ term arises in $\dot{A}$ because it affects capital formation, which, in turn, affects $H$. 


The intuition for the removal of scale effects is that the number of problems pursued \( H(t) \) increases with the stock of technology but at a slower pace since \( \Gamma < 1 \).

**The main contribution:**
Keely runs simulations to study the transitional dynamics of the model. The simulations reconcile the three stylized facts of growth as outlined on page 298. Hence, the paper contributes to the literature by explaining these stylized facts using a scale-free growth model that incorporates the insight of Schmookler.

**General Comments:**
The paper proposes a new mechanism to remove the scale effects by adapting the Schmooklerian thesis in a growth framework. According to Schmookler, capital investment and level of production labor can positively affect the number of technological problems pursued by researchers. This, in turn, can stimulate more rapid technological progress. At the balanced growth path with positive population growth, the rate of increase in the number of problems pursued over time triggered by a change in \( A(t) \) is less than the rate of change in \( A(t) \). This, by itself, introduces increasing R&D difficulty in the Jones spirit, but through a more explicit mechanism.

Keely argues that this is an endogenous way of introducing R&D difficulty, but I am not very convinced on this. It seems to me that she basically introduces an extra equation to capture the Schmooklerian insight without the complete micro-foundations. For instance, it seems to me that there are no additional costs associated with pursuing more problems. In that sense it reminded me more of models with spillovers (such as of Li’s) rather than the models that eliminate scale effects via variety creation or rent protection.

Motivation:
This paper is motivated to explain the reasons behind the “historical tendency for short periods of growth to be interspersed with long stretches of stagnation.”

Kelly argues that the existing endogenous growth models cannot adequately address this phenomenon since these models impose a rather restrictive structure on the linkage formation process. Kelly defines linkage formation as “the sequential process of innovation in learning models, starting with simple goods and progressing through a commodity space to increasingly complex ones.”

According to Kelly, the existing endogenous growth models based on learning by doing (such as Stokey (1998), Young (1991) and Lucas) or quality-ladders (such as Grossman and Helpman (1991), Aghion and Howitt (1992) and Young (1993)) impose two restrictive assumptions:
• all technological advances are equally difficult
• innovation in one industry does not facilitate the innovation process in another industry (i.e., there are no knowledge spillovers between industries).

Side comment: This spillover mechanism is different from the one considered by Li (2000). In Li’s framework spillovers take place among vertical and horizontal R&D activities rather than among industries.

Kelly’s objective is to construct a model that relaxes the above restrictive assumptions and thereby provide a better account of the linkage formation mechanism. Using this model he also intends to explain the observation of long stretches of stagnation and short durations of high growth in the historical data.

A basic model:
Kelly first builds a simple parametric model to convey the main message of the paper. Later in the paper though a more general but highly technical version is also presented. For the sake of simplicity, I only focus on the simple parametric model.

The basic model is a quality ladders model similar to Grossman and Helpman (1991) with two additional frictions:
• the cost of innovation varies randomly across each generation of a good,
• spillovers occur can occur between industries.

In each industry, research productivity is a random draw from a distribution. An unfavorable draw implies that research productivity falls to a sufficiently low level that renders further innovation activity unprofitable.

Hence, in this model, there are two types of industries, innovating and non-innovating industries. Innovating industries can generate spillovers for the neighboring industries. If
the receiving industry is a non-innovating industry, this spillover reignites the innovation process; if the receiving industry is an innovating industry nothing changes in terms of research productivity. Further, if the innovating industry that generates the spillover lies in the border of the industry space, this results in the creation of a new industry. Therefore, via spillovers the number of industries can actually expand.

**The main result:**
The main result of the paper can be understood easily with some notation. Let

- \( f(i) \) : the rate of new research productivity drawings
- \( \pi \) : the probability of favorable innovations (i.e. probability that the drawing of the research productivity is sufficiently high for positive innovation to occur)
- \( \sigma \) : the probability that the new drawing generates a spillover for the non-innovating industry.

“Sector \( j \) generates successful spillovers to each neighboring sector at Poisson rate \( \pi \sigma f(i_j) \) and receives adverse research productivity at rate \( (1 - \pi)f(i_j) \). The ratio of successful spillovers to unfavorable research draws is”:

\[
\lambda = \frac{\sigma \pi}{(1 - \pi)}
\]

Kelly finds that there exists a critical level \( \lambda_C \) such that if \( \lambda \) is below this level, then all innovation eventually comes to a halt; if \( \lambda \) is above this level, then innovation continues with positive probability. If the number of industries in which innovation occurs initially is sufficiently large then innovation continues definitely (i.e., with probability one). This main result is very clearly discussed and also illustrated with graphical simulations on page 45.

**Implications:**
This result highlights the role of linkage formation in determining the development path of an economy. If the linkages across industries as captured by the ratio of successful spillovers to unfavorable research outcomes is lower than a threshold level then in the long-run all innovation ceases. Moreover, Kelly finds that this transition takes place in a gradual fashion, unlike the growth-trap models which predict instantaneous and complete stagnation.

The existence of threshold levels also challenges the methodology of the empirical growth literature. In a typical growth regression, the explanatory variables enter in a linear or log-linear fashion. If threshold levels indeed exists, then linear specifications cannot capture cross-country differences in growth rates.

**Scale effects:**
The model does not explicitly address the scale effects issue; however it mentions the conditions under which scale effects are eliminated. Kelly states that scale effects are removed if and only if the growth rate in the number of industries equals the growth rate of population. In the paper there is no mechanism that guarantees this outcome. Note that this condition is essentially the same as the condition in the scale-free variety expansion models.
Comments:
As indicated above, the model does not directly deal with the scale effects issue. However, I find the paper very interesting with some useful insights. I think the empirical implications and the predictions of the model with regards to the development process clearly push the growth literature further.