THE NEW GROWTH THEORY

Yaw Nyarko
New York University, USA

Keywords: Literacy, Productivity, Adoption, Embodied, Explicitly Modeled, Exogenous, Knowledge Spillovers

Contents

Summary

This paper very briefly summarizes some of the new growth theory in economics. The emphasis will be on the role of knowledge in the growth process. The discussion begins by asking what exactly we mean by knowledge. It turns out that there are very many definitions of the word knowledge in the literature. Rather than looking for some dictionary definition of knowledge, good for all purposes, the definitions will be inferred from their use in various economic models.

There will be a formal treatment of models used in the new growth theory. These will be divided into two main groups: adoption models and invention models. As will be made very clear, this demarcation will not be strict. Some models will have features of both adoption and invention. This demarcation will, however, allow for better organization of the discussion. The argument will be made that the adoption models are more important in the context of less developed countries, where knowledge-based growth is more likely to occur from adoption of known techniques than from the invention of new ones.

When one talks of knowledge and growth, education very quickly enters the discussion. The analysis presented will point out how education enters the formal models of growth. There will also be a discussion on the empirical literature relating to knowledge and growth. In particular, a note will be made of what one should expect and what one should not expect from growth regressions and empirical studies. It will be argued that even if knowledge is very important for growth, one should not necessarily see it reflected in many of the standard or simple growth regressions.

1. Introduction

This paper summarizes some of the key ideas in the recent literature on economic growth. An important part of this new economic growth literature is the emphasis on knowledge or human capital. The discussion begins in Section 2 by asking what exactly is meant by "knowledge" in the context of economic growth. It turns out that there are very many definitions of the word knowledge used in the economic growth literature. Rather than looking for some dictionary definition of knowledge, good for all purposes, here the definitions will be inferred from their use in different contexts.

The discussion then moves on to some formal "models" explaining economic growth. These will be divided into two main groups: adoption models and invention models. As will be made very clear, this demarcation will not be strict. Some models will have features of both adoption and invention. However, this demarcation will enable better organization of the discussion. Invention models have received the bulk of the attention in the literature, but very recently, there has been more attention paid to the adoption models. The adoption models are particularly important in the context of less developed countries, where knowledge-based growth is more likely to occur from adoption of known techniques than from the invention of new ones.

When one talks of knowledge and growth, education very quickly enters the picture. In Section 5, some remarks on education are provided. Note will be made of what one should expect and should not expect from growth regressions. It will be argued that even if knowledge is very important for growth, one should not necessarily see it reflected in many of the standard growth regressions in the literature.

2. What is Knowledge?

Knowledge: to recognize as being something indicated (Webster's Third New International Dictionary).

A primary concern of the new growth economics is knowledge in its relation to growth. By growth, what is meant is the rate of change of output per capita—the goods and services produced in the economy divided by the population. Although there are measurement and index number problems—how do we aggregate all goods by one number?—most of us have a good understanding as to what is meant by the output per capita. The same is not true of knowledge. Rather than trying to give some all-inclusive abstract definition of knowledge, some definitions implied by the empirical and theoretical ideas used in the literature will be provided. The appropriateness of these measures will be discussed in Section 6, after we have discussed some of the theoretical models.

2.2. Literacy or Years of Schooling

This is one of most popular definitions of knowledge, and it is the easiest to take to the data for testing the various economic growth models. The reason is straightforward: one can actually get data on these measures. Sources include the United Nations, the World Bank, and the many data sets freely or easily available on the Internet. Further, this measure of knowledge stands out in the theoretical models in which a notion of human capital affects growth through improvements in the productivity in physical capital (see Section 3.2). The empirical literature uses either literacy rates—the percentage of the population that has some level of academic ability, for instance, in reading—or the average number of years of schooling of the population.

2.2. Productivity

The next measure of knowledge used in the literature is the productivity. Consider production that requires inputs of, say, capital and labor. More specifically suppose that the production function is of the form $Y = AF(K, L)$ where Y units of output are produced from K units of capital and L units of labor. Here, A is a parameter. The idea behind the productivity measures of knowledge is that all increases in output over and above that which is due to the clearly identified factors—physical capital and labor in the case of the above equation—should be classified as being due to knowledge. Hence, knowledge is a residual. Knowledge causes all the growth in output that we cannot explain as coming from increases in traditional inputs (like labor and capital). This knowledge is often referred to as the total factor productivity, TFP.

This "productivity" definition of knowledge is similar to measures of embodied knowledge or human capital used in the empirical microeconomics and labor economics literature. In those models, the interest is in determining the factors that control the wage of a worker. In these exercises, so-called wage regressions, it is supposed that an individual's labor has embodied knowledge that the individual gets from either schooling or their education level, as well as from the worker's tenure or experience with the current job and any on-the-job training. These ideas from labor economics have found their way into the new economic growth literature, as mentioned earlier.

The productivity definition of knowledge is what is implicit in many of theoretical models we study in Section 4—those we call the invention models. All of these models will assume some property of the technology referred to as constant returns to scale production function. It is often hard to consistently define TFP when the production function does not exhibit the property of constant returns to scale, as we shall indicate.

2.3. Knowledge "On" a Given Activity or Technology

In the theoretical models of Section 3, those we refer to as adoption models, there is typically a menu of different technologies. Individuals or firms have different amounts of knowledge on the different technologies. In these models, there is no scalar concept of knowledge. Instead, each individual or firm will have a vector of "knowledges" on the vector of different technologies. In those models, one does not talk of a firm's knowledge—instead one talks of a firm's knowledge on a particular technology or vintage of a technology.

When there are different kinds of knowledge, firms decide which of them to acquire. Often this acquisition process is costly. While acquiring new and potentially better technologies, the firms may experience productivity slowdowns. The intuition can be explained as follows. Suppose, for example, that you know that a prize is one of four boxes. You spend current resources to discover which box contains the prize. Suppose that you have eliminated two of the boxes as not containing the prize. Then your knowledge has definitely improved—you have ruled out two boxes as possibilities. Yet, you currently have nothing to show for it. Indeed, if you take into account the search costs, you are slightly worse off. This simple idea shows that one may expect productivity to fall as learning is taking place. When a new idea or technology is produced, firms have to determine how best to use it. This sometimes involves trial and error and may lead to losses in productivity during the trial phases. This basic idea will be exploited in the next section.

This definition of knowledge, with types or vintages of knowledge, implies that there may be knowledge traps. Suppose there are two nations, A and B, and two technologies, 1 and 2. Suppose that nation A knows technology 1 perfectly and has partial knowledge about technology 2. Suppose nation B has less knowledge on both technologies in comparison to nation A. Suppose that technology 2 is the better technology in the sense that, if the knowledge on both technologies is the same, technology 2 delivers more output. Then it is possible that nation A will decide to use technology 1 since it knows it perfectly and does not want to take the risk or reduction in output involved in using the partially known technology 2. Nation B, on the other hand, may decide that it will experiment with technology 2 since it is somewhat ignorant about both technologies.

Add to this story learning-by-doing, so that once a technology has been used, more knowledge is acquired on it. Then, over time, nation B will learn how to use technology 2, and will become proficient in its use. Nation A, however, is stuck with technology 1, which was a good technology initially but which, given B's knowledge on technology 2, is a better technology. In particular, we see in this simple example that the nation with high initial knowledge, nation A, gets stuck with the inferior technology while nation B, with the low initial knowledge, uses the better technology and eventually overtakes A. This knowledge trap will be further elaborated on in the next section in the context of a formal model.

The knowledge problem facing developing countries is not so much a question of knowledge of what they are currently doing—instead it is about knowledge of things that they are currently not doing. We conjecture that, given the environment in which they are working and the material they have to work with, Ghanaian farmers are probably the most knowledgeable at cocoa farming in the world. Ghanaian cocoa farmers certainly have greater amounts of human capital on cocoa farming than practically every American farmer. The bigger problem for Ghana and the Ghanaian farmer is that there may not be enough knowledge on other activities. Is the Ghanaian cocoa farmer in a knowledge trap?

2.5. Basic Versus Applied Knowledge

We have now described the three main definitions of knowledge as used in the literature: literacy or years of schooling; productivity; and knowledge on a grade of a technology. There are a couple of other classifications that we will find useful. The first is the classification into applied and basic knowledge or research.

The United States National Science Foundation (1959, pp. 124) defines basic research as follows: "... original investigation for the advancement of scientific knowledge.... which do(es) not have immediate commercial objectives." We therefore think of basic knowledge as fundamental knowledge about things like the laws of physics or chemistry, and basic research as spending directed to discovering this kind of knowledge. We define "applied" knowledge to be knowledge about the technological process a firm is already using, or about a good that it is already producing or very soon will produce. Applied research should be thought of as learning how to apply existing basic knowledge to the current production.

The next section organizes the discussion around the concepts of applied and basic knowledge. We begin with adoption models, where most of the research will be directed at acquiring applied knowledge. One typically thinks of skilled labor as helping both in the production of basic knowledge and in the adoption of new but existing technology, while less skilled workers would be thought of as only helping with applied research. In Section 4, we discuss the invention models, where we think of research as occurring in large clean laboratories with very highly skilled professionals producing basic knowledge.

In the real world, of course, the applied/basic divisions are not that tight. Where would you place a research professor in a university in a developing country, inventing new methods of applying known and old technologies to a developing environment? It is applied research since it has to do with the adoption of existing techniques, yet it is basic research since it may require important inventions to adapt existing techniques to the environment. How about an invention that allows workers to communicate across the factory floor to help them to coordinate what they are doing. Is this an adoption cost or an invention cost? Despite these problems with the classification, we still find it useful to organize our discussion around the applied versus basic demarcations.

2.5. General Purpose Technologies

There is one more concept of knowledge that is useful: the notion of general purpose technologies (GPTs). GPTs are technologies that are so important that they benefit many different sectors of the economy. The steam engine, electricity, and, in our times, the computer are examples of GPTs. There are those who argue that 1974 was the date of the introduction of the computer GPT. GPTs are so important that many firms decide to spend time and resources to learn how to adopt them for use in their firms. During this time of adoption, there may be productivity slowdowns. There have been assertions made, for example, that there was a productivity slowdown with the introduction of electricity around 1900 in the United States.

3. The Adoption Models

Two things will characterize adoption models. First, many of them will have the feature that the frontier technology is not always used. Second, it is possible for productivity to initially decrease before picking up again. In contrast, the invention models of the next section have no explicit adoption costs and typically result in firms using the frontier technology at each date.

Some back of the envelope calculations suggest that adoption costs may be between 20 and 30 times that of invention costs as a percentage of the gross domestic product (GDP) in the US, with much higher ratios in developing countries. This calculation is so compelling that it is worth repeating here. In the US, spending on research and development (R&D) is about 3 % of GDP, of which 20 % is basic research (inventions) and the rest is applied research (adoption). Hence, invention costs amount to 0.6 % of GDP.

As regards adoption costs, the figures are:

- Schooling: since schooling is 10 % of GDP, and assuming that 50 % of schooling costs are for adoption of technologies, this amounts to 5 % GDP.
- On the job training and learning costs amount to 3 % of GDP.
- Applied R&D spending (80 % of 3 %) amounts to 2.4 % of GDP.

Hence, the total adoption costs are approximately 10 % of GDP. Therefore, the ratio of adoption costs to invention costs is 10:0.6 or almost 20.

Let us try the same calculation for a developing country like Ghana. Invention costs are much less in Ghana than in the US. Let us grossly exaggerate and set this equal to one half of the US figure, making 0.3 % for Ghana. The schooling costs for Ghana are closer to 20 % of GDP, so again assume that half goes for adoption. Even if we keep the other figures—on the job training and applied research—the same as in the US, we arrive at adoption costs equal to 15 % of GDP. Hence, the ratio of adoption to invention costs is now 15:0.3 or close to 50. Adoption costs exceed invention costs in Ghana by a factor of 50!

If a huge part of technical progress occurs through the adoption of technologies, then the incentives for adoption will be very important for growth. As noted above, this is even more important in the developing country context. In this context, the big question may be what kinds of education foster adoption of technologies as opposed to invention. Perhaps this is where too much reliance on ivory tower higher education has no payoff. Dr. W. Arthur Lewis, a Nobel Laureate in Economics, is quoted in private conversation as saying that perhaps it is secondary education, and not primary or tertiary, that is really important to adoption of modern technology.

3.1. The Leader–Follower Model

One of the first adoption models is the leader–follower model. In this model, it is argued that by positing human capital simply as another factor of production, like labor or physical capital, we are incorrectly specifying its role. Instead, human capital speeds up the technological diffusion process, and the benefits of skill are greater, the faster is the pace of innovation. Skilled workers aid in the adoption of newer, better technologies.

The following is a brief technical description of a very simplified version of the leader–follower model. Suppose that there are only two firms (or two countries): a leader and a follower. The leader invents new technologies, at a cost of η, while the follower can adopt a technology previously invented by the leader at a cost of ν. Since it is easier to adopt than to invest, it is assumed that $\nu < \eta$. The production functions for each country are as below, with *i* representing the leader or follower:

$$Y_i = A_i L_i^{1-\alpha} \sum_{j=1}^{N_i} X_{ij}^{\alpha} \qquad (1)$$

Here Y_i is the output for country *i*, A_i is a productivity parameter, L_i is the labor input, X_{ij} is country *i*'s input of the *j*th intermediate good, and N_i represents the number of available intermediate inputs to country *i*. The leader will have more intermediate inputs available, so $N_{\text{leader}} > N_{\text{follower}}$.

Suppose that both the leader and follower share the same parameter *A* and the same labor supply *L* (so that $A_{\text{leader}} = A_{\text{follower}}$ and $L_{\text{leader}} = L_{\text{follower}}$). Since the follower has a lower cost of acquiring improved technologies, < as opposed to 0, the follower will initially have a faster growth rate. Indeed, the growth rate of the follower country will be higher the further away it is from the leader. In the long run, however, the follower will catch up with the leader, and eventually the two countries will grow at the same rate.

We could extend the above model by supposing that each country has a different value of A_i and/or L_i. Then it is easy to see that there may be overtaking. Country A may initially be the follower nation, adopting technologies invented by the leader country. If the follower country has a higher A_i and perhaps a higher L_i, then that country will eventually overtake the leader and maintain its lead forever thereafter. The long-run growth rate will be some increasing function of the parameters A_i and L_i.

Some details of the model were left out above. In particular, it was assumed implicitly that firms care about their profits and seek to choose input levels that maximize their profits, perhaps over time with future profits discounted at some fixed rate relative to current profits. There are also consumers in the background who own shares of the firms and who seek to choose consumption flows over time to maximize a discounted sum of utilities. We do not spell out the details of the consumer problem here, and focus instead on the firms' decision problems, since this is where most of the action is, as far as results are concerned.

The above models do not make explicit the source of the adoption and inventing costs, ν and η. The discussion will now turn to two models where the costs of adoption are learning costs. These models will also have the feature that the adoption of new technologies may result in reductions in productivity or at least a slowdown in the rate of growth of productivity.

-
-
-

Bibliography

Aghion P. and Howitt P. (1992). A model of growth through creative destruction. *Econometrica* **60**, 323–351. [Analyzed here is a model with creative destruction, which is used in Section 4.2.5.]

Arrow K. (1962). The economic implications of learning by doing. *Review of Economic Studies* 29, 155–174. [This paper proposed the model of Section 4.2.3.]

Barro R. J. (1996). Determinants of economic growth: A cross-country empirical study. *NBER Working Paper no.* 5698.

Barro R. J. and Lee J. W. (1993). International comparisons of educational attainment. *Journal of Monetary Economics* 32, 363–394.

Barro R. J. and Sala-i-Martin X. (1995). *Economic Growth*. 539 pages. New York: McGraw Hill. [An important modern textbook on economic growth. It has the "leader–follower" model we present in Section 3. It is a source that we have borrowed from heavily.]

Baumol W., Blackman A., and Wolff E. (1989). Productivity and American leadership: The long view. 395 pages. Cambridge, MA: MIT Press. [This has the reference to statements of W. Arthur Lewis mentioned in Section 3.]

Benhabib J. and Spiegel M. (1994). The role of human capital in economic development. Evidence from aggregate cross-country data. *Journal of Monetary Economics* 34, 143–173. [Has very good empirical work involving years of schooling as measures of knowledge, and tests an adoption model—the leader–follower model of Section 3.]

Benhabib J. and Spiegel M. (1997). Growth and investment across countries: Are primitives all that matter? Manuscript, New York University. [Provides data to show that human capital enters into regressions insignificantly or even negatively when modeled as a factor of production.]

Brezis E., Krugman P., and Tsiddon D. (1993). Leapfrogging in international competition: A theory of cycles in national technological leadership. *American Economic Review* 83, 1211–1219. [This paper has a knowledge growth trap.]

Galor O. and Zeira J. (1993). Income distribution and macroeconomics. *Review of Economic Studies* 60, 35–52.

Greenwood J. and Yorukoglu M. (1997). 1974. *Carnegie Rochester Series in Public Policy* 46, 49–95. [This paper shows that there may be productivity slowdowns as knowledge is being acquired. The model of Section 3b is taken from this paper.]

Jones C. (1995a). Time series tests of endogenous growth models. *Quarterly Journal of Economics*, Vol. 110. 495–525.

Jones C. (1995b). R&D-based models of economic growth. *Journal of Political Economy* CIII. [Provides the data on US scientists, used in Section 4.4.]

Jovanovic B. (1997). Learning and growth. In *Advances in Economics*. National Bureau of Economic Research, Inc. Working Paper No 5383, Boston Massachusetts. [This is the source of the envelope calculations at the beginning of Section 3.]

Jovanovic B. and Nyarko Y. (1996). Learning by doing and the choice of technology. *Econometrica* 64, 1299–1310. [This paper alerts us to the possibility of knowledge traps. This is the model of Section 3.3.]

Kremer J. (1993). Population growth and technological change: One million BC to 1990. *Quarterly Journal of Economics* 108, 681–716. [Provides the arguments about growth since the melting of the polar caps in 10 000 BC referred to in Section 4.4.]

Lucas R. E. (1988). On the mechanics of economic development. *Journal of Monetary Economics* 22, 3–42. [The model of this paper is Eqs. (19) and (20), but where for the human capital sector the only required input is human capital, so that $\eta = 0$.]

Lucas R. E. (1990). Why doesn't capital flow from rich to poor countries? *American Economic Review* 80, 92–96.

Lucas R. E. (1993). Making a miracle. *Econometrica* 61, 251–272.

Mankiw G., Romer D., and Weil D. N. (1992). A contribution to the empirics of economic growth. *Quarterly Journal of Economics* 106, 407–437. [This is an example of a paper that uses average years of schooling as the measure of "knowledge."]

Mas-Collel A., Whinston M., and Green J. (1998). *Microeconomic Theory*. 981 pages. New York: Oxford University Press. [See Proposition 5.B.2 for a proof of the assertion made in Section 4.2 that any production function that has diminishing returns can be converted into a production function with constant returns to scale if we consider some omitted factor whose value has been set to unity.]

National Science Foundation (1959). *Methodology of Statistics on Research and Development*. Washington, DC.

Nelson R. R. and Phelps E. S. (1966). Investment in humans, technological diffusion, and economic growth. *American Economic Review* 56, 69–75. [One of the first adoption models.]

Parente S. (1994). Technology adoption, learning-by-doing, and economic growth. *Journal of Economic Theory* 63, 346–369.

Rebelo S. (1991). Long-run policy analysis and long run growth. *Journal of Political Economy* 99, 500–521. [This paper has the model of Eqs. (19) and (20).]

Romer P. M. (1990). Endogenous technological change. *Journal of Political Economy* 98, S71–S102. [This paper proposes the model discussed at the end of Section 4.2.4.]

Romer P. M. (1994). New goods, old theory, and the welfare costs of trade restrictions. *Journal of Development Economics* 43, 5–38.

Solow R. M. (1956). A contribution to the empirics of economic growth. *Quarterly Journal of Economics* 70, 65–94. [One of the first exogenous growth models—described in Section 4.1.]

Stokey N. (1991). Human capital, product quality and growth. *Quarterly Journal of Economics* 106, 587–616.

Young A. (1993). Invention and bounded learning by doing. *Journal of Political Economy* 101, 443–472.

Young A. (1994). Lessons from the East Asian NICs: A contrarian view. *European Economic Review* 38, 964–973.

Biographical Sketch

Professor Yaw Nyarko teaches economics at New York University. He was born and raised in Ghana. He attained M.A. and Ph.D. degrees in economics from Cornell University, and undergraduate degrees in mathematics and economics from the University of Ghana. His major interests include game theory, learning theory, human capital theory, and growth theory.