Technological Innovations and Learning-by-doing Relations: Contributions and Limits of the Endogenous Growth Theory

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Abstract

This paper surveys the economic literature by focusing on alternative explanations of the relations between technological innovation and learning-by-doing. The most commonly model used to account for this is the so-called endogenous growth model. This model explains some richer dynamics by considering explicitly the determiners of the growth. But the counterpart of this most major power of these models is a bigger fragility. This fragility appears repeatedly through five major themes which are the following ones: the problem of the aggregation, the complementarity between the production factors, the hypothesis of constant returns to scale in the production function of capital goods, the economic policies, and finally the steady-state as a reference. This critic underlines the necessity of further studies examining transitional dynamics in economical growth models.

Key Words

Technological innovation, learning-by-doing, transitional dynamics, steady-state, growth theory, endogenous growth theory

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1. Introduction

Generally, growth models of technical change fall into two broad categories. On the one hand, there are *models of "innovation"*[2], in which technical change is the outcome of costly and deliberate research aimed at the development of new technologies. These models make the surprising assumption that new technologies attain their full productive potential at the moment of their introduction and are, at that point in time, superior to the older technologies for which they substitute. But one may recognise that most products of research at the moment of their introduction in the production of goods may be broadly inferior to more mature technologies. On the other hand, there are *models of "learning-by-doing"*[3], in which technical change is the by-product of experience gained in the production of goods. One of the most surprising features of some existing learning-by-doing models is the assumption that the potential productivity gains from learning are essentially unbounded. Intuitively, it seems reasonable to assume that the potential for learning in the production of any particular good, using any particular process, is in fact finite and bounded.

For these two reasons, we may study growth models, which integrate discrete innovations and continuous improvement that is learning-by-doing. That is why from theoretical relevance, this may lead to more explanations of growth problems.

Our objective is to explore the relations of technological innovations and learning-by–doing and their impacts on growth rate in economical growth models.

[2] See P. Romer [1990], G. Grossman and E. Helpman [1991], and P. Aghion and P. Howitt [1992].
[3] See K. Arrow [1962], R. Lucas [1988], and N. Stokey [1988].

So, we would like to answer at the question: ***Could Endogenous Growth Theory explain the relations between technological innovation and learning-by–doing?***

In order to answer this question, we will focus our analysis on endogenous growth models, which take in account these two sources of growth. Our goal with this paper, therefore, is to present the importance of transitional periods in an analysis in which human capital is formed according to the learning-by-doing approach, and physical capital is formed according to discrete technological innovations.

The plan is as follows. First, we will see in the section 2 the endogenous growth theory contributions in the explanation of the consequences of the relations between technological innovations and learning-by-doing processes. We will see the technological innovations and learning-by-doing relations in the recent growth theory. Probably the most popular explanation of the relations between technological innovation and learning-by-doing is the P. Aghion and P. Howitt's model [1998, chapter 6], while the leading alternative model is the R. Lucas [1993] on economic miracles. We will expose these two ways of thinking about innovation and learning-by-doing relations. Then, in the section 3, we will see the limits of such analysis in the explanation of the consequences of the relations between technological innovations and learning-by-doing processes. And we will close with some final reflections in section 4.

2. Endogenous Growth Theory Contributions

The main endogenous growth theory contributions are to introduce the behaviour of agents in growth model, to analyse the multiplicity of the growth sources, and to justify the economy policy. The modern theories of the endogenous growth try to explain the rate of technological progress. These theories appeared in the middle of the years eighty after the articles of P. Romer [1986] and R. Lucas [1988]. Their purpose was to explain the persevering differences of growth rate between countries because the exogenous growth model could not explain it[4].

❖ Behaviour of Agents

The essential point of this theoretical wave is the assertion of the endogenous character of the growth, in the sense that **the behaviour of agents determines the rhythm of it**. The agents may have the choice between two activities like the production or the research as in P. Aghion and P. Howitt [1998 and 1992]. In S. Parente and E. Prescott [1991] technological change is modelled as the result of individual decisions to adopt more advanced technologies. And S. Parente [1994] has constructed an endogenous model of growth in which firms choose the technologies they adopt as well as the accumulate expertise or learning in a technology.

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4 At the origin of this theory there are two observations. On one hand, most of the countries knew periods of prolonged growth of the product per head for an almost unchanged population. On the other hand, the growth rates per head can sharply vary from a country to the other one. These stylised facts are contradictory to the conclusions of R. Solow [1956], which predicts a convergence of the long-term economies. That is why, this theory of the endogenous growth tries to analyse the economic growth of the product per head from the process of accumulation, and this without having to resort to exogenous factors.

The ambition of the endogenous growth theory is to understand the decisions, which are on the base of the creation of knowledge. That is why, the concept of economic growth is widened by the introduction of activities, which were until now at the border of the macroeconomics: activities such as the education, the institutions, the research and development, and the learning in the production process. And new variables appear as the quality and the knowledge of the workforce, the learning-by-doing and the arrival of next technology innovation.

❖ **Growth Sources Multiplicity**

The interest of the endogenous growth theory lies in the revealing of **the growth sources multiplicity**. We may recognise that endogenous growth explains some richer dynamics by considering explicitly the determiners of the growth such as the technological innovations and the learning-by-doing.

While the model of R. Solow [1956] shows that the only factor of durable growth is the exogenous technical progress[5], endogenous growth theory clarifies the so-called endogenous sources of the economic growth. The main factors of the growth that this theory puts in evidence are:

- the technical or scientific knowledge (research capital) coming from a specific activity called the research and development,

[5] In steady-state, the exogenous technical progress, which determines the accumulation of the capital, constitutes the only factor of growth. This vision places the source of the growth outside the economic field, because the technical progress, which is this source of the growth "fall from the sky". Whereas the theory of the endogenous growth wants to substitute a richer analysis which indicates the economic factors of the growth.

- the competence of the employees (human capital) accumulated thanks to learning-by-doing or thanks to investments in education[6],
- constant or increasing returns to scale in the investment which can result of externalities or from complementarities between firms or from learning-by-doing too,
- the public infrastructures, which have for property, that every user benefits completely from their effects while paying only a fraction of the cost.

Although the explanations of the growth proposed by the endogenous growth theory are not new[7], the contribution of these theories lies in the explicit writing factors such as the technology, the learning[8], the competence, and in the functioning of these in a formalised framework of general equilibrium. These models turn out more powerful as far as they integrate economic behaviours whose links with the accumulation of the physical capital are narrow. It seems difficult to speak about accumulation of the capital without considering the technological innovations and the learning of the labour force so much these various forms of investment seem imbricated and inter-connected.

[6] The first one and second factors can serve as engine of sustained growth only if the accumulation activity of research capital and/or human capital benefits completely from the already accumulated quantity. And an elasticity of one unit is a necessity.

[7] E. Malinvaud [1993] shows that the explanations proposed by the theories of the endogenous growth are not new. Indeed, M. Abramovitz and R. Solow introduced the technology and the education. Besides, the increasing returns to scale were the central argument of N. Kaldor, and it is even justified to go back up until Adam Smith.

[8] A nuance can be brought, because the first analysis modelling the learning-by-doing made by K. Arrow [1962] stays an exogenous growth model even if the technical progress is becoming endogenous through the learning-by-doing.

❖ **Economic Policy**

The endogenous growth theory reintroduces the role of economic policy, to the extent that the key role of externalities makes sub-optimal the mechanisms of market. The competitive equilibrium, so, obtained is not any more as in the model of R. Solow [1956] equal to the social optimum. This inequality between the competitive equilibrium and the social optimum serves as justification in the intervention of institutions situated outside the market; the agents endowed with powers and with resources not trying to maximise their own profit. These institutions establish a not trade co-ordination among the private agents. These institutions can, therefore, allow moving the competitive equilibrium closer to the social optimum. **Thanks to the endogenous growth theory the role of the economic policy is updated; the economic policy become a necessity again.**

On the basis of these arguments, the role of the State should be revised to lead economic policies the purpose of which is to accelerate the growth. For instance, R. Lucas [1993] recommends policy which involve sustained movement of the workforce from less to more sophisticated products. Furthermore, P. Aghion and P. Howitt [1998] recommends a higher mobility of production workers across products, not because it increases aggregate learning-by-doing as in R. Lucas [1993] but rather because it increases the steady-state mass of researchers.

3. Endogenous Growth Limits

The counterpart of this most major power of endogenous growth models is a bigger fragility. This fragility appears repeatedly through five major themes which are the following ones: the problem of the aggregation and the micro-economic foundations, the complementarity between the factors of production, the hypothesis of constant returns to scale in the function of production of the accumulables or intermediate goods, the economic policies, and finally the steady-state as a reference.

❖ Aggregation and Micro-economic Foundations

In the endogenous growth theory, in order to have an aggregate model, all the firms need to have the same production function, the same capital stock, and the same labour stock. We do not criticise the aggregation principle, but we criticise the way which leads to an aggregate endogenous growth model[9]. Endogenous growth models come from a different methodology of exogenous growth models, namely the requirement of microeconomic foundations. One of the fundamental principles, which characterise this approach in macroeconomics, is the optimisation rationality of agents. The particular shape of the technology of production of the capital goods

[9] Contrary to endogenous growth models, the exogenous growth models (as the model of R. Solow [1956]) are aggregate models with production functions, which represent all the economic agents in their whole. These exogenous growth models behave as if there was only a unique agent.

used is not based on these principles because the shape of the functions of production is independent from the optimisation behaviour of the firms[10].

In these models, the growth engine one is in externalities[11] whose existence is possible only if there are **interactions among several agents**. Consequently, endogenous growth models should approach the problem of the aggregation without doing as if the economy was reduced to a unique agent. That is why these models suppose in a implicit way **"symmetric" situations** such as firms which have the same production function, the same capital stock, and the same labour stock. In additionthey suppose that the capital goods production functions are homogeneous of degrees 1. As a result, the aggregated production function is the same that the individual production functions of the firms, firms which are completely identical[12].

Besides, to propose macroeconomic models these theories are brought to **strongly aggregate diverse variables the meaning of which is then ambiguous**, as for example the " stock of human capital ", and the " stock of research capital ". Nevertheless in a lesser measure this criticism can be spread to the traditional concept of stock of physical capital.

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[10] In fact, the object of this maximisation are not the shape of the production function. But the object of this maximisation are the result of maximisation individual behaviours, that is to say the economic variables such as the prices and the quantities.

[11] One of the manners to introduce externalities is to suppose that the increase of the total quantity of current capital in the economy entails an increase of the labour productivity. In fact, this introduction appears thaks to the learning and the accumulation of the knowledge being made as the activity develops (in other words the learning-by-doing).

[12] We will next see this point.

❖ **Increasing Return to Scale in the Final Good Production and Complementarity between Production Factors**

The hypothesis on the increasing returns to scale in the final good production function is not robust to obtain an endogenous growth, because the increasing returns to scale are not the key of the endogenous growth. What is necessary for endogeneing the growth is a much stronger hypothesis concerning the complementarity between the production factors.

R. Solow [1992 and 2000], actually, shows that an endogenous growth can exist without increasing returns to scale in the production function of final good. If we put aside this hypothesis of increasing returns in the production function of final good, and if we retain the hypothesis of complementarity of the production factors and the inter-temporal equilibrium, then it is possible to obtain an endogenous growth. That is why the **complementarity between the factors is without any doubt the determining element of a sustained growth**. For instance, P. Aghion and P. Howitt [1998] assume that the two sources of growth in their model are complementary.

❖ **Constant Return to Scale in the Capital Goods Production**

The hypothesis of constant returns to scale in the capital goods production function is indispensable to obtain a sustained growth path. In order to introduce the research and development or the learning-by-doing, the growth models should put strong hypotheses on the characteristics of these tow activities. These growth models are based on hypotheses such as economies of scale or externalities, hypotheses that question the convexity of the whole production. However this not convexity of the whole production always comes along with constant returns to scale in the capital goods production function which pulls the growth (research capital such as the innovations or human resources such as the learning-by-doing). This constancy of the returns to scale at the level of the firm in the capital goods production function is a crucial hypothesis for these endogenous growth models[13].

The growth bases either on the capital goods accumulation thanks to the technological innovations production or on the human capital accumulation thanks to the learning-by-doing for example. If we consider the sector of the research which produces the technological innovations the technology of which is the type $\dot{A} = \delta H_A A$ where A is the number of produced innovations and H_A the part of the human capital assigned to this sector. As $\dot{A}$ is linear in A, then the growth rate of A is constant (δH_A). If it was not the case the growth would be zero or explosive. For this reason, we can say that this hypothesis is indispensable to lead to a sustained growth. If the returns to scale in the capital goods production function were not exactly constant, then the growth would be divergent in the long term. In the long term, we do not observe either destruction, or explosion of the growth rates. In the same way, this reasoning can be considered for the human capital accumulation by means of the learning-by-doing.

[13] Contrary to the endogenous growth models, the exogenous growth models distinguish themselves on this point. For R. Solow [1994], constant returns to scale is not crucial to obtain a sustained growth path.

Consequently, **this hypothesis of constant returns to scale in the capital goods production function strongly conditions the results of these models and it is indispensable to obtain a sustained growth path**. From an empirical point of view, the statistics are contradictory on the shape of the returns to scale in the capiatl goods production[14]. So, this hypothesis bases on no precise empirical justifications **simply allows to endogeneing the capital goods accumulation, in order that this endogeneisation could generate a sustained growth**.

❖ **Economic policies**

Although we saw that the endogenous growth models reintroduce the economic policy, we think that economic policy recommendations are difficult with these models. The endogenous growth models support the idea that the investments in physical capital and in human capital have positive external effects on the production. But given that the competitive equilibrium is a state of the economy for which firms do not consider in their calculations these external effects. This equilibrium is going to be different from the social optimum. As a result, the State can intervene to allow a better inter-temporal allocation of the resources and so to allow an amount of higher investment. As we saw, endogenous growth models are not robust in the hypothesis of constant returns to scale in the capital goods production as far as their main conclusion on the existence of a sustained growth rate collapses if this hypothesis is eliminated. The convergence to the steady-state is assured only with this incredibly

[14] The studies concerning the returns to scale in the capital goods production at the industry level are contradictory; they would seem to be increasing for J. Squared, p. Dubois and E. Malinvaud, while the other analyses would tend to show that they are decreasing R. Baldwin. But nevertheless, they would be increasing at the national level. See in that case S. Carcillo and V. Reiffers [2001].

restrictive and improbable hypothesis of exactly constant returns to scale in the capital goods production. If this hypothesis were open to criticism, it would be rather on the basis of its lack of realism because it has no empirical foundations. Then, it becomes difficult to justify to base recommendations in terms of economic policies on such models.

We need to notice that the problem in a discipline such as the economics and more particularly for the economic growth models is not the problem of the realism of the models. But the problem is to know what we can do of the models conclusions. More exactly, the degree of realism of a hypothesis or a model should be to estimate with regard to the end of these models. A model having for object to put in evidence the fundamental mechanisms in the analysis of a problem will not have the same realism requirement degree of its hypotheses as the model which has for vocation to estimate the impact of an economic policy. From this point of view, it is questionable to base recommendations of economic policy on endogenous growth models.

❖ **Steady-state as a Reference**

The endogenous growth models mechanism is a movment of the workforce across sectors. Nevertheless this explanation may be criticised because the part of the research workers in the labour force is too small. The neo-classical growth theory considers that technical change and economic growth are **processes involving moving equilibria**. There may be forces at work at any time to move the system toward equilibrium given the prevailing state of technology. These models do not recognise that in a regime of continuing technical advance, the economy as a whole is in a continuing state of disequilibrium. Endogenous growth models are interested in explaining long-run per-capita growth and, therefore, confine their analysis to balanced growth paths[15]. Some special assumptions are required. As we saw before, endogenous growth models are based on individual comportments. They have some particular micro-economic basis for aggregation. One of the most important assumptions is the requirement that technological progress, however it arises, should be labour augmenting in character, that is a complementarity between production factors. Quite analogously, if there are increasing returns to scales in the final good production, they must affect production in a special labour-enhancing way. Furthermore, they need the hypothesis of constant return to scale in the capital goods production. And they reach to economic policies.

What is the mechanism, which leads from one steady-state to another in endogenous growth models which consider the relations between technological innovations and learning-by-doing?

The main characteristics of such endogenous growth models are that the mechanism of such models is a movement of the workforce across sectors. When learning–by-doing is purely external to the firm, then in equilibrium many resources may end up being devoted to research at the expense of learning–by-doing, which in turn will slow down growth. This possibility called the "tale of two cities effect", was earlier pointed out by A.Young [1992]. When each product's quality improvements

[15] A broad definition of the balanced growth paths (called steady-states too) is dynamic paths on which all economic variables grow at the same rate.

depends on only the internal learning–by-doing of the firm producing that product, then research always has a positive effect on growth in the steady-state. This is due to more forward-looking nature of research compared with learning–by-doing. This, together with positive discounting and decreasing returns to learning–by-doing on existing lines, implies than even the flow of secondary innovations will be affected more by research than by learning–by-doing.

The main conclusion of the model of P. Aghion and P. Howitt [1998] is that the steady-state rate of growth may be increased if production workers become more adaptable, that is, if the rate at which they are able to switch from producing old products to producing new ones increases. This result supports R. Lucas [1993] claim to the effect that the key to high growth performance is the ability to move skilled workers quickly between sectors. This leads to a positive effect of competition on growth: an increase in the substitutability between new and old products, which implies an increase in competitiveness between them. This substitutability between investment goods may induce production workers to leave old products more rapidly, with the effect of inducing a higher level of research. However, contrary to R. Lucas [1993], a higher mobility enhances growth not because it increases the pace of learning–by-doing but rather because it enhances the profitability of research (a successful fundamental innovator benefits from having more workers starting up on a line he has just discovered). And insofar as learning–by-doing is internalised by firms, research has an unambiguously positive effect on growth at the margin in a steady-state.

This explanations may be criticised because the part of research workers in the labour force is about five persons every thousand[16], and do not increase rapidly. Consequently, these models only partially capture the forces at play when the learning technology improves, R&D costs decline, or the labour force size increases.

4. Conclusion

Although the endogenous growth theory updates a dynamics much richer than the previous models we remain sceptic as for the mechanisms put in evidence and the conclusions in terms of economic policies. These endogenous growth theory is dedicated to the analysis of the determiners of the growth such as the technological innovations and the learning-by-doing and so in their accounting decomposition. The consideration of the technological innovations and the learning-by-doing is one step of the growth theory towards more realism. On the other hand, the conclusions of this theory do not seem satisfactory, by the way that the main mechanism, which reaches the results, is a movement of the workforce[17]. Nevertheless, the endogenous growth theory has the interest to be the first to have studied the relations between the technological innovations and the learning-by-doing. It opens, hence, the way to new analyses and to new studies in this domain. This conclusion underlines the necessity of further studies examining transitional dynamics in growth theory.

[16] For the OECD countries the number of researchers in the workforce is 5.1 persons every 1000. This number ranges between 0.6 per thousand for Mexico and 9.2 per thousand for Japan.

[17] As we underlined it first, the models of R. Lucas [1993] and P. Aghion and P. Howitt [1998] are analyses, which are in terms of allocation of the resources.

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