Education and Innovation as Twin-Engines of Growth*

Manfred Stadler[a)]

Abstract

We develop a dynamic general equilibrium model of education, quality and variety innovation, and scale-invariant growth. The early endogenous innovation-based growth models incorporate a scale effect predicting that larger economies are characterized by higher per capita growth rates. Recent models of semi-endogenous growth remove this scale effect but instead imply that economic growth depends proportionally on population growth. In contrast to the predecessor models, this paper argues that endogenous human-capital accumulation rather than an exogenously given continuing increase of the population is decisive for per capita growth. The consequence of the proposed integration of human capital accumulation into a two-R&D-sector model of quality and variety innovation is that education and innovation appear as twin-engines of growth and that steady state growth rates can be enhanced by subsidizing education.

Keywords: Education, quality and variety innovation, scale-invariant growth

JEL Classification: O2, O3

[a)] University of Tübingen, Department of Economics, Mohlstraße 36, D-72074 Tübingen, Germany.
E-mail: manfred.stadler@uni-tuebingen.de

1 Introduction

Within the modern growth literature it is widely accepted that human capital accumulation and techological progress are the two most important engines of economic growth. In his pioneering contribution, Lucas (1988) has emphasized human capital accumulation by education as a decisive source of endogenous growth. In their empirical studies, Hanushek/Kimko (2000) and Barro (2001) have found that especially the quality, but also the quantity of schooling are positively related to subsequent economic growth. Since the early nineties, however, endogenous growth theory is undoubtedly dominated by the innovation-based growth models which exclusively build on innovation dynamics as the main engine of growth. Romer (1990), Grossman/Helpman (1991) and Aghion/Howitt (1992, 1998) were among the first to introduce dynamic general equilibrium models which explain per-capita growth by intentional R&D activities of private firms. According to their approach, technological change results from an endless sequence of vertical improvements of goods along a given quality ladder or, alternatively, from a continuing horizontal expansion of the variety of goods. The innovation-based endogenous growth models share a common property which is well-known as the scale effect. This scale effect predicts that larger economies grow faster and that population growth causes higher per-capita growth. This counterfactual prediction continues to hold in a related sense if population growth is replaced by an increasing qualification of the labor force due to educational investment in human capital. Any enlargement of human capital now inevitably induces increasing per-capita growth rates which is certainly at odds with the empirical evidence. For this reason, no successful attempts have been made to integrate the sustainable process of human capital accumulation, as suggested e.g. by the influential model by Lucas (1988), into the early endogenous innovation-based growth models. Therefore, until recently, education on the one hand and innovation on the other hand were treated separately as two alternative and independent engines of economic growth.

In the mid nineties, Jones (1995a) presented an influential empirical study in which he could find no support for the scale effect as predicted by the endogenous growth models. In response to this "Jones critique", a new class of semi-endogenous growth models has emerged (see, e.g. Jones 1995b, 2002, Kortum 1997, Segerstrom 1998). As a distinguishing feature, these models remove the scale effect but instead imply that per-capita growth depends proportionally on population growth. Without doubt, this property of the semi-endogenous growth models is at odds with the empirical findings, too. However, from a technical point of view, it opens the challenging possibility of integrating skill acquisition of workers in accordance with the empirical evidence if exogenous population growth is replaced by endogenous human capital accumulation. A few attempts in this promising direction have recently been made. Arnold (1998) and Blackburn/Hung/Pozzolo (2000) have integrated education in Romer's (1990) variety-expansion model, Arnold (2002) has incorporated education into Segerstrom's (1998) quality-ladder model. The crucial assumption which removes the scale effect in the Segerstrom-Arnold approach is a continuing deterioration of the technological opportunities which results in a declining productivity of workers in the R&D sector. However, a historical analysis of the occurrence of technological innovations in different industries clearly shows that periods of increasing and decreasing technological opportunities have alternated. In our view, the existing empirical evidence is not convincing enough to support the hypothesis of a continuing declining trend in the R&D productivity.

In this paper, we therefore follow the suggestions by Arnold (1998, 2002) and Blackburn/Hung/Pozzolo (2000) to focus on human capital growth rather than on population growth within the framework of a semi-endogenous growth model, but we prefer to build on another even more convincing specification which provides an alternative mechanism of eliminating the scale effect.[1] We adapt this mechanism from the latest generation of growth models as represented by Young (1998), Peretto (1998), Dinopoulos/Thompson (1998), Jones (1999), and Li (2002) who argue that the variety of products grows proportionally to the population of the economy. Extending an appropriate version of such a basic model by accounting for endogenous accumulation of human capital instead of exogenous population growth yields some new insights about the impact of education on innovation and growth. Most important, human capital accumulation and technological innovation appear as twin engines of growth which are closely linked to each other.

The paper is organized as follows. Section 2 introduces the model. In Section 3, the steady-state growth equilibrium is derived and the factors explaining education,

[1] Another strand of the literature emphasizes the role of human capital in the absorption of new technology (see, e.g. Stokey 1991, Eicher 1996, Lloyd-Ellis/Roberts 2002).

innovation and growth are identified. Finally, Section 4 concludes.

2 The Model

We consider an economy which consists of a continuum of firms, each producing a differentiated consumer good. The goods are sold to households having a taste for quantity, quality and variety. Improvements of quality and extensions of variety take place stochastically with intensities increasing in the innovative efforts of firms. Households are endowed with human capital which can be accumulated by education. Thus, there are two engines of growth which will prove to be closely linked to each other: education and innovation.

2.1 Education and Spending Behavior of Households

There is a continuum of unit mass of households which live forever and inelastically supply human capital services in exchange for wage payments. They share identical preferences and maximize their discounted utility

$$U_t = \int_0^\infty e^{-\rho t} \ln D_t \, dt, \tag{1}$$

where ρ is the constant subjective discount rate and

$$D_t = \left[\int_0^{N_t} q_{jt}^{1-\alpha} x_{jt}^{\alpha} dj \right]^{1/\alpha}, \quad 0 < \alpha < 1, \tag{2}$$

is a quality-augmented Dixit-Stiglitz consumption index which measures instantaneous utility at time t. It reflects the households' tastes for quantity x_{jt} and quality q_{jt} of the demanded goods available in industry j as well as their love for variety of horizontally differentiated goods indexed on the interval $[0, N_t]$. With these preferences, the elasticity of substitution between any two products across industries is given by $\varepsilon = 1/(1-\alpha) > 1$.

For each household, the discounted utility maximization problem can be solved in two steps. The first step is to solve the across-industry static optimization problem. Maximizing the consumption index (2) subject to the budget constraint

$$E_t = \int_0^{N_t} p_{jt} x_{jt} dj$$

where E_t is the household's expenditure, and p_{jt} is the price of product j, yields the static demand function

$$x_{jt} = \frac{q_{jt} p_{jt}^{-\frac{1}{1-\alpha}} E}{\int_0^{N_t} q_{jt} p_{jt}^{-\frac{\alpha}{1-\alpha}} dj} \tag{3}$$

for product j at time t. Hence, the consumption index (2) can be written as

$$D_t = E_t / p_t^D \ ; \quad p_t^D \equiv \left[\int_0^{N_t} q_{jt} p_{jt}^{-\frac{\alpha}{1-\alpha}} \right]^{-\frac{1-\alpha}{\alpha}} . \tag{4}$$

The second step is to solve the dynamic optimization problem by maximizing discounted utility. Households supply human capital services to production, R&D, and education. By devoting H_t^E units to education, households can raise their human capital according to the Uzawa-Lucas technology

$$\dot{H}_t = \kappa H_t^E - \delta H_t, \tag{5}$$

where $\kappa (> \delta + \rho)$ reflects the efficiency of the education system and δ is the constant depreciation rate of human capital. The dynamic budget constraint is given by

$$\dot{A}_t = r_t A_t + w_t (H_t - H_t^E) + \sigma w_t H_t^E - E_t - T_t, \tag{6}$$

where A_t is the value of asset holdings, r_t is the nominal interest rate, w_t is the nominal wage rate, and $\sigma \geq 0$ is a constant education subsidy rate for foregone income. The subsidies are publicly financed by a non-distorting lump-sum tax T_t which is exogenously given for the households. Each household maximizes its discounted utility (1), given (4), subject to the accumulation function (5) and the dynamic budget constraint (6).

The current-value Hamiltonian of this optimal control problem is given by

$$\mathscr{H} = \ln E_t - \ln p_t^D + \psi_1 [r_t A_t + w_t (H_t - H_t^E) + \sigma w_t H_t^E - E_t - T_t] + \psi_2 [\kappa H_t^E - \delta H_t] \ ,$$

where ψ_1 and ψ_2 are the costate variables of A_t and H_t. The necessary first-order conditions are given by

$$\mathscr{H}_E = 1/E_t - \psi_1 = 0, \tag{7}$$

$$\mathscr{H}_A = \psi_1 r_t = \psi_1 \rho - \dot{\psi}_1, \tag{8}$$

$$\mathscr{H}_{H^E} = -\psi_1(1-\sigma)w_t + \psi_2 \kappa = 0, \tag{9}$$

$$\mathscr{H}_H = \psi_1 w_t - \psi_2 \delta = \psi_2 \rho - \dot{\psi}_2. \tag{10}$$

Conditions (7) and (8) yield the well-known differential equation

$$\dot{E}/E = r_t - \rho.$$

The optimal time path of consumer expenditures applies not only to a representative household but also to the aggregate economy. At this aggregation level, it proves convenient to impose the normalization $E_t = p_t^D D_t = 1$ which implies that the nominal interest rate r_t equals the subjective discount rate ρ. Using this identity, we derive from (8), (9), and (10) the differential equation

$$\dot{w}_t/w_t = -[\kappa/(1-\sigma) - \delta - \rho]. \tag{11}$$

The larger the discount and depreciation rates, the lower the efficiency of education, and the lower the education subsidy rate, the larger is the growth rate of nominal wages required by the households in order to invest in human capital.

2.2 The Product Markets

Each product line is initially created by a horizontal innovation. Once a new variety is available on the market, its quality can be improved by vertical innovations. The quality grades of the products are arrayed along the rungs of a quality ladder which is assumed to be equal across industries. Each new generation of products provides a λ times higher quality, where the upgrading factor $\lambda > 1$ is assumed to be exogenously given and constant over time. Thus the quality of the top-of-the-line product in industry j at time t is given by

$$q_{jt} = \lambda^{m_{jt}} Q_{t_N},$$

where Q_{t_N} denotes the initial level of quality of variety j when it was introduced at time $t_N \leq t$ and m_{jt} is the number of sequential upgrading innovations in industry j until time t. The average quality of all existing varieties is defined by

$$Q_t = (1/N_t) \int_0^{N_t} q_{jt} \, dj. \tag{12}$$

To avoid an unplausible effect of declining average quality as a result of the introduction of new varieties, we assume that the initial quality level of a variety innovation equals the average quality at this time.

All consumer goods are produced subject to a constant-returns-to-scale technology with human capital as the single input factor. By an appropriate choice of units, production of one unit of each variety x_{jt} requires one unit of human capital H_{jt}^X. According to this technology, marginal production cost is equal to the wage rate w_t. Therefore, the supplier of variety j maximizes flow profits

$$\pi_{jt} = (p_{jt} - w_t)x_{jt}. \tag{13}$$

The price setting behavior of firms depends on the underlying market structure which in turn is endogenously determined by the basic technological conditions in the industries. In the case of drastic innovations, which will be assumed throughout, the pricing decisions of the technological leaders are constrained by competition from the producers of substitutive goods in the other industries. According to the demand function (3), the price elasticity of demand is given by $-\varepsilon = -1/(1-\alpha)$ and, hence, the optimal pricing rule is given by[2]

$$p_{jt} = (1/\alpha)w_t. \tag{14}$$

Since the leading firms charge identical prices $p_{jt} = p_t \; \forall \; j$, independent of product qualities, the demand function (3) can now be written as

$$x_{jt} = \frac{q_{jt}}{N_t Q_t p_t} \, . \tag{15}$$

[2] In the alternative case of non-drastic quality innovations, each technological leader would charge a limit price $p_t = \lambda^{\frac{1-\alpha}{\alpha}} w_t$, thereby driving the rivals out of the market. Similar to our version the mark-up factor remains constant, so that the following considerations continue to hold in this case.

Obviously, the demand for product j depends negatively on price p_t and the variety mass N_t of existing products, but positively on the ratio of its quality to the average quality of all products, q_{jt}/Q_t.

Therefore, the maximized flow profits (13) are given by

$$\pi_{jt} = \frac{(1-\alpha)q_{jt}}{N_t Q_t} \; . \tag{16}$$

Once the quality of a new variety is improved by a drastic vertical innovation it becomes obsolete. However, such an improvement may infringe on the patent of the variety innovator. Therefore, following Li (2000), we allow for the possibility of a license agreement between the variety and quality innovators in which the latter have to pay a fixed fraction $0 \leq \beta < 1$ of the operating profits as a royalty to the former. The parameter β can then be interpreted as the scope of the variety patent or, alternatively, as a measure of the relative bargaining power of variety and quality innovators. Each further quality innovation, which is assumed not to infringe on the patent of the previous quality innovator, drives the lower quality product out of the industry, so that all varieties are exclusively produced by the patent holders of the top-of the-line products. However, even these patent holders are required to pay the royalty to the original variety innovator. This license aggreement implies that each quality innovator receives the flow profits $(1-\beta)\pi_{jt}$, while the flow profits of the variety innovator reduce to $\beta\pi_{jt}$, as soon as the first quality innovation occurs.

The innovation dynamics, rising quality Q_t and expanding variety N_t are governed by the human capital resources devoted to both R&D dimensions. Following Li (2000, 2002), we assume that both types of innovative activities take place simultaneously, but in contrast to the existing literature we treat not only quality innovations but also variety innovations as stochastic processes.

2.3 Quality-upgrading Innovations

The quality of the consumer goods can be upgraded by a sequence of innovations, each of which builds upon its predecessors. To produce a higher quality product, a blueprint is needed. These blueprints are developed by innovative firms in a separate R&D sector. The lure of temporary monopoly rents drives potential entrants to engage in risky R&D projects in order to search for the blueprint of a higher quality product. The first firm to develop the higher quality product is granted an infinitely-lived patent for the intellectual property rights. Competition therefore takes the form of a patent race between rival firms. Any quality innovation opens up the opportunity for all firms to search for the next vertical innovation in this industry. This implies an external spillover effect of technological knowledge since even laggard firms can equally participate in each patent race without having taken all of the rungs of the quality ladder themselves. It is only the patent protection which guarantees temporary appropriability of innovation rents. Each firm may target its research efforts at any of the continuum of state-of-the-art products, i.e. it may engage in any industry. If it undertakes R&D at intensity h^Q_{jt} for a time interval of length dt, it will succeed in taking the next step up the quality ladder for the targeted product j with probability $h^Q_{jt}dt$. This implies that the number of realized innovations in each industry follows a Poisson process with the arrival rate h^Q_{jt} which is specified as

$$h^Q_{jt} = \frac{H^Q_{jt} Q_t}{\mu^Q q_{jt}}. \tag{17}$$

The arrival rate of vertical innovations is assumed to depend proportionally on the amount of human capital H^Q_{jt} devoted to R&D activities in order to realize a quality improvement in industry j. The parameter μ^Q denotes the degree of technological difficulty in realizing a vertical innovation and is assumed to be constant and common to all industries. The ratio q_{jt}/Q_t reflects a negative externality of industry specific innovation successes in the past by indicating that the realization of a further quality innovation becomes more and more difficult as the technological lead of the achieved quality to the average quality level increases. If a firm succeeds in a quality innovation it attains the stock market value V^Q_{jt}. To participate in a patent race the firms have to employ skilled labor in their research labs. An entrepreneur who devotes H^Q_{jt} units of human capital to vertical R&D at a cost of $(1-\xi)w_t H^Q_{jt}$ for a time interval of length dt attains the patent value V^Q_{jt} with probability $(H^Q_{jt}Q_t)/(\mu^Q q_{jt})dt$, where $\xi \geq 0$ denotes the R&D subsidy rate financed by a non-distorting lump-sum tax. The entrepreneur can finance this R&D venture by issuing equity claims that pay nothing in the case that the research effort fails but entitle the claimants to the income stream π_{jt} if the effort succeeds. Free entry into each patent race implies

$$V^Q_{jt} = \mu^Q (1-\xi) w_t q_{jt}/Q_t \ . \tag{18}$$

The stock market value V_{jt}^Q of a successful firm is given by the no-arbitrage condition

$$r_t = \pi_{jt}/V_{jt}^Q + \dot{V}_{jt}^Q/V_{jt}^Q - h_{jt}^Q, \tag{19}$$

which implies that the expected return on equities of quality innovators must equal the return on an equal size investment in a riskless bond. Since the risks associated with industrial research efforts are idiosyncratic, equity holders can earn a safe return by holding a well-diversified portfolio of firms' shares in different industries. Substituting (16) and (18) into (19), taking the derivative of V_{jt}^Q, and using $r_t = \rho$ yields

$$\rho = (1-\beta)(1-\alpha)/[\mu^Q(1-\xi)w_t N_t] + \dot{w}_t/w_t - \dot{Q}_t/Q_t - h_t^Q, \tag{20}$$

where the arrival rate proves to be independent of the industry, i.e. $h_{jt}^Q = h_t^Q \; \forall \, j$.

The law of large numbers then implies that aggregate quality growth is deterministic and satisfies

$$g_Q = (\lambda - 1)h_t^Q. \tag{21}$$

We now turn to variety innovations.

2.4 Variety-expanding Innovations

In the tradition of the models introduced by Romer (1990) and Grossman/Helpman (1990) variety innovations are usually assumed to follow a deterministic process.[3] However, there seems to be no plausible reason to suppose riskless variety innovations. Therefore, we assume that, according to the case of quality innovations, the number of variety innovations also follows a stochastic process. In contrast to the predecessor models we assume that variety innovation is not only occurring in a single industry but takes place in all industries of the economy. Each firm i undertaking horizontal R&D at intensity h_{it}^N for a time interval of length dt will succeed

[3] In their simplified models, Aghion/Howitt (1998) and Dinopoulos/Thompson (1999) even assume, that variety innovations are pure results of costless imitation.

with probability $h_{it}^N dt$. At the aggregate level this implies that the numbers of realized variety innovations follows a Poisson process with an arrival rate h_t^N which is specified as

$$h_t^N = H_t^N / \mu^N, \tag{22}$$

where μ^N denotes the degree of technological difficulty in realizing a variety innovation. The arrival rate of variety innovations depends proportionally on the amount of human capital H_t^N devoted to horizontal R&D activities.[4] The mass of horizontally differentiated products at time t is then determined by

$$N_t = \int_0^t h_{t'}^N \, dt',$$

implying the growth rate

$$g_N = \frac{H_t^N}{\mu^N N_t} \; . \tag{23}$$

Free entry into each horizontal patent race implies

$$V_t^N = \mu^N (1 - \xi) w_t \; , \tag{24}$$

where ξ is the same R&D subsidy rate as it was supposed in the case of quality innovations. The stock market value V_t^N of a variety innovation is given by the no-arbitrage condition

$$r_t = \pi_t^N / V_t^N + \dot{V}_t^N / V_t^N - ((V_t^N - V_t^R)/V_t^N) h_t^Q, \tag{25}$$

where the right-hand side is the rate of return on equities of variety innovators, consisting of the dividend rate, the capital gains and the risk of losing part of the profits in the future. The term $(V_t^N - V_t^R)$ denotes the expected capital loss when the first quality innovation occurs, where V_t^R is the expected discounted value of the royalties $\beta \pi_{jt}$ at time t_Q, when the first quality innovation in the industry occurs.

[4] Note that there is no intersectoral spillover effect as it was assumed in the case with vertical innovations. The justification of the absence of this kind of spillover effects is the above assumption that each variety innovation arrives with the average quality of all top-of the-line products available at that time.

At time t_N of the variety innovation, expected royalties are expected to be given by $\beta(1-\alpha)/N$, since the expected future quality q_{jt} of the improved product equals the expected average quality Q_t at the same time.

Simple calculations show that the expected difference $V_t^N - V_t^R$ equals $V_{jt}^Q(q_{jt}/Q_t)$ at time t_N. Hence, using (18) and (24) yields $(V_t^N - V_t^R)/V_t^N = \mu^Q/\mu^N \equiv \mu$. The expected relative capital loss at time t_Q is nothing but the ratio of the degrees of technological difficulties of realizing quality and variety innovations. Thus, substituting (16) and (24), taking the derivative of V_t^N, and using $r_t = \rho$, the variety R&D no-arbitrage condition (25) can be rewritten as

$$\rho = (1-\alpha)/[\mu^N(1-\xi)w_t N_t] + \dot{w}_t/w_t - \mu h_t^Q. \qquad (26)$$

To close the model, we finally use the market-clearing condition for human capital

$$H_t = H_t^X + H_t^E + H_t^Q + H_t^N, \qquad (27)$$

which can be devoted to production, to education, and to both types of R&D.

3 The Steady-state Growth Equilibrium

We restrict our attention to the steady-state growth equilibrium where the shares of human capital in the different sectors remain constant over time. Aggregate human capital devoted to production can be derived, using (14) and (15), as

$$H_t^X = \int_0^{N_t} x_{jt} dj = 1/p_t = \alpha/w_t.$$

Since the mark-ups in the price-setting equation (14) are constant, it follows that $g_{H^X} = -g_w$. Therefore, the steady state growth rates of human capital in all sectors are determined by

$$g_H = g_{H^X} = g_{H^E} = g_{H^Q} = g_{H^N} = -g_w = \kappa/(1-\sigma) - \delta - \rho. \qquad (28)$$

The quality-augmented consumption index (2) is given by aggregating (15) across the industries and using the average quality index defined in (12) to obtain

$$D_t = \alpha[N_t Q_t]^{\frac{1-\alpha}{\alpha}}/w_t.$$

Using (28), the steady state growth rate of the index is

$$g_D = \frac{1-\alpha}{\alpha}(g_N + g_Q) + g_H. \tag{29}$$

Variety expansion and quality improvement of the products as well as human capital accumulation are the interrelated channels of growth. Most important, the dynamics of quality and variety innovations decisively depend on the pace of human capital accumulation. From (23) the growth rate of the mass of horizontally differentiated products is given by

$$g_N = g_H \ . \tag{30}$$

The growth rate of the average quality results from (20) and (26) by using (21) and (28) as

$$g_Q = \frac{(\lambda-1)(1-\beta-\mu)}{(\lambda-1+\beta)\mu} \ (g_H+\rho) = \frac{(\lambda-1)(1-\beta-\mu)}{(\lambda-1+\beta)\mu} \ (\frac{\kappa}{1-\sigma} - \delta). \tag{31}$$

It depends not only on the basic conditions of the education system but also on the technological conditions as well as on the endogenously determined market structure. Inserting these growth rates into (29) finally yields[5]

$$g_D = \left[\left(1 + \frac{(1-\alpha)(\lambda-1)(1-\beta-\mu)}{(\lambda-1+\beta)\mu}\right) \left(\frac{\kappa}{1-\sigma} \ - \delta\right) - \ \rho\right] /\alpha. \tag{32}$$

As is characteristic for semi-endogenous growth models, the long-run growth rate is unrelated to scale. However, in accordance with the empirical evidence the explanatory factors of the accumulation of both human capital and technological knowledge are derived as important determinants of growth. As can be seen from (32), the growth rate depends

- positively on market power $1/\alpha$,
- positively on the innovation size λ,

[5] Using the equations $H_t^X = \alpha/w_t$, $H_t^E = (g_H+\delta)H_t/\kappa$, $H_t^Q = g_Q N_t/(\lambda-1)$, and $H_t^N = g_H \mu^N N_t$ for the factor input in the various sectors, the market clearing condition (27), and condition (20) or (26) can be used to determine the equilibrium values of w_t and N_t.

- positively on the subsidy rate σ,
- positively on the efficiency of the education system κ,
- negatively on the scope of the patent of a variety innovation β,
- negatively on the ratio of the degrees of difficulty of realizing quality and variety innovations μ,
- negatively on the subjective discount rate ρ, and
- negatively on the depreciation rate δ.

The efficiency of education as well as the education subsidy rate not only accelerate the pace of human capital accumulation but also the dynamics of quality and variety innovation. In this sense, human capital accumulation of households and innovations as a result of intentional R&D activities of firms can be interpreted as twin engines of economic growth which are closely linked to each other.

4 Conclusion

Recent semi-endogenous growth models have accomplished a valuable task by removing the scale effect present in the early endogenous growth models. A disturbing property of these non-scale models is, however, that the long-run growth rate depends proportionally on population growth. Without doubt, this property is at odds with the empirical evidence. The present paper has offered an alternative interpretation of the role of the input factor labor by replacing exogenous population growth by endogenous human capital accumulation. Therefore, consistent with the empirical evidence, the rate of growth is not driven by population growth but by education of the households. Human capital resources devoted to education and R&D appear as engines of economic growth which are inextricably linked to each other. As was shown, human-capital accumulation not only has a direct growth effect, but also an indirect effect via an acceleration of quality and variety innovations. The factors enhancing the skill acquisition of the households are therefore as important as they are in the endogenous human capital growth model of Lucas (1988), but they are complemented by the technological and structural conditions influencing the innovative activities of firms.

It has turned out that subsidizing education is a suitable policy to raise the long-run growth rate. Thus, education policy plays a decisive role within the public growth policy. On the one hand, it influences human capital accumulation as one important engine of growth. On the other hand, since human capital is an essential input into R&D, the model also highlights the impact of public education expenditures on the innovation dynamics which are considered as the second of the twin engines of growth.

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