# The Implications of Wage Structure Rigidity on Human Capital Accumulation, Economic Growth and Unemployment: A Schumpeterian Approach to Endogenous Growth Theory

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**Abstract**

The approach put forward in this article is based on Schumpeter`s idea of creative destruction, the competitive process by which entrepreneurs are always looking for new ideas that will render their rivals` ideas obsolete. I present a model in which the rate of economic growth is sensitive to the interactions between relative wage and human capital accumulation. Human capital is an important source of sustained growth. By focusing explicity on innovation as an economic activity with different economic causes and effects, this article tries to open the door to a deeper understanding of how labor market rigidity in the form of wage structure rigidity affects human capital accumulation, and thereby the long-run growth through their effects on economic agent`s incentives to engage in knowledge-producing (education) activities. New technological vintages make it necessary that workers must become reeducated in order to qualify as skilled workers with the new generation of technology. Wage structure rigidity limits the incentives of agents to accumulate and adjust their human capital. This will be harmful to growth and employment.

**Keywords**: Economic growth, human capital accumulation, innovation, labor market rigidity, unemployment, wage (structure) rigidity.

**JEL-Classification**: J1, J2, J3, J6, O3, O4.

# The Implications of Wage Structure Rigidity on Human Capital Accumulation, Economic Growth and Unemployment: A Schumpeterian Approach to Endogenous Growth Theory

## I. Introduction

The increase in material well-being that has taken place in industrialized countries since the second world war has been characterized by technical progress and innovations. Openness to technical change and innovation is a salient characteristic of the nations that become economic leaders of their time.

The international innovation race has intensified in the 1980s and 1990s, with EU firms facing new competitors from Asia and postsocialist countries of Eastern Europe. Therefore, countries continously need to adjust to high technology competition and the broader technological catching up process. This requires structural adjustment in the whole economy. For example, the worldwide increase in unskilled labor supply during the 1980s and 1990s requires a corresponding adjustment in relative wage rates (skilled versus unskilled labor) if employment is to grow.

Technological change does not fall like manna from heaven. Innovative, education and absorption (technological knowledge diffusion) activities are conditioned by income, laws, institutions, customs, and regulations. These conditions affect the incentives to invest in human capital accumulation (technological knowlege) and the ability to appropriate rents from newly created knowledge.

The purpose of this article is to seek some understanding of the interplay between structural characteristics, especially wage structure rigidity, and human capital accumulation and the implication of this interplay on technological progress and economic growth. The approach put forward in this article is based on Schumpeter`s idea of creative destruction, the competitive process by which entrepreneurs are always looking for new ideas that will render their rivals ideas obsolete. Firms surviving the competitive struggle do so not so much by varying price and quantities as by improving qualities (for example product innovations).

Using mainstream economic theory it is nearly impossible to capture the vision of economic life as a process of perpetual change and innovation through competition. For example, the general equilibrium theory that dominates the mainstream is one in which the product space is given, technology is given and firms are mere placeholders for technological possibilities available to everyone[1]. Thus most of the the neoclassical growth models assume technological progress to be exogenous not because this is a realistic assumption, but because it is the only manageable one within this framework.

[1] Technological knowledge is modeled as a public good. In reality however, firms have only a local and very limited knowledge of existing technologies (Eliasson 1990). They do not have timeless and costless access to any technology other than they use. This is due to the fact that the access to other technologies requires learning by doing, and firm and product specific human capital and knowledge.

By focusing explicity on innovation as an economic activity with different economic causes and effects, this article tries to open the door to a deeper understanding of how labor market rigidity in form of wage structure rigidity affects human capital accumulation, and thereby the long-run growth through their effects on the incentives of economic agents to engage in education or more generally knowledge-producing activities. That is, to the extent that wage structure rigidity limits these incentives to invest in human capital accumulation, it will be harmful to mobility (labor reallocation) and growth.

In other words: the intensified international technology race has led to a rise in the demand for skilled labor. That is, high technology manufacturing was indeed the sector which recorded employment growth in OECD countries (see Welfens et al. 1998). The higher demand for skilled labor, coupled with the expansion in the supply of unskilled labor (due to the opening up of Asia and Eastern Europe) implies a relative fall in wages of unskilled labor. Given relative wage rigidity in many EU countries, this will be harmful to mobility (e.g., accumulation and adjustment of human capital) and faster structural change; impediments to mobility will reduce potential production possibilities as well as skill mismatches will raise the unemployment rate.

The model presented in this article relies on the notion of a steady state, in which output, wages, and knowledge all grow at the same constant rate. Due to the fact that innovations (especially drastic innovations) often have effects that take decades to work out, I am primarly interested in the long run. Steady state analysis is a convenient analytical device for modeling the long run. In some cases however steady state analysis may be a misleading device, because temporary effects (short run analysis) might persist for generations before fully disappearing. Nevertheless, steady state analysis is a starting point from which a more complete dynamic analysis should proceed.

First, I will present a basic Schumpeterian growth model. This model will be extended by integrating different kinds of labor and then endogenizing different wage paths. Then, the model will be extended by wage structure rigidity in order to analyse the effects of labor market rigidity (in form of wage structure rigidity) on human capital accumulation and thereby on economic growth.[2] I will present a model in which the rate of economic growth is sensitive to the interaction between relative wage and human capital accumulation.

## II. Growth Theory: A Short Review

Most of the widely used growth model make explicit a distinction between capital accumulation and technological progress.

The vision of the neoclassical growth theory puts (physical) capital accumulation at the heart of the growth process, eliminating endogenous technological progress through innovations a priori. In the Solow-Swan growth model, diminishing returns to capital accumulation would

[2] The reverse causation from growth to income distribution (see Aghion and Howitt 1998, chapter 9) is not analysed in this article.

eventually make any growth in excess of the exogenously determined rate of technological progress self-limiting. Endogenous growth models including capital as well as technological progress through innovation (e.g., Romer 1990 or Grossman and Helpman 1991, chapter 5) come to the same results[3]: the incentives to innovate determines the rate of technological progress, which in turn determines the economy`s long-run growth rate, independently of the level of the economy`s capital stock.[4]

Schumpeter`s idea of perpetual technical change and innovation through competition however is at the heart of the growth process within the Schumpeterian approach to endogenous innovation growth theory (see Aghion and Howitt 1998). The excitement of endogenous innovation growth theory is providing tools to handle endogenous technological change and innovation within a dynamic general equilibrium setting. The object of the Schumpeterian approach to endogenous growth theory is not to supplant capital accumulation as an explanation of economic growth but to supplement it. Both capital accumulation and innovation are crucial ingredients for growth to be sustained. "The problem with neoclassical theory is not that it analyzes capital accumulation but that it does *not* analyze technological progress. The purpose of endogenous growth theory is to fill this gap in neoclassical theory — to open up technological progress and innovation to systematic analysis, and to study their effects on growth, not to show that they explain everything" (Aghion and Howitt 1998, p. 7).

Recent research activities (see Aghion and Howitt 1998 b), however, show by combinig elements of the Solow-Swan neoclassical model and the Aghion-Howitt (see Aghion and Howitt 1998, ch. 2) model of creative destruction that capital accumulation and innovative activities should be regarded as complementary processes, both playing a critical role in an economy`s long-run growth rate[5]: "capital accumulation cannot be sustained indefinitely without technological progress to offset diminishing returns, so too technological progress cannot be sustained indefinitely without the accumulation of capital to be used in the R&D process that creates innovations and in the production process that implements them ... even in the absence of embodied technical progress and learning by doing." (Aghion and Howitt 1998 b, p. 112):

- An increase in the capital stock will raise national income and hence raise the demand for products created by successful innovators and imitators. This in turn raises the discounted

[3] This is due to the special and unrealistic assumption that capital is not used in the R&D technology (only labor-dependent). In more general words: In order to model the growth process more realistic, one have to extend previous growth models by integrating capital accumulation both in the R&D technology, education (or more general human capital accumulation) technology, and in the production (absorption of innovations into the production process) technology (see chapter X).

[4] The view of mainstream textbooks is the same: "growth must ultimately be due to technological progress" and "the rate of output growth in steady state is independent of the saving rate" (see Blanchard 1997, pp. 461, 496) and "the driving force of growth is the accumulation of knowledge ... capital aacumulation is not central to growth" (Romer 1996, p. 95).

[5] For empirical support of the capital-skill complementarity see Griliches (1969) and Bartel and Lichtenberg (1987)

expected payoff to an innovation and imitation and thereby induce higher R&D and absorption (into the production process) activities ("scale effect").

- An increase in the capital stock will ceteris paribus reduce the long-run cost of capital, thereby reducing the capital cost of R&D and absorption activities.

In this article I will show a further channel providing a link between capital accumulation and long-run growth (see chapter VIII). That is, the stock of capital in an econmy will influence the interest rate, which in turn will influence the cost-benefit analysis of the decision to invest in human capital (e.g., cost of capital and present consumption, discouted future income). The accumulation and adjustment of human capital however is a crucial determinant of sustained economic growth.

*This new insights might be from great importance for economic policy. Subsidies to capital accumulation in general can have the same qualitative effects as direct subsidies to R&D, absorption and education activities (in countries where education is not publicy financed), while subsidies to capital accumulation being less subjected to insoluble incentive problems*[6]*.* *Furthermore, the embodiment of new technologies in physical capital or learning by doing*[7] *as possible reasons for capital accumulation to affect the rate of technological progress, may be less important than the role of capital as an input to R&D, education and absorption of innovations into the production process (implementation).*

*Moreover, these insights support a main hypothesis of the fixed-price models*[8] *(e.g., Clower, Leijonhufvud, Malinvaud, Patinkin): contraints or rigidities within one market could induce significant spillover effects to other markets. Therefore if one have to examine wage structure rigidity, it is necessary to examine not only the constrained labor market, but also the other markets.*

## III. The Basic Setup

First, I will present a simple model (based on Aghion and Howitt 1998, chapter 2) where growth is generated by a random sequence of quality improving (or vertical) innovations that themselves result from uncertain research activities. This model abstacts from capital accumulation completely. Nusser (1998) provides a detailed derivation and interpretation of the following equations, comparative statics results and welfare analysis.

The output of the consumption good depends on the input of an intermediate good, x, according to

(1) $y = Ax^{\alpha}$, where $0 < \alpha < 1$.

Innovations are characterized by a new variety of intermediate good that replaces the old one (vertical innovation). The use of these new intermediate goods raises the technology parameter, A, by the constant factor, $\gamma > 1$.

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[6] Physical capital accumulation is easier to monitor and verify than the production of intangible human capital.

[7] In this case it is possible that there exists no diminishing returns to capital accumulation due to continously learning by doing. This in turn would also make sustained growth possible (see Arrow 1962).

[8] Carlin and Soskice (1990) provide a survey.

Innovations arrive randomly with a Poisson arrival rate $\lambda n$, where $\lambda > 0$. Firms that succeed in innovating can monopolize the intermediate sector until replaced by the next innovator. There is a positive externality (spillover) from the innovation activities in the form that invention makes it possible for other researchers to begin working on the next innovation. There is also a negative externality, whereby the successful monopolist destroys the surplus of the monopolist of the previous generation of intermediate good by making it obsolete.

The research sector is portrayed as in the patent-race literatur in the industrial organization literature (see Tirole 1988 and Reinganum 1989). The amount of labor devoted to research is determined by the arbitrage condition, which reflects the fact that labor can be freely allocated between manufacturing and research, and which can be expressed as

(2) $w_t = \lambda V_{t+1}$,

where w is the wage, $V_{t+1}$ the discounted expected payoff to the (t + 1) innovator, and t is not the real time but the number of innovations that have occured.

The value $V_{t+1}$ is just

(3) $V_{t+1} = \pi_{t+1} / (r + \lambda n_{t+1})$.

The denominator of (3) can be interpreted as the obsolence-adjusted interest rate showing Schumpeter`s idea of creative destruction through competition: the more future research is expected, the shorter the likely duration of the monopoly profits, and hence the smaller the payoff of innovating. This introduces a negative dependency of current research upon the amount of expected future research.

The model has to be entirely specified by determining the profit flow $\pi$ and the flow demand for manufacturing labor x. Both are determined by a profit-maximation problem.

The entirely specified model is characterized by

1. the arbitrage equation: labor can be freely allocated between manufacturing and research.[9]

$$(A) \quad w_t = l \underbrace{\frac{g\bar{p}(w_{t+1})}{r + l n_{t+1}}}_{V_{t+1}}.$$

2. and the labor market clearing equation[10], reflecting the frictionless nature of the labor market and determining the productivity-adjusted wage $\omega_t$ as a function of the residual supply of manufacturing labor $L - n_t$ .

$$(L) \quad \mathrm{L} = \mathrm{n}_t + \bar{\mathrm{x}}(w_t).$$

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[9] This implicity assumes that no mobility costs exist. In reality, mobility is not costless (for instance, search cost, investment in new human capital and technological knowledge).

[10] The fixed stock of labor L has two competing uses. It can produces intermediate goods (x) and labor can also be used in research (n).

To summarize, the model shows us that there exists a negative relationship between current and future research in equilibrium: a higher level of future research $n_{t+1}$ will both imply more creative destruction ($r + \lambda n_{t+1} \uparrow$) and less profit ($\pi_{t+1} \downarrow$) for the next innovator. Therefore, current research $n_t$ will decrease.

The *steady-state equilibrium* is characterized as a stationary solution to (A) and (L), where $\omega_t \equiv \omega$, $n_t \equiv n$, and $x_t \equiv x$ and wages, profit, and final output are all scaled up by the same $\gamma > 1$ (factor that raises the technology parameter A) each time a new innovation occurs.[11]

The steady-state level of research $\bar{n}$ is then characterized by

$$(4) \qquad 1 = \lambda \frac{\gamma \frac{1-\alpha}{\alpha}\left(L - \bar{n}\right)}{r + \lambda \bar{n}} \; .$$

The steady state flow of the consumption good is $y_t = A_t \; \bar{x}^{\alpha} = A_t \, (L - \bar{n})^{\alpha}$ which implies $y_{t+1} = A_{t+1} \, (L - \bar{n})^{\alpha} = \gamma A_t \, (L - \bar{n})^{\alpha} = \gamma \, y_t$ . Therefore, if new innovations occurs, the log of final output increases by an amount equal to $\ln \gamma$ each time an innovation occurs. The real time[12] interval between innovations is random and exponentially distributed with the (Poisson) arrival parameter $\lambda \bar{n}$ . This yields the simple expression for the steady state average *growth rate*:

$$(5) \qquad g = \lambda \bar{n} \ln \gamma \, .$$

Then one is able to show the impact of parameter changes on g. An *increase in the stock of skilled workers L* (see ch. VII) and a reduction of the interest rate r and in the degree of product market competition $\alpha$ will increase $\bar{n}$ and thereby g. An increase in the size of each innovation $\gamma$ and/ or in the R&D productiviy parameter $\lambda$ will foster growth by increasing directly $\lambda \ln \gamma$ and indirectly through increasing $\bar{n}$.

Yet to use these models for policy design, it is necessary to take the externalities caused by the diffusion of innovations into account (*Welfare analysis*). When comparing the above equation (4) with the socially optimal level of research $n^*$ (see Aghion and Howitt 1998, p. 61)

$$(6) \qquad 1 = \lambda \frac{\left(\gamma - 1\right)\left(\frac{1}{\alpha}\right)\left(L - n^*\right)}{r + \lambda n^* - \gamma \lambda n^*} \; ,$$

one can now summarize the welfare implications of introducing creative destruction:

[11] Because the two curves (arbitrage equation and labor market clearing equation) are downward and upward sloping in the $(n, \omega)$ space, the steady-state equilibrium is unique (see Aghion and Howitt 1998, p. 59).

[12] Note that t in this model does not refer to real time, but rather to the sequence of innovations.

1. If the intertemporal technological knowledge spillover effect[13] and the appropriability effect[14] dominate the business stealing effect[15], **laissez-faire growth will be less than optimal ($\bar{n} < n^*$).**
2. Note that if the business stealing effect dominates the intertemporal technological knowledge spillover effect and the appropriability effect, **laissez-faire growth will be excessive ($\bar{n} > n^*$).** Or in more general words: If the extent of negative externalities induced by innovations is greater than the extent of positive externalities induced by innovations, the average growth rate is greater than optimal. This implication is a very important result of welfare analysis introducing creative destruction in the process of economic growth. In reality further important negative spillovers exist which make excessive laissez-faire growth possible. For example, if we introduce (human) capital in the model argumentation, the cost of (human) capital is also affected by obsolence caused by new waves of innovations. In other words: The successful monopolist destroys to a certain degree[16] the previous (human) capital stock by making the previous capital stock or technological knowledge obsolete.

## IV. Wage Structure Rigidity: Some Remarks

Two main approaches exist to a theoretical analysis of the structure of wages. The market approach would seek to apply theories of competition or of marginalism to relative rates of wage payment in different firms, industries, areas and occupations and to changes in these rates. In its pure perfect form this approach must assume the existence of a representative rational, profit-maximizing firm which demands labor -that may somehow be regarded as homogenous- according to its marginal physical product and a supply of homogenous labour produced by competing households. In this approach wage structure rigidity problems do not exist.

It is agreed that even if employers do aim maximizing profits they cannot perform the necessary marginal calculations, including that of the value of the marginal physical product of labor, required as a basis of marginal wage theory. In reality, the forces finally determining the wage structure will be such institutional factors as bargaining power, the climate of public opinion and the like. This leads us to the second approach. Therefore, the wage positions are

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[13] The social discount rate $r + \lambda n - \gamma\lambda n$ is less than the private discount rate $r + \lambda n$ (because $\gamma > 1$): the social planner takes into account that an innovation makes it possible for the next innovator to begin working on the present technological knowledge.

[14] The factor $(1 - \alpha)$ will be replace with 1: the private monopolist is unable to capture the whole consumer surplus created by the intermediate good; he captures only $(1 - \alpha)$ of that output.

[15] $(\gamma - 1)$ will be replace with $\gamma$: the successful monopolist destroys the surplus of the previous monopolist by making the previous generation of intermediate good obsolete. A social planner takes into account that a new innovation destroys the social return from previous innovations.

[16] The degree depends on the form of the production technology, or more exactly to the extent one can use the old (human) capital stock in the production of the new intermediate good. For example, if you have a putty clay technology, that is old machines (or old human capital) cannot be used in the production of the new goods, the old (human) capital stock will be entirely destroyed by the innovation of new intermediate goods. In this case, the extent of the negative externality is very large.

attributed to various pressures whose main characteristics are that they are not strictly economic. Influence of bargaining power, location, public opinion, tradition, and organisations play also an important role in the establishment of wage structures. Wage structures are replete with historical hangovers (differentials based for example on crafts, locality or sex) which perhaps are more convential than logical. This will lead to persistent wage differentials.

## V. Rigid and Flexible Labor Markets: Some Hypothesis to a Long-Term Structural Component of the European Unemployment

In recent economic literature, two important labor market developments of the last two decades have attracted much atttention (see Bertola and Ichino 1995): *Decreasing wage dispersion* of European labor markets and increasing and persistent unemployment in Europe, and *widening wage differentials* across U.S. workers and decreasing and less persistent unemployment in the U.S.A.. While in the U.S.A. technological change has been absorbed by larger wage inequality, in Europe the preference for compressed and rigid wage differentials has priced out of the labor market a large number of workers, thereby causing higher unemployment among unskilled workers.

In other words: In Europe, institutional rigidities reduce wage dispersion and employment fluctuations. Therefore, stable wage differentials are accompanied by persistently high unemployment.

Wage rigidity may has prevented European labor markets from reacting to skill-biased technological progress by reducing the relative low-end wages (see Krugman 1994 and Wood 1994). If compressed wage differentials and relative rigid low-end wages clashed with reduced demand for low-skill labor (because of the technological progress in form of process innovation), then the unemployment rate of low-skill European workers will rise. This effect was strenghtened the last two decades by the increasing openness to trade with developing countries (especially with tradable goods), because the stock of cheap unskilled labor has been increased. This threatens the wage of unskilled workers in advanced economies. In full-employment equilibrium, the competition from developing countries decreases low-skill wages, and prices the unskilled out of work if their wages fail to respond.

In ”flexible” markets, the mobility decision of workers and ”flexible” wage differentials ensure that efficient labor reallocation does take place in equilibrium, whereas in ”rigid” markets, where non-competitive central wage setting takes place, labor reallocation is inefficient.

For example, in modern advanced economies, employment relationships entail highly (firm) specific human capital. Therefore mobility is costly and time consuming. *In flexible labor markets where mobility costs (especially investment in human capital and technological knowledge) are paid by workers, the wage differentials needed to trigger (re)education and labor reallocation are larger in a more volatile economic environment.* In *”rigid” labor markets* where wages are constrained by institutional rigidities, the model as presented in this article suggests that a similar increase in the volatility of the economic environment should be associated to *inefficient (re)education and labor reallocation* (from the manufacturing sector into the R&D sector). Therefore, aggregate innovation activities and long-term economic growth will decrease. A suboptimal lower economic growth rate - that means that the economy does not exhaust the potential production possibilities because innovative and absorption activities are suboptimal low - in turn induces sluggish employment growth. Together with an increasing stock of labor supply, this might induce unemployment.

*Therefore, I will support in this article the view that the European Unemployment problem is partly one of sluggish employment growth* (see Welfens et al. 1998).

In this article, I will show within a dynamic framework that rigid labor markets are harmful to economic growth by reducing the incentives of economic agents to accumulate and adjust their human capital.

## VI. Some Dynamic Interactions between Human Capital Accumulation, Technological Progress and Economic Growth

Assuming that human capital accumulation arrives as a benefit of the production process without cost ("learning by doing"), neither the private incentives for human capital accumulation, nor the costs of absorbing technological change into production have to be examined. Note that if learning by doing is an important part of human capital accumulation, then time spent producing output will also raise the level of the human capital stock. The trade-off between faster rates of human capital accumulation and less output (time spent in education reduce time spent in production) then disappears.

In reality however learning by doing exists only to some degree. To most part, human capital accumulation does not fall like manna from heaven. Skills and competences have to be accumulated by different kinds of education (e.g., primary and secondary education, higher education like university education, or vocational education). The education technology of an economy is therefore very important in increasing the human capital *stock* and adapting the human capital *structure* of an economy. Hence, a better education technology increases the economic agents`s capacity to innovate and adapting to new technologies, thereby speeding up the technological diffusion throughout the economy. The economic literature shows that an economy`s ability to accumulate and adjust human capital is very important for sustainable economic growth because in reality there exists strong strategic complementarities between human capital accumulation (agents` education decision) and Research & Development investments and between human capital and the diffusion and absorption of innnovations into the production process.

Both the accumulation (*growth rate*) of human capital (e.g., Lucas 1988 [17]) and the *level* of human capital (e.g., Nelson and Phelps 1966 [18]) are important for sustained economic growth.

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[17] Human capital is in this model an input in the production function, just like any other input. Hence, the growth rate of output depends on the *growth rate of human capital* (more output is only possible with more input).

The level (stock of human capital) affects a country`s ability to innovate or catch up (diffusion or absorption of existing innovations) with more advanced countries. For example, a high level of education attainment (especially a high level of secondary and higher education) increase an economy`s ability to innovate (due to a greater number of potential researchers) and the speed at which individuals and firms adapt to new technologies (knowledge diffusion). Higher rates of technological progress yields a higher growth rate of output and thereby higher wages of skilled worker (due to an increasing marginal product of skilled labor). This in turn increase the returns to investments in human capital accumulation and therefore speed up human capital accumulation.

This has important policy implications. Due to the complementarity between human capital accumulation and R&D activities, government will increase the average level of education not only through eduaction policy but also indirectly by actively supporting R&D, diffusion and absorption activities. This is due to the fact that education (or more general human capital) will increase the profitability of R&D, diffusion and absorption activities.

The growth rate of human capital could also be from great importance, because the human capital accumulation technology may be characterized by positive threshold externalities (see Aghion and Howitt 1998, chapter 10.1.2). That is the case if the return to investments in human capital accumulation is dependent on the amount previous generations have invested in education (e.g., more previous investment in education has induced an increase in the productivity of the today education technology [for example better teaching methods] and thereby increase the returns to invest in human capital today). Then, if previous generations have insufficiently invested in education, investing in education tends to become also unattractive for the current and all successive generations ("low-growth path"). Note that a high-growth path is also possible. This provide an explanation for why countries with unequal initial growth rates of human capital may keep growing at different rates forever.

I will now summarize some further important aspects of the dynamic interactions between human capital accumulation, technological progress and economic growth:

- Skilled labor or more general human capital is an essential input not only in the Research and Development (R&D) sector, but also in the education sector and in the absorption of R&D results into the production process and marketable products (see Eicher 1996 and chapter VIII in this article). Hence, human capital is of great importance not only to R&D (as in most previous growth model), but also to the productivity of the human capital accumulation technology, diffusion of innovations, and absorption of innovations into the production process.
- What about the effects of increasing education spending? Note that the accumulation and adjustment of human capital will not only affect the productivity of R&D, research incentives and the mobility of workers across vintage lines. It also affects the ability of

[18] Human capital is not an input just like any other. Human capital is the primary source of innovations and economic growth will depend on the rate of innovation and hence on the *human capital stock*.

learning by doing (costless benefit of the production process) across all skill levels. Assuming that learning by doing is also an important determinant of sustained economic growth[19] (e.g., Arrow 1962), then a government policy which encourages research (or more general only higher education) at the expense of production (or more general basic education) by channeling public resources toward universities instead to primary/secondary and vocational education may be harmful to growth. Hence, government education policy should avoid an excessive specialization in product-specific skills and knowledge or in more general words: human capital accumulation and adjustment policy needs to be adequately designed and channeled in order to be unambigously growth-enhancing.

- In the real economic world, it is obviously that the degree of complementarity between equipment and skilled labor is different from that between equipment and unskilled labor. A continously technological change in form of changed quantities and qualities of equipment affect the demand for the different types of labor. Then, agents have to invest in new vintage-specific human capital to learn about technological change.[20] Therefore, a *continous adjustment both in the level and the structure of human capital* is necessary in a dynamic volatile economic environment. As we will see later in this article, labor market rigidity in form of wage structure rigidity will induce dynamic inefficiencies in the labor reallocation process [between the R&D, education and production (where the absorption of innovations occurs) sector] due to suboptimal investment in human capital accumulation. This will induce that the level and the structure of human capital will not keep up with the speed of technological change, thereby reducing potential production possibilities and economic growth.

## VII. Education, Wage Structure Rigidity and Skill-Biased Technological Progress

In order to model wage structure rigidity, one has to extend the basic model by integrating more kinds of labor and by endogeneizing the different wage paths both of the skilled and the unskilled (based on Aghion and Howitt 1998, ch. 10.2.3). Then I will extend the model by integrating wage structure rigidity.

Final output is now produced with both intermediate good and unskilled labor, that is,

(7) $y_t = z_t + A_t x_t^{\alpha}$,

where $0 < \alpha < 1$ and $z_t$ is the stock of unskilled labor after t innovations, $A_t$ is the productivity parameter, and $x_t$ the flow of intermediate goods of vintage t. Equation (7) says that unskilled

[19] For example, fundamental knowledge generated by research and development could only be exploited entirely when a firm puts that knowledge into practice and resolve the unexpected problems and opportunities that only experience can reveal ("learning by doing").

[20] For example, the absorption of a new technology is very skill-intensive, because it requires the employment of skilled labor with knowledge of the new vintage to adapt the new technology to the production process or the continously improvement of new technologies requires also skilled labor in the Research and Development (R&D) sector (see Chapter VIII).

labor have to compete with increasingly productive ”robots” in the production of final output. Robots are produced with skilled labor accordingly to a linear one-for-one technology. That is, one unit of skilled labor invested in current production (manufacturing) yields one unit of current consumption good.

Innovations arrive as before at the Poisson rate $\lambda\ n_t$ , when $n_t$ is the amount of skilled labor allocated to research. Assuming that the total labor force is constant[21] and equal to N, then

(8) $L_t + z_t = N$,

where $L_t$ is the stock of skilled labor. As in the basic setup, in the intermediate sector (one-to-one technology) the usual labor-market clearing is valid, so that skilled labor is allocated between manufacturing and research

(9) $L_t = n_t + x_t$ .

The only difference to the basic setup is, that an extra "sector" that produces output one-for-one using unskilled labor is added. But this new sector with unskilled worker does not interact in any way with the "skilled sector" (due to the additive form of the production function). Therefore, the wage of skilled workers $w_t^s$ will behave exactly as in the basic setup, growing at the average steady-state growth rate [see also (5)]

(10) $w_t^s = g = \lambda\ \bar{n} \ln \gamma$ .

Assuming that there is also perfect competition in the sector that produces final output with unskilled labor, the unskilled wage $w_t^u$ will be equal to the marginal product of unskilled labor

(11) $w_t^u = 1$,

which is constant due to the form of the production function (7).

Thus in the basic setup there will be an ever-increasing skill differential, and an ever-increasing wage inequality between skilled and unskilled workers, if nothing is done to alter the skill composition of the work force.

[21] Endogeneizing the rate of labor force (or more general the rate of population) growth might be yield a potentially fruitful direction for further theoretical research, because in reality there exits important interactions between the population growth, human capital accumulation, technological progress, growth and unemployment. For example, assume that an economy is charcterized by a permanent technological progress through innovations (”creative destruction”). If there is a negative rate of population growth (as in Germany or the most industrialized countries), the old worker outnumber the young. The technological change however makes it necessary to adapt the human capital structure, because worker have to become educated in order to qualify as skilled workers with the new generation of technology. For old worker, the length of the amortization period of human capital investment is shorter, therefore they have lower incentives to invest in new human capital. As a result, the adjustment speed of the human capital stock could not keep up with the speed of technological change, if one assume a negative rate of the population growth. Therefore the rates of technological change and growth decrease due to a lack of new human capital needed in order to absorb technological change. Morever, if the technological change induces an increasing relative demand for skilled labor, unemployment could occur due to a qualification mismatch within the labor market.

Now, assume that a worker can alter this composition through education. A worker who chooses to be educated will be skilled, otherwise he will be unskilled.

Note again that innovations do not fall like manna from heaven. Skills and competences accumulated by education are very important in increasing the individual`s capacity to innovate and adapt to new technologies, thereby speeding up the technological diffusion throughout the economy. Human capital accumulation by education is therefore a very important determinant for sustainable economic growth (see ch. VI and VIII).

One has to recognize also the intertemporal aspects of human capital accumulation. Workers must decide whether to accumulate human capital and enter the education sector [22] or to work in production as unskilled labor. When workers decide to invest in human capital, they forgo income as unskilled labor and become ”educated”, paying ”tuitions” to enter the education sector. Hence investment in human capital requires borrowing against future income to finance the direct (tuition) cost of human capital accumulation and consumption during time spent in the education sector. After the education period they will become skilled labor, who participate in the dissemination of the new technology in the R&D, education and production sector, and would be able to earn a higher wage.

I now assume that the the incentives to invest in human capital (knowlege-producing activities) are strongly conditioned by the *relative income position*. Assuming that technological progress generates a higher relative demand for skilled labor, then a competitive labor market, where wages are decentrally set, increases wage differentials across skill levels as described in equation (10) and (11). A relative better-off position in the hierarchy of the wage structure then increases the incentives to invest in human capital and therefore foster innovative (R&D sector) and absorption (production sector) activities and thereby economic growth.

To simplify the analysis, suppose that with each innovation people must become reeducated in order to qualify as skilled workers with the new generation of technology. $e_t$ is the fraction of those who choose to be educated after the $t^{th}$ innovation. Then

(12) $L_t = e_t \cdot N$.

The basic setup is therefore a special case in which $e_t$ is constant and equal 1 (Note that in the basic setup all workers are skilled; see ch. III).

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[22] By arguing this way, I implicity ignore the process that learning arrives to some degree as a benefit of the production process without cost (”learning by doing”). Then neither the private incentives for human capital accumulation, nor the costs of absorbing technological change into production have to be examined.

In this model, each worker decides whether or not to become educated by making a cost-benefit analysis of education. I assume that education is private and therefore directly financed by each worker. The cost of becoming educated vary with a worker`s native ability and the fraction of worker to whom the cost is less than or equal to any amount c (e.g., tuitions) is given by the distribution F (c). The private benefit to becoming educated is the expected present value of the corresponding gain in earnings (which is equal to the future discounted income as skilled labor minus the discounted income as unskilled labor) until the next innovation (Note that I assume an entirely human capital obsolence each time an innovation occurs). The fraction of educated workers $e_t$ will be the fraction for whom the education cost is less than or equal to this benefit.[23]

$$(13) \qquad e_t = F\left(\frac{w_t^s - 1}{r + l n_t}\right) = F(c).$$

Due to the labor market clearing equation (Note that there is an endogenous stock of skilled labor)

$$(L) \qquad \mathrm{L}_t = \mathrm{n}_t + \bar{\mathrm{x}}\left(w_t^s\right),$$

the stock of skilled workers after the $t^{th}$ innovation [after transforming (L) to $n_t$ and then replace $n_t$ in (13)] is given by

$$(14) \qquad L_t = e_t \cdot N = F\left(\frac{w_t^s - 1}{r + l\left[L_t - \bar{x}(w_t^s)\right]}\right) \cdot N .$$

This yields $\partial L_t / \partial w_t^s > 0$ and $\partial L_t / \partial \omega_t^s < 0$. In other words: A higher absolute real wage $w_t^s$ increases directly the wage differential and therefore the private benefit of human capital accumulation (income gain), thereby increasing the worker`s incentives to engage in education (or more generally in knowledge producing activities). A higher productivity-adjusted wage $\omega_t^s$ encourages research activities (due to labor reallocation from the manufacturing sector of the intermediate good to the research sector, which means that n increases) and thus shortens the expected duration of the payoff to education (”human capital obsolence”) through creative destruction.

[23] For simplicity, I assume that the individual time preference $p$ is equal to the market interest rate r.

Now assuming for simplicity, there is a finite upper limit to the cost of education[24] ($c^{ul} > 0$) and that everyone have the native ability to become educated.[25] In this basic setup the wage of the skilled worker grow with the average growth rate $w_t^s = g = \lambda \bar{n} \ln \gamma$ [see (10)]. Due to $w_t^u = 1$ [see (11)], there will be an ever increasing wage differential. Then, as long as research takes place and therefore new innovations occurs, the gain to becoming educated (future discounted income as skilled worker minus future discouted income of unskilled worker) increases and will exceed $c^{ul}$, so that it will become optimal for more and more worker to acquire skills through education. This process ends when it becomes optimal for everyone to acquire skills through education, so that the stock of skilled labor L is equal to the total labor force N (which is assumed to be constant) . Formally, this will be governed by the condition

$$(15) \qquad \frac{A_t w^s - w^u}{r + l\left[\underbrace{L_t - x(w^s)}_{n}\right]} < c^{ul} \leq \frac{A_{t+1} w^s - w^u}{r + l\left[\underbrace{N - \bar{x}(w^s)}_{\bar{n}}\right]} .$$

Note that $\bar{n}$ is the steady state equilibrium level of research, $\omega^s$ is equal to the steady-state, productivity-adjusted skilled wage in the basic setup when L = N, and $A_{t+1} = \gamma A_t$ . In this model education will therefore eliminate the inequality in wages[26], because at date t+1 each worker will receive the same skilled wage. Note that private education will not eliminate lifetime wealth inequality. Even if each worker earns the same skilled wage, some will have sacrificed more lifetime consumption to pay for the cost of their education. Only publicly subsidized education can thus eliminate lifetime wealth inequality attributable to differences in native ability. Moreover, if innate ability affects not just the cost of education but also a person's productivity while employed (”learning by doing”), even public education will not go all the way to eliminating wealth inequality.

[24] This is possible due to the fact, that I assume that there is an *exogenous education sector*. More realistic (see chapter VIII), skilled labor have to be assumed to be an essential input in R&D, but also in education and in the absorption of innovations into production. Therefore an increasing ”production of human capital” in the education sector requires the withdrawal of skilled labor from the R&D and the production sector (of the consumption or intermediate good) which subsequently increases the wage of skilled labor in the education sector and thereby the costs of human capital investment (see Eicher 1996).

[25] This assumptions are only for simplicity. They do not change the main conclusions of the model.

[26] Note that if one assume that there is a decreasing marginal product of labor, then as the number of unskilled workers falls down to zero the wage of unskilled workers would rise to infinity, because the scarcity of unskilled labor would benefit those who continue to remain unskilled. This effect acts in the same direction as the ”education effect” in the above model (decreasing wage differential).

Note that I have assumed that the decision to invest in human capital is strongly conditioned by income affecting the incentives to invest in human capital and technological knowledge-producing activities. I also have assumed that technological progress generates a higher relative demand for skilled labor. In competitive labor markets, where wages are decentrally set, this will increase wage differentials across skill levels as described in equation (15) and (16). An income increase or a relative better-off position in the hierarchy of the wage structure then increases the incentives to invest in human capital and technological knowlege and therefore foster innovative and absorption activities and thereby economic growth.

Now I would like to introduce wage structure rigidity in a way that both the wage of skilled worker and the wage of unskilled worker increases with the same rate, so that the relative productivity-adjusted wage of skilled worker remains constant [$(\omega^s/\omega^u)$ = const.]. In other more general words:

**Proposition 1**

If there exists wage structure rigidity, the relative ”skill wage differential” stops to grow and remains constant. Assuming that private incentives or the private benefit of education (a relative better-off position in the hierarchy of the wage structure) induces agents to invest in human capital, then a constant relative skill wage differential will reduce incentives to invest in human capital accumulation or more generally in knowledge-producing activities. That is, to the extent that wage structure rigidity limits the incentives to invest in knowledge-producing activities, it will reduce the potential production possibilities of an economy and therefore be harmful to economic growth and thereby to the employment growth rate. Together with a constant or increasing stock of labor supply this will induce unemployment.

The main result is to be valid for all kind of knowledge-producing activities, both for fundamental innovative activities in R&D or secondary innovative activities in the absorption of new technologies into the production process (e.g., product or process innovations through learning by doing).[27]

In order to introduce the problem of wage structure rigidity (wsr) in the model, I will extend the model by replacing the condition (15) by ($15^{wsr}$)

$$\left(15^{wsr}\right)\qquad \frac{A_t w^s - w^u}{r + l\left[\underbrace{L_t - x(w^s)}_{n}\right]} < \frac{\overbrace{A_{t+1}w^s - A_{t+1}w^u}^{\Rightarrow \frac{w^s}{w^u} = const.}}{r + l\left[\underbrace{\underbrace{L^{wsr}}_{const.} - \bar{x}(w^s)}_{n^{wsr}}\right]} < \frac{\overbrace{A_{t+1}w^s - w^u}^{Without\ wsr}}{r + l\left[\underbrace{N - \bar{x}(w^s)}_{\bar{n}}\right]},$$

where $n^{wsr}$ is the steady-state equilibrium level of research, $\omega^u$ is the productivity-adjusted wage of unskilled labor, and $A_{t+1} = \gamma^{we} A_t$ (where $\gamma^{we} < \gamma$)[28].

This extension will show us some new interesting insights in the dynamic interactions between the rate of technological change and the relative wage and supply of skilled labor.

Assuming for simplicity, that there is a finite upper limit to the cost of education $c^{ul} > 0$ and that everyone has the native ability to become educated. Without wsr, there would be an ever increasing wage differential [see (15)]. Then, as long as research takes place and therefore new innovations occurs, the private benefit to becoming educated increases and will exceed $c^{ul}$ for more and more workers, so that it will become optimal for them to acquire skills through education. This process ends however, when one introduces wage structure rigidity at date t+1 (e.g., institutional transition from a competitive labor market, where wages are decentrally set, to a ”rigid” labor market, where non-competitive central wage setting takes place). Then the relative skill wage differential stops to grow and remains constant, and thereby from date t+1 on the division between skilled and unskilled workers remains fix [$L^{wsr}$ (= const.) < N].

*Note also that in the presence of wage structure rigidity education will no longer eliminate the inequality in wages.*

One can see that the integration of wage structure rigidity will negatively affect the level of research ($n^{wsr} < \bar{n}$) by inducing a suboptimal low accumulation and adjustment of human capital and therefore reducing the steady-state average growth rate ($g^{wsr} = \lambda\, n^{wsr} \ln \gamma < g = \lambda\, \bar{n} \ln \gamma$).

The integration of wage structure rigidity therefore yields some new interesting insights in the dynamic welfare analysis of wage (structure) rigidity:

I. If the intertemporal technological knowledge spillover effect and the appropriability effect dominates the business stealing effect, **laissez-faire growth will be less than**

[27] Note that in reality fundamental and secondary research are complementary activities. The fundamental knowledge generated by research and development could only be exploited entirely when a firm puts that knowledge into practice and resolve the unexpected problems and opportunities that only experience can reveal.

[28] Non-competitive central wage setting means, that the labor union form an ”average productivity parameter” of the whole sector (or economy) $\gamma^{we}$, which reflects a weight average productivity increase both of skilled and unskilled workers together. Note that $\gamma$ reflects the productivity increase of skilled labor.

**optimal ($\grave{n} < n^*$).** In this case, wage structure rigidity (wsr) will induce a further decrease in the welfare, because $\mathbf{n^{wsr} < \grave{n} < n^*}$ . This means that wsr not only induce static inefficiencies[29] but also dynamic inefficiencies in the form of an **inefficient (re)education and labor reallocation process**. However, continously (re)education and labor-force reallocation plays an essential role in the process of technological change and economic growth. Hence, an inefficient accumulation and adjustment of human capital due to wage structure rigidity reduces innovative, education and absorption activities and therefore potential production possibilities of an economy and thereby long-term economic growth. This in turn induces sluggish employment growth. Together with an increasing stock of labor supply (e.g., in many European countries) this might induce unemployment.

II. If the extent of negative externalities induced by innovations is greater than the extent of positive externalities induced by innovations, **laissez-faire growth will be excessive ($\grave{n} > n^*$).** Or in more general words: the average growth rate is greater than optimal. In this case, **wage structure rigidity will induce an increase in the welfare**, because $\mathbf{n^* < n^{wsr} < \grave{n}}$ . This is a new very important result of the dynamic analysis of wage structure rigidity. Such dynamic interactions remain unexplained by static models of wage determination.

## VIII. An Endogenous Education Sector: A More Complex View

In the previous section the costs of eduction were assumed to be fixed. This implicity assumes that there exists an education sector that requires no skilled labor. Hence, incentives to invest in human capital depend only on an exogenously specified education technology.

*Skilled labor however is not only an essential input in R&D, but also in education and absorption of innovations into production.* Permanent technological change therefore requires a permanent reeducation and labor reallocation process of skilled labor. For example, the absorption of bursts in technological change into production requires (due to skill-biased labor demand) the withdrawal of skilled labor from the R&D and education sector (thereby draining the pool of skilled labor available to the education sector) which subsequently increases the costs of both human capital investment (e.g., higher wages for teachers[30]) and innovation (e.g., higher wages for reseachers). From a theoretical perspective, it is therefore necessary to examine explicitly both the direct (e.g., tuition) and indirect (e.g., lost income during the education period) costs of education, and the link between the rate of technological change and the relative supply, demand and wage of skilled labor.

[29] The main focus of the static (microeconomic) labor market theory (for instance, efficiency wage theory, theory of implicit contracts, job search theory) is to examine the (static) effects of wage rigidity on unemployment.

[30] Psacharopoulos and Woodhall (1985) report that teachers`salaries represent at least 70% of the total current costs of education in many developing countries.

This extension yields new interesting insights in the dynamic analysis of the interactions between endogenous human capital accumulation, technological change, relative wages and economic growth (see Eicher 1996). The model of Eicher also provides a theoretical foundation for recent empirical findings (see Katz and Murphy 1992) of a positive link between technological change and the relative wage, and long-term inverse fluctuations in the relative supply and wage of skilled labor ("supply paradox" [31] ).

In reality, movements in the supply, demand and relative wage of skilled labor depend on the *channel* that promotes higher technological change.

For example, if the whole economy experiences an increase in the productivity of unskilled labor, higher rates of growth and technological change can be accompanied by *lower* relative wages. That is due to the fact that less skilled labor is then required to absorb new technologies into the production sector. This depresses the relative wage and allows for a reallocation of skilled labor to the Research and Development (R&D) and the education sector.

In more general words: technological change induces skill-biased labor demand. Skilled labor needed in one sector must be withdrawn from the other sectors and thereby induces relative wage and supply movements.

## 1. An Endogenous Education Sector, Technological Change and Relative Wage and Supply Movements

**Proposition 2**

Assuming that innovations (and thereby technological change) is to some degree a non-rival[32] by-product of the human capital accumulation process ("education process")[33], then privately financed human capital production yields a positive, intertemporal relationship between human capital investment at time t and the relative wage of skilled labor at time t + 1, or alternatively, between technological change at time t and skilled labor demand at time t + 1.

Note that higher growth and technological change have to come at the expense of increased income inequality.

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[31] Katz and Murphy (1992) show that relative wage and supply of skilled labor have been fluctuating in an inverse relation to each other. Especially in the 1980`s, bursts in technological change (such as the computer revolution) lead to a *higher growth path*, characterized by *higher relative wage* and *increased relative demand*, but *decreased relative supply of skilled labor*.

[32] For a critical view of non-rival technologies see footnote one. Note also that even in the presence of non-rival technologies, nevertheless there exists costs of absorbing new technologies into production (”absorption and improvement effect”, see later in this section).

[33] For example, Jaffe (1989) documents significant spillover effects of academic research on commercial innovation (see section 3 of this chapter). Note also that I implicity ignore the process that learning arrives to some degree as a benefit of the production process without cost ("learning by doing"). Then neither the private

That is from an intertemporal perspective, higher investment in human capital (education) increases the demand for teachers, and thus the wage of teachers, and thereby the number of teachers. Under the above assumption (innovation as a by-product of the education process), this will generate more rapid technological change (e.g., increasing commercial innovation patents based on academic research) that must be absorbed. This absorption of an increased rate of technological change into the production process ("absorption effect", see Eicher 1996) and the continous improvements upon these new technologies in the R&D sector (I will call this effect "improvement effect") create skill-biased labor demand at time t + 1, which in turn increases the relative wage of skilled labor at time t + 1 (cost of absorption and improvement of new technologies).

Note that the cost of human capital accumulation also increase at time t + 1 (due to higher wages for teachers at time t + 1). This effect discourages human capital investment at time t + 1. That is, higher rates of technological change induce not only *cost side effects* (increased relative demand and wages of skilled labor), but also a *resource effect* (skilled labor is being drained from the education sector due to the need to absorb and improve new technologies), which raises the cost of future human capital investment and thereby reduces future supply of skilled labor.[34] Thus, an *initially high rate of technological change cannot be sustained with a decreasing rate of human capital accumulation*. Therefore, the stock of human capital should not be determined exogenously as in Romer (1990), since the stock of human capital is strongly tied to the rate of technological change (see also Eicher 1996).

This argumentation documents *significant interactions and complementarities* between human capital accumulation and the rate of technological change and thereby the rate of economic growth of an economy, since the cost of human capital accumulation is affected by the rate of technological change and the rate of technological change in turn is affected by human capital accumulation (e.g., education influences the rate of innovative, absorption and improvement activities due to higher productivity of skilled labor).

*Moreover, an economy experiences dynamic benefits (intertemporal externalities) to human capital accumulation, as an incremental increase in human capital investment raises the subsequent level of new technologies available for future research by creating cumulative productivity effects (e.g., better R&D, education and production technology) for future generations. More human capital investment thus enhances an economy`s ability to obtain*

incentives for human capital accumulation, nor the costs of absorbing technological change into production have to be examined.

[34] This reveals an explanation of the "supply paradox" described in the introduction of this chapter.

*more from its physical capital stock. A failure to maintain the pace of human capital accumulation relative to competing economies reduces the domestic economy`s ability to innovate and absorb new future technologies, inducing a cycle of industrial stagnation.*

**Proposition 3 (see Eicher 1996, p. 142)**

An increase in the basic skills of unskilled labor increases the relative supply of skilled labor, decreases the relative demand for skilled labor and the relative wage of skilled labor, while increasing the rate of technological change and long-run growth.

Note that higher growth and technological change does not have to come at the expense of increased income inequality.

The following effects occurs:

- Higher basic skills increase the wage of unskilled labor, which induces a decline in the relative wage of skilled labor.
- A smaller amount of skilled labor is necessary to absorb new technologies into the production process, since unskilled labor is more productive in absorption and improvement of new technologies (e.g., higher rates of learning by doing). Therefore the relative demand for skilled labor decreases.
- A decline in the market interest, since the higher wage of unskilled worker will translate ceteris paribus[35] into higher savings (excess supply in the capital market). This in turn will influence the direct (lower borrowing costs) and indirect cost (increase in the lost of the discounted earnings during the human capital accumulation period) and the future benefit (increase in the future discounted income as skilled labor) of human capital accumulation. Assuming that the direct cost and future benefit effect dominate, the incentives to invest in human capital accumulation increases. Therefore the relative supply of skilled labor increases.

The decline in the relative wage of skilled (especially the wages of teachers), and thereby decreasing costs of education, and the increasing supply of skilled labor increase the stock of human capital, therefore increasing the rates of technological change and economic growth. Note that this however induces the above resource effect (technological change induces skill-biased labor demand, thereby increasing the relative wage of skilled labor, which in turns

[35] Assuming that the marginal propensity to save of the unskilled worker remains constant.

increases the costs of absorption and improvement). If the resource effect is dominated by the former effects (see Eicher, p. 142), this implies an increase in the rate of economic growth.

Analysing wage structure rigidity in a more realistic (e.g., endogenous education sector) dynamic context might be crucial since it will show that technological change and the growth process is strongly determined by the efficiency of the (re)education and labor reallocation process between the education, R&D and the production (absorption) sector. Assuming that labor mobility and human capital accumulation decisions are conditioned by income calculations, it is obviously that wage structure rigidity will induce less (re)education and labor reaallocation, thereby reducing the rate of technological change and long-run economic growth.

**2. Intertemporal and Intratemporal Aspects of the Decision to Invest in Human Capital**

Note again the intertemporal aspects of the decision to invest in human capital. Agents have to decide whether to accumulate human capital and enter the education sector[36] or to work in production as unskilled labor. When worker decides to invest in human capital, workers forgo income as unskilled labor and become "educated workers", who pay "tuitions" to enter the education sector. Hence investment in human capital requires borrowing against future income to finance the direct (tuition) cost of human capital accumulation and consumption during time spent in the education sector. After the education period they become skilled labor, who participate in the dissemination of the new technology in the R&D, education or production sector, and therefore earn a higher future wage as skilled labor.

Therefore, it is very important to include both the direct (tuition) and indirect (loss in income) cost and the future benefit of human capital accumulation in the analysis:

- Agents care about their *future* wage as skilled labor. The calculations however are made on the basis of the present wage of skilled labor. Hence, a high wage of skilled labor at t represents both a higher private benefit of education in the future period (gain in future income) and higher costs of human capital accumulation (higher wages as teacher) in the present period. One can see, that the intertemporal decision to invest in human capital is directly tied to technological change, since the wages of skilled labor are influenced by the rate of technological change ("absorption and improvement effect", see proposition 2).
- Both the direct (borrowing against future income) and the indirect cost (loss of the discounted income as unskilled labor during the human capital accumulation period) of human capital accumulation and the future discounted income as skilled labor are influenced by the market interest rate. For example, a higher interest rate will increase the direct cost (increasing costs of borrowing and increasing opportunity costs of consumption during the

[36] Note that I implicity ignore the process that learning arrives to some degree as a benefit of the production process without cost ("learning by doing").

education period), but also reduce the indirect cost (discounted income as unskilled labor decreases) and the future discounted income as skilled labor. **Therefore, this argumentation provides a new link between capital accumulation and long-run economic growth. One can see that physical capital accumulation and technological change (innovation, absorption and improvement) should be regarded as complementary processes, both playing a critical role in long-run growth** (see also Chapter II): **the stock of physical capital will influence the interest rate and thereby the cost and benefit of human capital accumulation.** This in turn will influence technological change and thereby economic growth which depends on different channels (e.g., innovative activities in R&D, absorption and improvement effect). Therefore aspects as the marginal propensity to save[37] or the rate of population growth[38] or more general, adjustment in the capital market, will become relevant in the Schumpeterian approach to endogenous growth theory and exhibits new interesting dynamics.

- An overall increase in wages both of skilled and unskilled labor (as it is the case if wage structure rigidity exists) might increase savings[39] and thereby the stock of physical capital, which in turn might influence the interest rate and thereby economic growth (see above argumentation). Or more general: *the income distribution of an economy influences the stock of physical capital and therefore economic growth.*

### 3. Human Capital Accumulation and Externalities

Human capital externalities arise when an agent`s human capital investment creates benefits for other agents in the economy without internalizing these benefits about the price mechanism. In most of the economic literature these externalities are simply built into an aggregate production function in the form of technological increasing returns (see Lucas 1988), where the rate of return on human capital accumulation is increasing in the human capital stock of the workforce. Although part of the human capital externalities is technological, assuming that this is the only form of externality is unsatisfactory (see Acemoglu 1996), because it is a macroeconomic black box interpretation of human capital externalities. However, major human capital interactions happen among employees within a firm (e.g., young workers learn from their more experienced colleagues).

In the real economic world, the structure of the human accumulation process reveals possible mechanisms how different kind of human capital externalities might be generated. Some interesting kind of these externalities have to be examined now (see Acemoglu 1996 and Eicher 1996):

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[37] Note that in reality a decrease in the discount rate have the same effect as an decrease in the interest rate due to an increase in the marginal propensity to save.

[38] When assuming that the marginal propensity to save is age-dependent or the supply of savings depends on the population size.

[39] This effect depends on the structure of private savings and how this structure is influenced by wage increases (e.g., substitution effects between different kinds of savings).

- The education process produces to some degree research output as a by-product. For example, Jaffe (1989) documents significant positive knowledge spillover effects of academic research on commercial innovation. That is, the education sector offers workers (or more general agents) the opportunity to accumulate human capital, while also generating new technological vintages. This form of externalities exists especially in the technological orientated education sector where students acquire skills by accumulating knowledge about the leading-edge technology.
- Workers (or general agents) who enter the education sector to become skilled labor, pay tuitions to learn about new technologies. Thus, private incentives to invest in education finance teacher earnings in the education sector and influence thereby the amount of teachers.[40] If the education process produces research output as a by-product, this will change the rate of innovative activities (technological change) and thereby economic growth. Therefore, by changing the amount of the labor force in the education sector, agents who enter the education sector induce externalities.
- Even if new technological vintages are assumed to be non-rival (see footnote 1 for a critical view), the requirement for the future use of these new vintages in either production sector ("absorption sector") or research sector (as ”improvement sector”) is that skilled labor with knowledge of that particular technology must be employed to absorb (production sector) or improve (R&D sector) upon the vintage. Therefore, while higher rates of technological change shifts the production possibilities, it simultaneously reduces the pool of skilled labor available to the education sector. This reduces the speed of future technological change and economic growth if innovations are a by-product of education ("intertemporal spillover effect"), thereby influencing the relative demand, wage and supply of skilled labor (see ch. VIII.1).
- Acemoglu (1996) provides another *microeconomic* evidence of increasing returns in human capital accumulation. Agents need to sink a large fraction of their human capital investments (e.g., acquisition of general knowledge) before contracting with the firm for which they are going to work (a time lag exists between the decision and the realisation). The private benefit of education depends on what type of jobs will be available, and what kind of equipment and machinery the agents expect to use. The firms`choice of jobs and physical capital however depend on the education and skills of the workforce. Assuming that the matching process between firms and workers is imperfect then increase investments in education (human capital accumulation) induce that firms would respond with correspondingly higher investments in labor market search, equipment and training programmes in order to attract those better educated agents and take advantage of the average improvement in human capital induced by the initial education investments. This

[40] Agents, who collectively "buy the teachers` time", have to pay the teachers` opportunity cost which is equal to the wage of skilled labor in the production (absorption) or R&D sector.

positive feedback[41] from the firms would in turn increase the expected return to human capital investments of those agents who did not participate to the initial educational investments (these workers use also more physical capital and have higher incomes). This induces increasing social returns to human capital accumulation. Underinvestment in human capital accumulation is the consequence. This externality is also an justification for an education system, in which education facilities and firms are more intensively interconnected.

These different kinds of externalities existing in the education sector are worth of being examined because they introduce the possibility that laissez-faire growth can be socially suboptimal low due to the fact that agents do not fully internalize human capital spillovers when allocating their time between current production (absorption), R&D, leisure and skill acquisition.

## IX. Conclusions and Outlook

Cross-country regressions reveal that human capital is an important role in explaining international variations in economic growth rates (see for example Benhabib and Spiegel 1994).

The simple dynamic model presented in this article offers further insights into the structural features of economic growth and European unemployment. The integration of wage structure rigidity in the basic Schumpeterian growth model will show us some new interesting insights in the dynamic analysis of wage (structure) rigidity.

Dynamics are very important in reality. Due to the fact that the static and dynamic structure of the industrialized countries changes continously, (re)education and labor-force reallocation play a very important role in the process of long-term economic growth induced by technical progress. Inasmuch as human capital accumulation is costly for workers, equilibrium wage differentials may offer dynamic compensation for such costs. However, in ”rigid” labor markets (e.g. the European or German labor market) where human capital accumulation and adjustment (e.g., vocational education within the firm) and labor reallocation is hampered by centralized wage setting, wage structure rigidity reduces or eliminates the incentives to invest efficiently in human capital accumulation. These dynamic inefficiencies in (re)education and labor reallocation due to wage structure rigidity reduce the innovative, education and absorption activities of an economy and thereby long-term economic growth. *Income*

[41] The external effects work through changes in the *value of future matches in an economy characterized by ex ante investments and costly search.*

*inequality, induced by human capital accumulation, is therefore essentially for human capital accumulation and should be viewed as being growth-enhancing*.[42]

A lower long-term economic growth rate (due to suboptimal accumulation and adjustment of human capital) in turn induces long-term decreases in the employment rate. Together with an constant or increasing stock of labor supply[43] (e.g. in Germany), this could be a dynamic explanation (dynamic losses in potential production possibilities) of the increasing and persistent unemployment in Europe due to labor market rigidities.

Inasmuch as a ”rigid” labor market structure can have desirable labor-income stabilization effects, European (especially German) institutions may well be inspired by a desire to shelter individual workers` welfare from shocks, at the cost of dynamic inefficiences in the (re)education and labor reallocation process.

A failure to maintain the pace of human capital accumulation relative to competing economies reduces the domestic economy`s ability to innovate and absorb new future technologies, inducing a cycle of industrial stagnation. Therefore, ”flexible” markets are a more important determinant of outcomes and structural change than in the past. Therefore, the results of the dynamic model presented in this article are consistent with the common view that labor-market flexibility has become an increasingly important determinant of market performance in the last two decades, especially in a more volatile economic environment. Therefore, if generalized instability has increased the returns to flexibility, rigid institutions may have become too costly in terms of efficiency.

However, a new very important result is that if the extent of negative externalities induced by innovations is greater than the extent of positive externalities induced by innovations, wage structure rigidity will induce an increase in the welfare by decreasing the excessive laissez-faire growth rate**.** Such dynamic interactions remain unexplained by static models.

The simple endogenous growth model discussed above are not meant to be fully realsitic, and should be complicated in a number of directions in order to discuss labor market issues in a dynamic economic environment (e.g., an endogenous education sector, endogenous physical capital accumulation, endogenous unemployment due to a qualification mismatch, and endogenous business cycles; see Nusser 1998).

In most part of this article, I implicity assume that agents have the same characteristics. In reality however, the benefits of education differ between agents. For example, the benefits of

[42] Aghion and Howitt (1998) point in Chapter 9 to several important reasons why excessive inequality may reduce investment opportunities and thereby discourage growth.

[43] For instance, because of an increasing openess to trade or an increasing labor-force participation of women.

education for older workers might be low (e.g., because of learning problems, short amortization period), so that the return to education will depend on the age structure of the workforce. Note that most industrialized countries are faced with negative population growth rate, so that the old outnumber the young. This might be an explanation of why these countries are faced with decreasing output growth rates, because old workers have less incentives to accumulate and adjust their human capital in order to keep up with the speed of technological change. Endogeneizing the population growth rate in the Schumpeterian approach to endogenous growth therefore might also suggest a potentially fruitful directions for further theoretical research.

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