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# The Skill Premium, Technological Change and Appropriability


RICHARD NAHUIS

*CPB Netherlands Bureau for Economic Policy Analysis and Nijmegen University, The Netherlands*

SJAK SMULDERS*

*Department of Economics and CentER, Tilburg University, The Netherlands*



forthcoming in *Journal of Economic Growth*



Correspondence to:

Sjak Smulders, P.O. Box 90153, 5000 LE Tilburg, The Netherlands,

phone: +31.13.466.2920

fax: + 31.13.466.3042

e-mail: j.a.smulders@kub.nl

**Abstract**

This paper demonstrates that an increase in the relative supply of educated workers generates a structural change in the production structure towards a knowledge-intensive production process. This structural shift may ultimately lead to an increase in the return to educated labour despite the increase in their supply. The paper argues that the steady increase in the supply of educated workers that most Western economies have experienced in recent decades may be viewed as the driving force behind the observed pattern of wage inequality. In particular, the paper demonstrates that if firms can appropriate a sufficient share of the intertemporal return from knowledge generating activities of their labour force, a gradual increase in the supply of skilled workers would generate only a temporary reduction in the skill premium followed by a permanent increase in the return to skill.

***Keywords:*** wage inequality, growth, technological change, research productivity, appropriability

***JEL classification***: J31, O14, O31, O33

## 1. Introduction

The decline in wage inequality in the US as well as other European economies in the 1970s has been followed by a monotonic rise since the early 1980s, despite a steady increase in the relative supply of educated workers. In particular, as demonstrated in Table 1, wages of non-production workers have risen relative to those of production workers. Anecdotal evidence suggests that blue-collar production activities have been replaced by automated processes that shifted demand towards white-collar workers in management and control, skill-intensive service and maintenance, and science-based research and development.[1]

*** insert Table 1 about here ***

This paper demonstrates that an increase in the relative supply of educated workers generates a structural change towards a knowledge-intensive production process that may ultimately lead to an increase in the return to educated labour despite the increase in their supply. The paper argues that the steady increase in the supply of educated workers that most Western economies have experienced in recent decades may be viewed as the driving force behind the observed pattern of wage inequality.

Our key assumption is that unskilled workers perform tasks ("production tasks") that are fundamentally different from those of skilled workers ("non-production tasks"). While unskilled workers produce final goods and services directly for the market, skilled workers produce services for internal use that indirectly affect market performance. They use their skills to improve the firm's production process and product quality, the firm's organization, management, and marketing. Basically, non-production tasks entail investments in the capabilities of the firm, or the firm's knowledge stock, which ultimately determines its productivity. This firm-specific knowledge stock determines not only productivity in final goods production, but also the productivity of future non-production tasks. Skilled workers build on the knowledge stock that has already been accumulated within the firm; not only their skills, but also the firm's knowledge stock is thus an input in the knowledge-accumulation process. Thus, non-production workers both *use* and *produce* new firm-specific knowledge, thereby creating their own complementary assets.

An increase in the number of skilled workers affects skill premiums in two ways. First, it raises the value of firm-specific knowledge. This is because of the non-rival nature of knowledge: a larger number of non-production workers implies that the same knowledge stock can be used more intensively as an input (complementary asset) in non-production activities. Firms that are willing to pay more for knowledge are also willing to pay higher wages for skilled workers that can develop the knowledge. Thus, skill premiums tend to increase in response to a larger supply of skilled labour because firms start investing more in knowledge, which is the non-rival complementary asset for skilled labour. This induced investment effect must be balanced against the second effect: holding technology -- and the organization of firms -- constant, an increase in the supply of skilled workers creates the usual substitution effect and reduces skill premiums. On balance, skill premiums rise if the induced investment effect is strong relative to the substitution effect, that is, if the return to investment in knowledge that firms can appropriate is large enough.

Although skilled workers produce their own complementary assets, they might also rely on knowledge created elsewhere. Firms internalize intertemporal knowledge spillovers within the company (taking into account that knowledge developed today becomes input for tomorrow's non-production workers), but they cannot appropriate intertemporal knowledge spillovers to other firms. If a small fraction of the knowledge created by a firm's skilled workers accrues to other firms, then the appropriability of that firm's investment activities is said to be high (spillovers are low). High appropriability, in turn, boosts a firm's investment in knowledge and drives up the skill premium.

In the extended version of our model, the degree of appropriability is endogenous and depends on the allocation of skilled workers over two types of knowledge investment. First, firms can accumulate knowledge internally (in-house R&D); second, they can buy technology in the patent market. Internally developed knowledge serves as a firm-specific input into non-production work, and firms internalize these (intra-firm) intertemporal spillovers. Research for the patent market builds on general knowledge, which generates intertemporal spillovers that cannot be appropriated. At low levels of the supply of skilled labour, patents are shown to be the dominant source of technology acquisition, economy-wide appropriability is weak, and skill premiums are mainly determined by the conventional substitution effect. However, with a high supply of skilled labour, most research effort is endogenously allocated to firm-specific knowledge accumulation, more intertemporal knowledge spillovers can be appropriated, and the induced investment effect dominates the substitution effect. Hence, when skilled labour gradually becomes more abundant, the share of patents in total R&D output declines steadily, while the skill premium at first decreases, and then increases.

This paper is related to the literature that investigates how changes in technology and the supply of human capital affect wage inequality. Two strands stand out in this literature. The first strand focusses on the adjustment process to technology shocks, and finds that wage inequality may rise in the short run because skilled labour has a comparative advantage in coping with a changing technological environment (Bartel and Lichtenberg, 1987; Greenwood and Yorukoglu, 1997; Lloyd-Ellis, 1999). In Caselli (1999), only the workers with sufficiently low training costs can profitably acquire the skills necessary to gain access to new technologies, while low-skilled workers keep using older low-productivity technologies. The advent of a new technology therefore initially creates inequality. Since it also triggers growth, which enhances the return to education, more low-skilled workers acquire training over time, thus offsetting the initial rise in inequality. Galor and Tsiddon (1997) explain the cyclical pattern of wage inequality by the evolution of the return to ability. Workers differ with respect to ability. The return to ability changes because of two types of technological change. First, infrequently occurring major technological breakthroughs raise the return to ability and increase wage inequality. Second, subsequent incremental innovations gradually make technological advances more accessible for low ability workers, which reverses inequality. Galor and Moav (2000) explore how the advent of a new technology makes part of the skills of workers obsolete. In particular, uneducated workers are hit more severely than the educated, and within both groups, workers with lower ability are hit more severely. Hence, inequality within and between groups increases. Inequality increases only temporarily in response to a productivity shock, since it is the *change* in productivity that erodes the human capital of low-skilled workers.[2]

Papers in this strand of literature have in common that an ongoing series of positive productivity shocks (or a permanent rise in the growth rate) is needed to permanently raise inequality. Also predicted is a positive correlation between skilled labour supply, inequality and growth. With endogenous levels of education, increased skill premiums result in a higher supply of skills. Alternatively, if growth depends endogenously on the level of human capital, then any shock that permanently increases human capital raises the growth rate, and hence inequality.

The second strand of analysis in the literature focusses on the long-run response of wage inequality to increases in the supply of skilled labour. Technological change may reflect a permanent shift in favour of skilled labour because of increasing returns (Acemoglu, 2000). In Acemoglu's (1998) R&D model, a greater number of skilled workers encourages firms to create more skill-complementary technologies.[3] Only in a large market can fixed innovation costs be recouped. In Acemoglu's (1999) matching model of the labour market, firms open up (better-paid) specialized jobs for skilled labour only if a sufficient number of such workers are available. Only in a large market can the fixed costs of posting vacancies be recouped. In both papers, increasing returns (due to the presence of fixed costs of vacancies and innovation) are crucial in order to provide bigger investment incentives in larger markets (that is, markets with more skilled labour).

Both of the main driving forces behind inequality that are stressed in the literature -- comparative advantage to cope with technological change and increasing returns, respectively -- play a role in our analysis. As is stressed in the second strand of literature, we study the inequality effects of labour supply changes. More skilled labour implies a larger market for knowledge inputs, which are produced subject to increasing returns due to complementarities and the non-rival nature of knowledge. Hence, technology may shift in favour of skilled labour. As is maintained in the first strand of literature, we find that inequality rises permanently only if the growth rate is permanently higher. Skilled labour can take better advantage of technological change than can unskilled labour because when technological improvements arrive rapidly, skilled workers have a large pool of new ideas to build on, which makes them more productive.

Our approach differs from the literature on wage inequality in three main respects. First, we explicitly acknowledge the different nature of production work versus non-production work. Second, we stress the firm-specific nature of innovation and other non-production tasks. Investment incentives, and thus the reward to skilled labour, crucially depend on the degree to which the value of innovations can be appropriated by firms. Third, we focus on how firms change their organisation of innovative and other non-production activities. This allows us to look beyond the labour market effects that have been the traditional focus of the inequality literature. Our model provides a new testable prediction, borne by the data, that the number of patents per R&D dollar decreases when the supply of skilled labour increases.

To connect wage inequality to innovation and growth, we use building blocks from growth theory. We combine R&D growth models in which patents are assumed to take care of rent appropriation (e.g. Grossman and Helpman, 1991, and Romer, 1990), with a model of firm-specific knowledge (cf. Peretto, 1998 and 1999, Smulders and Van de Klundert, 1995 and Thompson and Waldo, 1994). We use the well documented fact that spillovers are not complete and instantaneous (Jaffe et al. 1993). We extend the theory of growth based on firm-specific knowledge by broadening the concept of technological change to organisation change.

The plan of the paper is as follows. In section 2 we present the main model to study the relationship between appropriability and the skill premium. In section 3 we endogenize our appropriability measure by distinguishing between patentable and tacit firm-specific knowledge. In section 4 we confront stylized facts and model predictions. Section 5 concludes.

## 2. A general-equilibrium model of non-production jobs

### 2.1 Overview of the model

There is a continuum of firms, each supplying a unique product under monopolistic competition. For notational convenience we normalize the mass of firms to unity. Firms hire two types of labour, labelled skilled ($H$) and unskilled ($L$). The supply of both types of labour is exogenously given and grows at a common rate $l$. Unskilled labour performs production tasks. Skilled labour is engaged in non-production activities, which includes marketing, organisation and management, financial planning, and research and development. Firms maximize profits and consumers maximize utility. Consumers have Dixit-Stiglitz (1977) preferences over a variety of goods. The model generates a balanced growth path with growth driven by either innovation or population growth (in the endogenous and semi-endogenous growth variant respectively).

### 2.2 Preferences and households' behaviour

The consumer side of the model follows the by now standard approach of growth theory. The representative consumer cares about an index ($C$) of differentiated consumption goods ($x_i$):

$$C_t = \left( \int_0^1 x_{it}^{\frac{\varepsilon}{\varepsilon-1}} di \right)^{\frac{\varepsilon-1}{\varepsilon}} , \tag{1}$$

where $t$ denotes time, $\varepsilon$ is the constant elasticity of substitution. Consumers maximize intertemporal welfare that features a constant discount rate ($\vartheta$) and constant elasticity of intertemporal substitution ($1/\rho$):

$$U_0 = \int_0^\infty \frac{C_t^{1-\rho} - 1}{1-\rho} \, e^{-\vartheta t} dt. \tag{2}$$

Maximization of (1)-(2) subject to the appropriate budget constraints implies that the price elasticity of demand for any good $x_i$ equals $\varepsilon$, and that the change of consumption over time is governed by the Keynes-Ramsey rule (from now on we omit the time index $t$ for notational convenience):

$$r - \hat{p}_c = \vartheta + \rho \hat{C} , \tag{3}$$

where hats denote growth rates, $r$ is the nominal interest rate, and $p_c$ is the price index for the differentiated consumption good.

### 2.3 Production and non-production activities

Final output in each firm ($x$) is produced by production workers (unskilled labour $L$).[4] Their productivity is determined by the stock of firm-specific knowledge ($f$):

$$x_i = f_i^{\beta} \cdot L_i^{\delta} \equiv F(f_i, L_i) . \tag{4}$$

Skilled workers ($H$) gradually improve the firm's organisation, production technology or (perceived) product quality (through marketing). These non-production activities are valuable for the firm because they represent investments in the firm's productivity. Accordingly, non-production workers accumulate firm-specific knowledge ($f$). The stylized representation of the accumulation process is as follows:

$$\dot{f}_i = \xi \cdot \left(f_i^{\alpha} S^{1-\alpha}\right)^{\phi} \cdot H_i^{\lambda} \equiv G(H_i, f_i, S), \qquad \alpha \geq 0, \ \phi, \lambda \in (0,1] \ . \tag{5}$$

$$K_i \equiv \xi \cdot \left(f_i^{\alpha} S^{1-\alpha}\right)^{\phi} ,$$

$$S \equiv \int_0^1 f_j \, dj .$$

The productivity of skilled workers in non-production activities ($H$) is determined by two different types of knowledge inputs: own knowledge ($f$) and spillovers ($S$). These inputs are aggregated in index $K$, the "knowledge base". The importance of knowledge inputs, and thus of the intertemporal effects of research, is governed by $\phi$, which we label the intertemporal spillover parameter. $\xi$ is the research productivity parameter. The (non-production) work of skilled workers is possibly subject to decreasing returns governed by $\lambda$.[5]

Non-production workers use knowledge inputs from two sources. First, they analyse, exploit (and expand) the stock of accumulated firm-specific experience and organisational knowledge capital ($f_i$).[6] Second, skilled workers benefit from spillovers, that is knowledge developed by other firms ($S$). This second type of knowledge inputs is beyond control of the individual firm and is an intertemporal knowledge-spillover externality that is familiar from R&D-based endogenous growth models. Firms do not internalise the intertemporal spillovers to other firms because they cannot appropriate the associated returns. However, firms do internalize the intertemporal spillover effect from own knowledge generation to their own non-production activities: they take into account that accumulation of specific knowledge not only affects production but also provides inputs for future research. The degree to which firms appropriate the fruits of their own research is crucial for the incentive to invest. Therefore we need to be more precise:

*By (the degree of) appropriability we mean the fraction of the total returns generated by firm i's research that accrues to firm i itself.*

More formally, we define firm $i$'s appropriability ($a_{fi}$) as:

$$a_{fi} \equiv \frac{q_{Ki}\left(\frac{\partial K_i}{\partial f_i}\right) df_i}{q_{Ki}\left(\frac{\partial K_i}{\partial f_i}\right) df_i + \int_0^1 q_{Kj}\left(\frac{\partial K_j}{\partial S_j}\frac{\partial S_j}{\partial f_i} df_i\right) dj} \qquad (6)$$

where $q_{Ki}$ is the value of an increase in $K_i$. The numerator is the value of an increase in $f$ that accrues to the firm undertaking the research, whereas the denominator is the total return of firm's research: the return accruing to the firm doing research plus the spillover from that research to other firms. Note that our definition of appropriability characterizes only the returns of investment in terms of improved productivity of non-production workers. The investment also improves productivity in final goods production, but since none of these returns leak to other firms, appropriability is complete in this respect and we can ignore them in our definition.

We extend the regularities related to spillovers and knowledge accumulation –

familiar to the R&D-based endogenous growth literature – to all non-production activities, which deserves some elaboration. To see the analogy between R&D and other non-production work, think of a new way of organising a firm. The implementation and development of new organisational schemes often takes years and builds on past experience. From the organisational scheme that a specific firm works out some more general principles can be useful for other firms too. If this information is written down or disseminates in some way, other firms might benefit too (*S*). However, a next firm reorganising might use this information but still needs to go through the process of convincing, motivating and adapting to specific "own" circumstances [7] (that is increasing the firm's specific knowledge stock, $f_i$). Note that spillovers do not happen automatically or completely. Hence, we do not assume *perfect* nor automatic knowledge spillovers, as is clear from the distinction between *S* and $f_i$ in our specification and the fact that other firms' knowledge enters (5) but not (4). Though we argue the model to be applicable to the broad category of all non-production workers, the remainder of the analysis is largely expressed in R&D terms.

### 2.4 Firm behaviour

Firms maximize profits, discounted by interest rate *r*, subject to (4),(5) and the downward sloping demand curve for its output. Suppressing firm index *i*, we may write the Hamiltonian as:

$$p(F(f,L))\cdot F(f,L) - w_L L - w_H H + q\,G(H,f,S),$$

where $p(.)$ is the firm's demand function and *q* is the shadow value of firm-specific knowledge, that is, the firm’s internal accounting price for non-production workers' output. First order conditions are:

$$w_L = p\left(1 - \frac{1}{\varepsilon}\right)\frac{\partial x}{\partial L} \,, \tag{7}$$

$$w_H = q\frac{\partial \dot{f}}{\partial H} \,, \tag{8}$$

$$rq = p\left(1 - \frac{1}{\varepsilon}\right)\frac{\partial x}{\partial f} + q\frac{\partial \dot{f}}{\partial f} + \dot{q}, \tag{9}$$

Equations (7) and (8) represent labour demand. The firm hires unskilled labour up to the point where the marginal cost of hiring (the wage for unskilled labour, $w_L$) equals its marginal revenue product. Similarly, the firm hires skilled labour up to the point where the marginal cost of hiring (the wage for skilled labour, $w_H$) equals its marginal product which is the marginal amount of knowledge it generates $\partial\dot{f}/\partial H$ valued at the internal accounting price of knowledge $q$.

Equation (9) represents investment demand. The firm invests in firm-specific knowledge up to the point where the marginal return to investment equals the cost of borrowing. This investment equation becomes easier to understand after we substitute (7) and

(8):

$$rq \;=\; \left(\frac{\partial x/\partial f}{\partial x/\partial L}\right) w_L + \left(\frac{\partial \dot{f}/\partial f}{\partial \dot{f}/\partial H}\right) w_H \;+\; \dot{q}\;. \tag{10}$$

The left-hand side (lhs) represents the opportunity cost of a marginal increase in firm-specific knowledge: the return to investing an amount $q$ (the cost of a unit of firm-specific knowledge) in the capital market. The three terms on the right-hand side (rhs) denote the benefits from investing in firm-specific knowledge: (1) labour-cost savings in final goods production, (2) labour-cost savings in non-production work and (3) capital gains, i.e. savings in research costs by doing research now rather than in the future.

**2.5 General equilibrium**

We assume that firms are symmetric, which allows us to drop all subsripts $i$. Goods-market equilibrium implies $C=x$, and $p_c=p$. The capital market is in equilibrium if the rate of return satisfies the Keynes-Ramsey rule (3), which can now be written as $r-\hat{p} = \vartheta+\rho\hat{x}$. Combining the Keynes-Ramsey rule with (9), (8) and (7) and using (4) to solve for $\hat{x}$, we find:

$$\widehat{\left(\frac{w_H}{w_L}\right)} \;=\; -\,\alpha\,\phi\hat{S} \;+\; \phi\hat{S} \;+\; \left(\rho\,\beta\hat{f} \;+\; \vartheta_l\right) - \left[1 \;+\; \frac{\lambda}{\delta}\,\frac{L/H}{w_H/w_L}\right]\beta\hat{f}\;, \tag{11}$$

where the rate of time preference is adjusted for population growth $l$: $\vartheta_l \equiv \vartheta+[\lambda+\delta(\rho-1)]l$.

The symmetry assumption implies that $f$ and $S$ grow at a common rate, denoted by $g$, which can be written (from (5)) as:

$$\hat{f} = \hat{S} = g = \xi H^{\lambda}/f^{1-\phi}. \tag{12}$$

Finally we can solve for the degree of appropriability, defined in (6). First, we use the fact that $q_{Ki}$, the value of a marginal increase in knowledge capital $K_i$, equals the marginal product of $K_i$ valued at the shadow price of firm-specific capital, $q_{Ki} = q_i \partial \dot{f}_i / \partial K_i$. Next, we use equation (5) and the symmetry results $q_i = q_j$ and $S = f$. Then (6) boils down to:

$$a_{fi} = \alpha.$$

Hence, appropriability is measured by elasticity $\alpha$, the share of own knowledge inputs in the knowledge base, see (5).

**2.6 Appropriability and the skill premium**

We use equation (11) to identify four different channels by which an increase in the supply of skilled labour, $H$, affects the skill premium $w_H/w_L$. This equation is basically a capital market equilibrium condition stating that the firm's rate of return to investment equals the rate of return that household require on their savings. The capital market plays a decisive role in determining wages of skilled workers, since the non-production activities they perform imply investments (in knowledge capital). Whenever the return to investment increases, there will be an induced demand for skilled labour and hence an upward pressure on their relative wage.

A change in $H$ affects the rhs of (11) directly and indirectly, which reflects different effects of an increase in skilled labour on the return to investment in firm-specific capital. For the time being, we assume that the skill premium is constant (which we will show to be true in the steady state). This implies that the lhs of equation (11) is zero and that the skill premium on the rhs should adjust to the increase in skilled labour.

More skilled labour $H$ directly increases the term in brackets in (11) and requires a fall in the skill premium $w_H/w_L$. This represents the *conventional* effect: if more non-production workers are employed, their marginal product falls due to *diminishing returns*. In other words, the returns to investment in knowledge falls so firms pay a lower wage to the marginal non-production worker.[8]

Skilled labour supply affects the skill premium *indirectly*, since an increase in $H$ increases both $\hat{f}$ and $\hat{S}$, see (12). Equation (11) helps us identify three indirect effects. First, the first (negative) term in (11) becomes larger. It is the share of the intertemporal returns to research that firms can appropriate. Firm take into account that if more skilled labour is hired, future research costs will decline more rapidly. The better they can appropriate these intertemporal returns (that is, the larger appropriability $\alpha$) the more they increase their demand for non-production workers and thereby drive up their wages. Hence, more skilled labour tends to drive up wages indirectly through an *appropriability effect*. Second, however, more rapid declines in the cost of research make firms want to postpone investment and thereby reduces their willingness to hire non-production workers, as long as these cost reductions stem from spillovers form other firms. Hence, a *spillovers effect* exerts a downward pressure on the skill premium (see the second term on the rhs). Third, there is a *cost of capital* effect (see third term on the rhs). An increase in $H$ increases the cost of investment as it increases growth of consumption ($\beta\hat{f}$), which makes households require a larger rate of return on their savings, see (3). If the degree of intertemporal substitution ($1/\rho$) is high this has only a moderate effect on the costs of investment. The higher investment cost induces firms to hire less skilled labour, which reduces the relative wage of non-production workers.

To sort out which of the four effects dominates, we investigate the general equilibrium dynamics implied by (11) and (12). Our main result is that an increase in the supply of skilled labour may increase the skill premium. The simplest case to show this result is under the assumption of constant returns with respect to knowledge accumulation in non-production activities ($\phi = 1$); endogenous growth. As a result, the rate of growth in the economy depends on the supply of skilled labour only; see (12). To avoid accelerating growth rates, we assume that there is no population growth ($l = 0$). Note that both restrictions are common in endogenous growth literature.

The model is now fully represented by equation (11) and (12). Figure 1 depicts equation (12) as the vertical line labelled GG. The SS-curve in the figure is the locus for which the skill premium, $w_H / w_L$, is constant, as can be derived from equation (11). This curve slopes upward as no-arbitrage requires that a high rate of growth – which makes it attractive to invest in knowledge by hiring skilled workers – is met by high costs. Full employment of skilled labour requires that the economy is always on the GG line. The skill premium jumps immediately to its long-run value, given by the point of intersection between the GG line and the SS curve.

*** insert Figure 1 about here ***

An increase in the supply of skilled labour may raise wage inequality in general equilibrium, since, if $H$ increases, the SS-locus shifts down and the GG-line shifts to the right.

To find the conditions for a rising skill premium, we derive the closed-form solution for the skill premium. Substituting (12) into (11), and taking into account that $\phi = 1$ and that the skill premium is constant, we find:

$$\frac{w_H}{w_L} = \frac{\beta(\lambda/\delta)L}{[\rho\beta + 1 - \beta - \alpha]H + (\vartheta/\xi)H^{1-\lambda}} \ . \tag{13}$$

Differentiation with respect to $H$ reveals that the condition for a rise in the skill premium is given by (use (12)):

$$\alpha > \rho\beta + (1-\beta) + (1-\lambda)\vartheta/g \ . \tag{14}$$

This last condition neatly reveals the determinants that may cause the demand curve for skills to slope upward.

First, appropriability of the (intertemporal) returns to non-production activities (as measured by $\alpha$) should be high. This underlines our key assumption that skilled workers create the knowledge that is subsequently used as an essential input in non-production activities. If new knowledge only affects the firm's production activities and all knowledge inputs in non-production activities come from outside (i.e. $\alpha = 0$), condition (14) is never satisfied and the demand curve for skills slopes conventionally downward. Note that most of the endogenous growth literature considers this case by assuming that all intertemporal spillovers from research are external effects for the individual firm. Intertemporal spillovers imply knowledge creation of which the returns cannot be appropriated by the inventor. They give rise to the only externality in our model. The larger $\alpha$, the smaller is the externality and the more likely is it that the skill premium rises with an increased supply of skilled labour.

Second, the cost of capital should not rise too fast with increased investment, that is, $\rho$ should be small (note from the Keynes-Ramsey rule (3) that $\rho$ governs the sensitivity of interest rates with respect to growth and investment). This emphasises that non-production labour is engaged in the *investment* process, rather than the production process. If firms hire more skilled labour, investment and growth rises in the economy, forcing households to save more.[9] This induces them to require a higher rate of return on their savings, especially when they prefer a smooth consumption pattern ($\rho$ large). When firms face a higher cost of capital, investments in firm-specific knowledge by hiring more skilled labour, becomes less attractive. The rise in the cost of capital thus mitigates the demand for skilled labour and partially offsets the rise in the skill premium.

Third, diminishing returns in non-production activities should be small. Diminishing returns with respect to the input (*H*) and output (*f*) of skilled labour (as measured by $1-\lambda$ and $1-\beta$, respecitively) reduce the skill premium.

To summarize our main result:

*A rise of the skill premium as a response to a higher supply of skilled labour requires that the appropiability of the intertemporal returns from an expansion of non-production activities is high. Hence the return should accrue mainly to the firm rather than to shareholders (in the form of higher rates of return) or other firms (because of spillovers). Moreover, the returns should not fall too quickly because of diminishing returns in non-production activities.*

Condition (14) is derived for the case of endogenous growth ($\phi = 1$ and $l = 0$). For the more general case with $\phi < 1$ and $l > 0$, we find that the skill premium rises in the short run under a condition basically identical to (14): $\alpha\phi > \beta\rho + (1-\beta) + (1-\lambda)\vartheta_l/g$.[10] In this case of "semi-endogenous growth" (Jones 1995), the short-run growth rate changes as in an endogenous growth model, but the long-run growth rate is exogenous because the productivity of investment falls as more knowledge per worker is accumulated. The long-run effect on the skill premium vanishes together with the long-run growth effect. This again reveals that the upward pressure on the skill premium is crucially linked to increased investment opportunities, which make hiring skilled workers that produce investment goods (knowledge) more attractive.

## 3. Endogenous appropriability and patents

The model discussed above can explain the upsurge in inequality in the 1980s from a sufficiently high degree of appropriability of intertemporal returns. We can explain *both* the decrease and the increase in inequality in the 1970s and 1980s respectively by increasing the appropriability parameter in the middle of the period, such that the inequality in (14) is reversed. This section shows that appropriability changes *endogenously* once we not only consider innovation based on inhouse R&D but also innovation based on external research and patents. We show that an increase in skilled labour supply causes a reallocation of skilled labour from external research to firm-specific R&D. Since intertemporal knowledge spillovers can be appropriated in the latter research type, but not in the former one, economy-wide appropriability improves.

### 3.1 A model with two types of research

From now on we distinguish two knowledge stocks: firm-specific knowledge (*f*, as above) and non-firm-specific (*n*). The latter is knowledge that can be directly applied in all firms, that can be codified and sold in a patent market. The former is largely uncodified or tacit, embedded in the organisation and monopolised by secrecy and specificity.

Spillovers and appropriability differ between the two types of knowledge. Firm-specific R&D creates knowledge with strong complementarities to the firm's own activities. It can be easily kept secret and exclusively exploited by the firm itself since it is intimately linked to its own idiosyncrasies. As a result, appropriability of returns is relatively high. In contrast, when taking out or acquiring patents, knowledge of a wider applicability is involved. Patents ensure that the inventor gets a reward from any firm that applies this knowledge in *production* activities. However, the patent system cannot prevent, and in fact stimulates, the disclosure of information about general principles and ideas behind the invention that can be used in *non-production* activities.

The importance of our distinction between firm-specific and patentable knowledge is supported by evidence in Cohen et al (2000) and in Keely and Quah's (1998) review of the empirical literature on R&D, technology and growth. The latter show that output of knowledge production is inaccurately proxied by patents, as "[m]ost knowledge accumulation does *not* occur from private firms' R&D producing *patentable* knowledge."[11] Cohen et al. (2000) point out that secrecy and complementarities between the firm's existing activities and new activities are more important to secure the returns to innovation than patents. Nevertheless patents are indispensable as a complementary appropriability mechanism and as a means to exchange knowledge.

To introduce this second type of knowledge we extend and modify the production and R&D functions of the model of section 2. Final goods production now benefits from own knowledge (*f*) as well as knowledge acquired by buying patents (*n*), so that (4) is replaced by:

$$x_i = f_i^{\beta} n_i^{1-\beta} \cdot L_i^{\delta} \; . \tag{4'}$$

Non-production workers who develop firm-specific knowledge now build on existing ideas accumulated in both knowledge stocks. That is, spillovers *S* in (5) are specified as:

$$S \equiv \bar{f}^{1-\omega} \, \bar{n}^{\omega} , \tag{5'}$$

where $\bar{f} \equiv \int_0^1 f_j dj$ is the economy-wide stock of firm-specific knowledge and $\bar{n}$ is the total number of patents in the economy; the firm takes both variables as given.

For the production of patentable knowledge we introduce a second type of firms, labeled "patent firms". They enter the market freely, hire skilled workers ($H_n$) and sell new patents ($\dot{n}$) to production firms. The productivity of research firms is increasing in the two aggregate knowledge stocks, $\bar{f}$ and $\bar{n}$, which firms take as given. Accordingly, a patent firm's production function is specified as:

$$\dot{n} = \chi \cdot \bar{n}^{1-\mu} \bar{f}^{\mu} \cdot H_n \; . \tag{16}$$

Equilibrium in the market for skilled labour requires that demand for skilled labour by production firms (*H*) and by patent firms ($H_n$) matches supply ($H^s$):

$$H + H_n = H^s \; . \tag{17}$$

Free entry of patent firms implies that the price of a patent, $p_n$, equals the production cost:

$$p_n = \frac{w_H}{\chi \bar{n}^{1-\mu} \bar{f}^{\mu}} . \tag{18}$$

The demand for patents follows from the no-arbitrage condition analogous to equation (9):[12]

$$p\left(1 - \frac{1}{\varepsilon}\right) \frac{\partial x}{\partial n} + \dot{p}_n = r p_n . \tag{19}$$

As in almost all R&D-based growth models (Romer, 1990, Grossman and Helpman, 1991, Aghion and Howitt, 1998), in our patent sector, researchers build on the total stock of public knowledge, but cannot internalize the contribution they make to this stock. Comparing equation (19) with (9) reveals this crucial difference between the two types of research: the private return to firm-specific research includes a term valuing the contribution of current research to future research productivity ($q \partial \dot{f} / \partial f$), while the private return to developing patents does not include such an intertemporal return.

As before, we relate this to appropriability. In firm-specific research intertemporal spillovers can be (partly) appropriated, but not in research in patent firms. Applying an analogous definition as in section 2, we find that appropriability for patent firms is zero and that appropriability for the firms producing final output and firm-specific knowledge is still increasing in $\alpha$. We calculate an aggregate index of appropriability conditions in the economy as a whole by weighing appropriability in firm-specific research by its share in total non-production (R&D) activity:

$$a = \alpha \frac{H}{H^s} . \tag{20}$$

The remainder of this section discusses symmetric steady-state equilibria with endogenous growth. Endogenous growth requires: $\phi = 1$ and $l = 0$. To simplify expressions we set $\lambda = \delta = 1$ and define $\nu = \omega(1 - \alpha)$, which represents the weight of patentable knowledge in the production firm's knowledge base *K*.

### 3.2 Appropriability and the skill premium

We solve the model in terms of the ratio of the stock of firm-specific knowledge to the number of patents $A \equiv f/n$. Using (17), we can rewrite (5) and (16) as $\hat{f} = \xi A^{-\nu} H$ and $\hat{n} = \chi A^{\mu}(H^s - H)$. It follows immediately that on a balanced growth path with *H* constant, *n* and *f* grow at a common rate, denoted by *g*, and *A* is constant. Solving for *H* and *g* gives:

$$H = \frac{H^s}{1 + \left( \frac{1}{(\chi/\xi) A^{\nu+\mu}} \right)} \tag{21}$$

and

$$g = \frac{\chi A^{\mu} H^s}{1 + (\chi/\xi) A^{\nu+\mu}} . \tag{22}$$

The ratio of firm-specific knowledge to patents $A \equiv f/n$ is tightly connected to appropriability: combining (20) and (21) reveals that *a* is monotonically increasing in *A* with $\lim_{A \to \infty} = \alpha$. In the remainder we will use *A* as an indicator of the degree of appropriability.

Equation (22) is depicted in the upper panel of Figure 2 as the BG-curve. It represents feasible balanced growth (BG) rates. It is hump-shaped, reaching its maximum at $A^{\nu+\mu} = \mu/\nu$. Its shape reflects declining productivity of research (of external or inhouse R&D) if the composition of knowledge is skewed towards one of the types of knowledge (patents or firm-specific knowledge respectively).

In equilibrium the return to patent development equals the cost of capital. We find this no-arbitrage condition by substituting (4'), (7), and (18) into (19). Along a balanced growth path (where $w_H/w_L$ and $A$ are constant) this boils down to:

$$r - \hat{p} = \frac{L}{w_H/w_L}(1 - \beta)\chi A^{\mu} \ . \tag{23}$$

A similar no-arbitrage equation holds for investment in firm-specific knowledge, see (11):

$$r - \hat{p} = \frac{L}{w_H/w_L}\beta \xi A^{-\nu} + \alpha g \ . \tag{24}$$

The expressions for the two rate of return at the right-hand sides of (23) and (24) are similar, but for the term that indicates the dynamic externality that is appropriated in inhouse R&D only (the strength of this mechanism is governed by $\alpha$).

Combining the capital-market equations (23) and (24), the Ramsey rule, (3), and $\hat{x} = g$ from (4'), we may solve for a relationship either in terms of between growth and appropriability, or in terms of the skill premium and appropriability, which gives, respectively:

$$g = \frac{(1-\beta)\chi A^{\nu+\mu} - \beta\xi}{(\alpha-\rho)(1-\beta)\chi A^{\nu+\mu} + \rho\beta\xi}\vartheta \ . \tag{25}$$

$$\frac{w_H}{w_L} = \left[(\alpha-\rho)(1-\beta)\chi A^{\nu+\mu} + \rho\beta\xi\right]\frac{L}{\alpha\vartheta A^{\nu}} \ . \tag{26}$$

The upper-panel of Figure 2 depicts equation (25) as the ARB-curve. Its upward slope implies that a higher growth rate is to be met with greater scarceness of patents to prevent arbitrage opportunities. High growth implies high returns to firm-specific research (see equation (24)). To equalise returns, *A* has to increase, as can be seen from equation (23).

The lower panel of Figure 2 depicts equation (26) as the U-shaped SS curve. The skill premium is unambiguously negatively related to appropriability *A* if $\alpha < \rho$. However, we from now on focus on the case where $\alpha > \rho$. Then, the skill premium depends negatively on *A* at low levels of *A* and positively at high levels of *A*.

*** insert Figure 2 about here ***

We now show that an increase in the supply of skilled labour moves the equilibrium along the SS curve in Figure 2, and replicates the empirically observed time pattern of the skill premium in the 1970s-1980s. An increase in the supply of skilled labour shifts up the BG-curve to BG'. The intersection of the curves BG' and ARB determines the new equilibrium in which the degree of appropriability of the research-capital stock is higher. In the lower panel, the skill premium decreases. Shifting the BG'-curve up by further increasing the supply of skill, we see that the degree of appropriability increases further, but now the skill premium increases. Hence:

*An increase in the supply of skilled labour increases the degree of appropriability in the economy and causes the skill premium to fall (rise) when appropriability is low (high),*

$$\frac{\partial A}{\partial H^s} > 0 \quad and \quad \frac{\partial (w_H/w_L)}{\partial H^s} < (>)\ 0 \quad iff \quad A^{\nu+\mu} < (>)\ \frac{\rho}{\alpha-\rho}\frac{\beta}{1-\beta}\frac{\xi}{\chi}\frac{\nu}{\mu}.$$

*Starting from a small skilled labour force, appropriability is low and a sequence of increases in skilled labour produces a non-monotonic development in the skill premium.*

## 4. Discussion: confronting model and empirics

The model is consistent with some main stylized facts from the wage-inequality debate. In particular, the model replicates the following. The non-production employment share increased in both the 1970s as the 1980s whereas the non-production/production wage ratio fell in the 1970s and increased in the 1980s. This non-monotonic change in inequality coincided with a monotonic increase in the supply of educated workers.

The mechanism driving our model results is also supported by empirical findings. The model stresses appropriability conditions and connects the non-monotonic pattern of the skill premium to a monotonic rise in the ratio of firm-specific knowledge to patentable knowledge.

Cohen et al (2000) find that such a rise indeed occurred in the US. They document the increasing importance of secrecy and complementary firm-specific activities in protecting the returns to innovation, relative to the importance of patents.

The distinction between patents and firm-specific knowledge allows us to look beyond the labour market implications and check whether other implications of the model match stylized facts. In particular, we connect the model to the fall in productivity of R&D that is documented in terms of patent output per real dollar of R&D (cf. Table 1). The fall is found for both the 1970s and the 1980s, that is, a monotonic fall that contrasts with the U-shaped pattern for the skill premium in the same period.[13]

In our extended model, an increase in skilled labour supply not only generates the observed pattern for the skill premium, but also a shift in the composition of research activity towards firm-specific research. Typically, firm-specific research generates less visible research output: secrecy and tacitness of the knowledge generated in this way make that the propensity to patent is typically lower and innovation is underestimated in the innovation statistics. As a result, research *output* statistics tend to report a fall in output when research shifts to firm-specific research because these statistics concentrate on patents. On the research *input* side, however, it is difficult to separate out the inputs in firm-specific research from those aimed at developing patents. Hence, typically, measured patent output falls, but measured input is not corrected for the reduction in inputs directed at patent development.

In the model, what comes closest to the statistic that is used in the empirical literature on research productivity is the number of new patents divided by the total real cost of R&D, ignoring the distinction between inputs into firm-specific research and those into other research. Using (17) and (21), we may write this ratio as:

$$\frac{\dot{n}}{H^s w_H / p_n} = \frac{H_n}{H^s} = \frac{1}{1 + (\chi/\xi) A^{\nu+\mu}} . \tag{27}$$

If inputs were measured correctly, the productivity statistic would be $\dot{n}p_n/H_n w_H$, which would be constant and equal to unity due to our assumption of zero profits in the research sector, see (16) and (18). However, the ratio above has total inputs $H^s$ instead of $H_n$ in the denominator, and because of zero profits the ratio boils down to $H_n/H^s$, which is inversely related to the appropriability measure $A$ in the steady state. As shown above, when $H^s$ increases, $A$ increases monotonically. Hence measured patent productivity falls monotonically and thus the model is consistent with the observed fall in patent productivity from the 1970s to the late 1980s.

Not all stylized facts stressed by others in the context of the wage inequality of the 1970s and 1980s are fully captured by our model. While the skill premium was falling in the earlier period (1970s) residual wage inequality increased throughout the period. Our model does not account for this. However, Galor and Moav (2000) develop a mechanism where high-ability skilled workers benefit from an acceleration in technological progress so that inequality within groups rises. We could incorporate this key insight in our model by allowing ability to differ within groups and by allowing the return to ability to rise with technological progress for both production and non-production workers. Our model would then replicate the observed increase in within-group inequality in both the 1970s and 1980s.

The model presented above suggests an increase in technological progress throughout the period we consider. In our simple setup this implies an increase in productivity growth that is at odds with the much-debated productivity slowdown in the early 1970s. Our model lacks the costs of adjustment to major shifts in the structure of production that in other models reconciles an acceleration in technological progress with a productivity slowdown (e.g. Greenwood and Yorukoglu, 1997). In our model, the transition to a knowledge-intensive economy smoothly follows when firms employ more researchers. We could introduce adjustment costs that imply a drop in short-run output. A faster pace of technological change might cause erosion of the efficiency of unskilled workers (e.g. Galor and Moav, 2000) or might require retraining of workers and changes in the organisation of the firm. These adjustments take time so that the fruits of technological change can not be immediately absorbed.

Finally, our model stresses changes in relative wages. It does not shed light on the empirical finding that wages of unskilled labour have been falling for a long time. Modelling a fall in real wages of unskilled labour requires us to introduce skilled labour in final goods production. The increase in the supply of skilled labour could induce a shift of skilled workers from production to non-production work causing wages of unskilled workers to fall. This would give us an additional desirable result but would also substantially complicate the analysis.

## 5. Conclusion

This paper demonstrates that an increase in the relative supply of educated workers generates a structural change towards a knowledge-intensive production process that may ultimately lead to an increase in the return to educated labour despite the increase in their supply. The paper argues that skilled workers produce knowledge that affects the firm's productivity directly by reducing current production costs, as well as indirectly by reducing the cost of future R&D. Hence, an increase in the supply of skilled workers would raise the wages of skilled workers provided that (1) the degree of appropriability of investment in knowledge capital is sufficiently large, (2) the investment costs do not rise too quickly, and (3) diminishing returns related to knowledge accumulation do not set in too strongly.

In order to focus on the novel connection between appropriability and wage inequality, we have abstracted from several important aspects of the phenomenon. First, as explained above, we did not consider within-group inequality. Second, we did not examine endogenous responses of labour supply to changes in equality. The literature has already developed useful insights into these aspects (see Galor and Moav (2000) and Acemoglu (1998, section 4), respectively). These insights can be easily applied to our model. Finally, the distinction between major innovation and incremental technological change can be incorporated into the analysis. Such a distinction would allow us to  study more explicitly in our set-up the introduction and diffusion of the computer, which plays a important role in the wage inequality debate. Moreover, since appropriability is likely to be higher for incremental change than for major inventions, the extension could directly interact with the central mechanism in our approach.

**Notes**

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Nahuis: P.O. Box 80510, 2508 GM The Hague, The Netherlands, e-mail: r.nahuis@cpb.nl, at the time of writing this paper Nahuis was affiliated with Tilburg University and CentER.

Smulders: P.O. Box 90153, 5000 LE Tilburg, The Netherlands, e-mail: j.a.smulders@kub.nl.

1. The steady rise in the relative employment of non- production employment as well as in R&D intensity, documented in Table 1, is consistent with this viewpoint (see, for example, Berman et al. (1994), Machin and Van Reenen (1998), and Adams (1999)).

2. Also focussing on the erosion of human capital, Gould, Moav and Weinberg (2001) explain how acceleration of technological progress increases the relative risk of not becoming educated and hence within-group and between-groups inequality.

3. A similar induced-innovation mechanism is found in Kiley's (1999) deterministic version of Acemoglu's analysis.

4. We allow for decreasing returns to unskilled labour ($0 < \delta < 1$). The underlying assumption is that the firm also employs a fixed factor whose size is normalized to one.

5. This captures Jones' (1995) "stepping on toes effect", indicating congestion and

duplication in research.

6. For a discussion on the firm-specific nature of knowledge, see Smulders and Van de Klundert (1995) and Peretto (1999). For an explicit treatment of the tacitness of knowledge, see Dosi (1988).

7. Jovanovic (1997) argues that adjustment and implementation costs of ideas dominate the non-rivalness of knowledge.

8. If more *un*skilled labour is employed ($L$ increases), the return to investment is higher, and hence the skill premium. This is due to the fact that more production workers benefit from the same increase in productivity due to the non-rivalness of knowledge.

9. Diminishing returns with respect to knowledge in production ($\beta$) mitigate this effect, as growth in the knowledge stock translates to lower growth in consumption if $\beta$ is small.

10. Results are available upon request.

11. See Keely and Quah (1998), page 3, second italics added.

12. The Hamiltonian for the producer's maximization problem now reads $p(F(f,n,L))\cdot F(f,n,L) - w_L L - w_H H + qG(H,f,\bar{f},\bar{n}) + (q_n - p_n)I_n$, where the final term captures patents: $q_n$ is the costate variable associated to the patent stock and $I_n = \dot{n}$ is the amount of

patents purchased. Equation (19) follows from the optimality conditions with respect to $I_n$ and $n$.

13. Though not apparent from Table 1, in the late 1980s the number of patents per R&D dollar increased again. It is, however, still unclear how important the numerous institutional changes with respect to the patent system are in explaining this (see Jaffe, 1999). According to Kortum and Lerner (1998), this upsurge in patenting (even per R&D dollar) is associated with an increase in research productivity. The increase could be mimicked in the model by increasing the exogenous research productivity in the patent sector.

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**Table 1** Non-production wage-bill and employment share, relative wage and R&D intensity and productivity in the US, 1973-1989.[a]

| | 1973 | 1977 | 1981 | 1989 |
|---|---|---|---|---|
| Non-production wage-bill share | 0.337 | 0.351 | 0.397 | 0.414 |
| Non-production employment share | 0.246 | 0.261 | 0.285 | 0.303 |
| Non-production/production wage differential | 1.55 | 1.53 | 1.53 | 1.62 |
| Relative supply of higher education[bc] | 0.35 | 0.41 | 0.46 | 0.60 |
| R&D intensity manufacturing | 0.063 | 0.062 | 0.077 | 0.100 |
| Patents per million $ R&D[d] | 1.7 | 1.5 | 1.1 | 1.0 |

[a] Source: Machin and Van Reenen (1998).

[b] Source: Acemoglu (2000)

[c] weeks worked by college equivalents divided by weeks worked of noncollege equivalents.

[d] Source: Kortum (1993).

**Figure legends**

Figure 1  Firm-specific knowledge and the skill premium

Figure 2 General equilibrium with endogenous appropriability

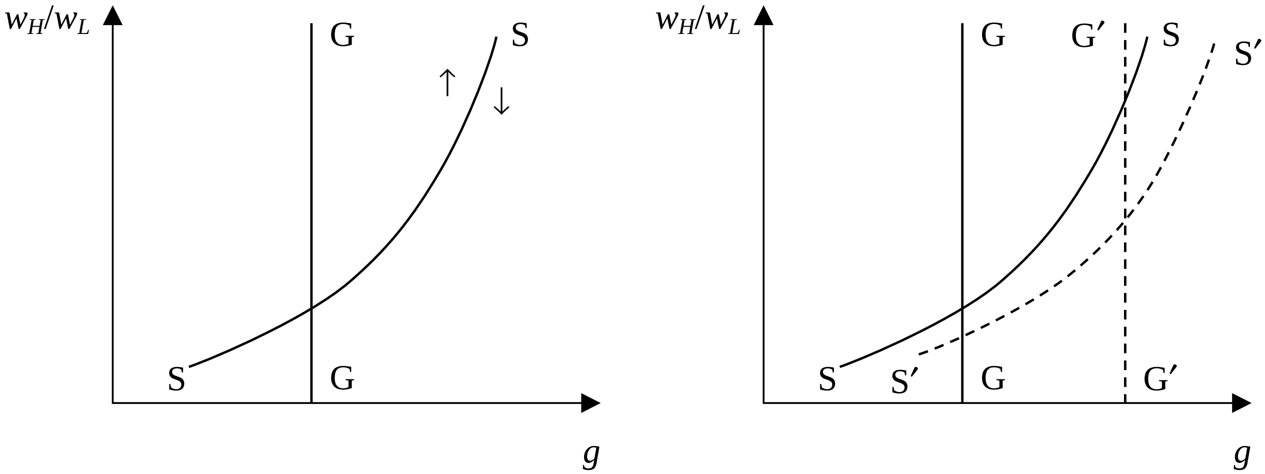



Figure 1  Firm-specific knowledge and the skill premium

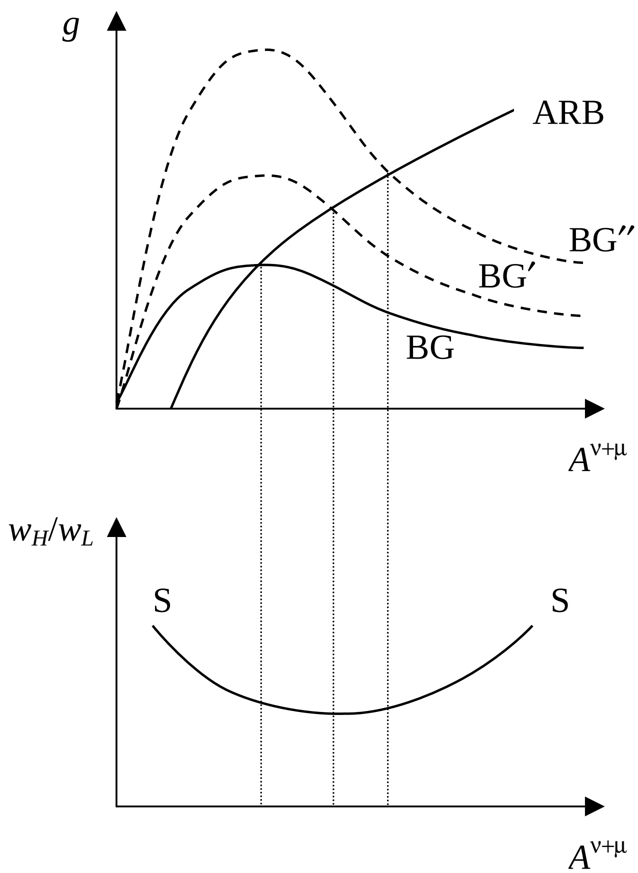



Figure 2 General equilibrium with endogenous appropriability

**The Skill Premium, Technological Change and Appropriability**

**Richard Nahuis and Sjak Smulders**

**Journal of Economic Growth, 7, 137-156, 2002.**

## Appendices

### A. Appropriability: derivation of equation (19).

To account for spillovers to patent firms, we modify the expression for appropriability in production firms, equation (6), into:

$$a_{fi} \equiv \frac{q_{Ki}\left(\frac{\partial K_i}{\partial f_i}\right) df_i}{q_{Ki}\left(\frac{\partial K_i}{\partial f_i}\right)^{/} df_i + \int_0^1 q_{Kj}\left(\frac{\partial K_j}{\partial S_j}\frac{\partial S_j}{\partial f_i} df_i\right) dj + q_{Kn}\left(\frac{\partial K_n}{\partial f_i}\right) df_i} \tag{A.1}$$

where $K_n \equiv \chi \bar{n}^{1-\mu} \bar{f}^{\mu}$ is the knowledge base in patent research and $q_{Kn} = p_n \partial \dot{n} / \partial K_n$ is the value of a marginal increase in this knowledge base. The third term in the denominator of (A.1) captures the spillovers from firm *i*'s research to patent-producing firms. Eliminating the shadow prices using (8) and (17), evaluating the partial derivatives, imposing symmetry and assuming $\lambda = \phi = 1$, we find:

$$a_{fi} \equiv \frac{H_i \alpha}{H_i(1 - \nu) + H_n \mu} \tag{A.2}$$

which is increasing in $\alpha$. Note that this is appropriability of individual production firms. To measure economy-wide appropriability we need to account for the spillovers generated by specialised patent-producing firms (of which they cannot appropriate any of the intertemporal returns). Since the spillovers of patent-producing firms enter the production function of patents with $(1-\mu)$ and the firm-specific knowledge production function with $\nu$, economy-wide appropriability can be written as

$$a = \frac{\int_0^1 H_i \alpha \, di}{\int_0^1 H_i(1-\nu)\, di + H_n \mu + \int_0^1 H_i \nu \, di + H_n(1-\mu)} \tag{A.3}$$

where the numerator represents total appropriated returns (by production firms) and the denominator represents total intertemporal spillovers. The last two terms in the denominator denote the spillovers of patent firms to firm-specific knowledge producers and patent producers respectively. Integration gives economy-wide appropriability, equation (19) in the main text.

**B. Equation (11)**

This appendix derives equation (11). Use (5) to rewrite (8) as:

$$w_H = q \lambda \xi \, (f^{\alpha} S^{1-\alpha})^{\phi} \, H^{\lambda - 1} \tag{B.1}$$

Similarly, use (4) to write (7) as

$$w_L = p \left( 1 - \frac{1}{\varepsilon} \right) \delta f^{\beta} L^{\delta - 1} \ . \tag{B.2}$$

Devide both sides of equation (9) by *q* and use (4) and (5) to get

$$r = \frac{p}{q} \left( 1 - \frac{1}{\varepsilon} \right) \beta f^{\beta-1} L^{\delta} + \alpha \phi f^{\alpha\phi - 1} S^{(1-\alpha)\phi} H^{\lambda} + \hat{q} \tag{B.3}$$

Note from (4), (B.2) and (1) that $\hat{w}_L - \hat{p} + l = \beta \hat{f} + \delta l = \hat{x} = \hat{c}$ and use the Keynes-Ramsey rule (3) to substitute for *r* an expression in $\hat{w}_L, \hat{f}$ and $\vartheta_l$. Use (B.1) to substitute out *q* and (B.2) to substitute out the price. Log differentiation of (B.1) gives an expression for $\hat{q}$ in terms of $\hat{f}, \hat{S}$ and $\hat{w}_H$. Substituting this and rearranging gives equation (11) in the main text.

**C. Non-scale growth**

Here we assume $\phi < 1$, $l > 0$. The main difference with the main text is that here long-run growth becomes independent of the size of the skilled labour force (Jones, 1995). Hence, there is no scale-effect on the growth rate from an increase in the supply of skills.

The growth rate depends on the growth of the supply of skilled labour and on the stock of firms-specific knowledge accumulated in the past, see equation (12). Accordingly, the growth rate is a predetermined variable that changes over time. Differentiating (12) with respect to time yields the equation of motion for the growth rate:

$$\hat{g} = \lambda l - (1 - \phi) g \ . \tag{C.1}$$

Hence the GG locus for constant growth rate reads

$$g = \lambda l \,/\, (1-\phi) \,. \tag{C.2}$$

The SS-locus is the same as in the case of endogenous growth (except for the fact that $\vartheta_l$ takes a different value because of population growth) and follows directly from (11). The Figure below depicts the phase diagram that results from equations (11) and (C.1). Transitional dynamics occur along the upward-sloping saddle path.

To analyse the consequences of an increase in the supply of skilled labour, we now need to distinguish between long-run and short-run effects. For simplicity, we consider a permanent positive shock to $H$ at $t$ = 0, but assume $H$ to grow at rate $l$ at all other dates. The long-run growth rate is not affected by the supply shock (GG-locus remains unchanged), while the SS-curve shifts down. Hence in the long run, the skill premium unambiguously declines in response to an increased supply of skilled labour. In the short run, the growth rate increases by the expansion of non-production jobs. The combination of the shift of the SS locus and the short-run increase of the growth rate produces a (short-run) result that is very similar to that in the endogenous growth case analysed in the main text. Indeed, the skill premium may increase in the short run.

To derive an exact condition for the upward-sloping demand curve to arise, we linearize equations (11) and (C.1) around the steady state and calculate the short-run response of the skill premium to a change in the supply of skilled labour. The linearized system reads:

$$\begin{bmatrix} \dot{\widetilde{w_H/w_L}} \\ \dot{\tilde{g}} \end{bmatrix} = \begin{bmatrix} d+\vartheta_l & -\vartheta_l \\ 0 & -\lambda l \end{bmatrix} \begin{bmatrix} \widetilde{w_H/w_L} \\ \tilde{g} \end{bmatrix} + \begin{bmatrix} d+\vartheta_l \\ 0 \end{bmatrix} \tilde{H} \,, \tag{C.3}$$

where tildes refer to percentage deviations from the initial steady state (log-linearized variables) and $d \equiv g\,[\beta(\rho-1) + (1-\alpha)\phi]$. From (12) we find the initial change (a time t = 0) in the growth rate (which is predetermined):

$$\tilde{g}(0) = \lambda \tilde{H} \,, \tag{C.4}$$

where $\tilde{H}$ is the permanent shock to the skill endowment.

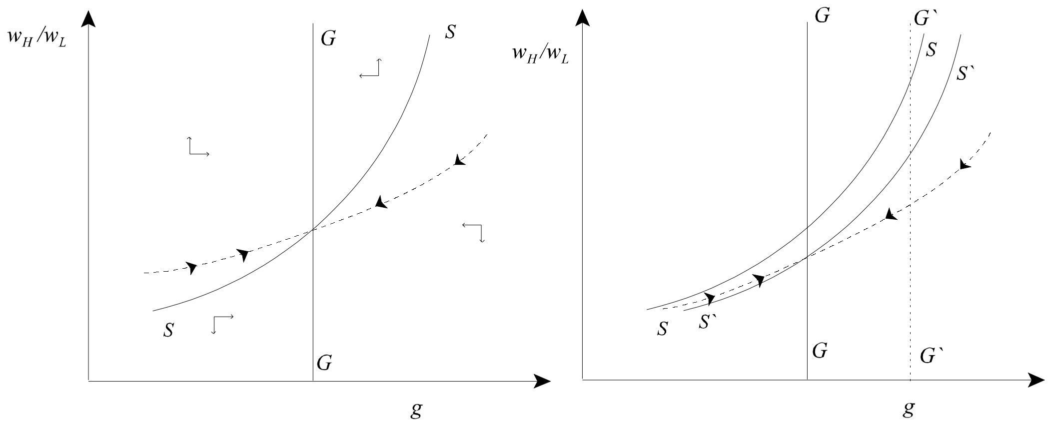
The stable root of this system is $\lambda l = (1-\phi)g$. Hence, we can calculate the jump in the skill premium as:

$$\widetilde{w_H/w_L}(0) = -\left(\frac{\lambda l + d + (1-\lambda)\vartheta_l}{\lambda l + d + \vartheta_l}\right)\tilde{H} . \tag{C.5}$$

The skill premium increases in the short run if the expression in parenthesis is negative. Taking into account the definition of $d$ given above, we find the following condition:

$$\alpha\phi > \beta\rho + (1-\beta) + (1-\lambda)\vartheta_l/g . \tag{C.6}$$

Note that this is nearly the same condition as for the endogenous growth case, see (14), although now of course $\phi$ is mitigating the effect of $\alpha$ (and $\vartheta$ takes a different value because of population growth). Hence, the very same mechanisms as already explained in the main text apply. The intuition behind this similarity is also provided in the main text.




The skill premium with firm-specific and semi-endogenous growth