

Inequality and growth: the dual role of human capital in development

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Abstract

To examine how human capital accumulation influences both economic growth and income inequality, we carefully endogenize the demand and supply of skills. We explicitly introduce the costs and externalities in education, and examine how both relate to learning-by-doing and R&D intensity. In addition, we endogenize the determinants of the skill-bias of labor demand: the complementarity between technology and skilled and unskilled labor. Our results identify parameters that are central to the evolution of inequality during the development process. We characterise development thresholds when countries switch endogenously from pure learning to deliberate R&D, and we show that technical change can generate multiple steady states that are consistent with the cross-country data on inequality and skill-premia. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

The relationship between equality and growth is of fundamental interest not only to economists, but also to policymakers. Despite the fact that the empirical

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literature on the subject dates back to Kuznets (1955), no definitive stylized facts have emerged that indicate how inequality and growth interact during the development process.¹ This lack of a clear relation between inequality and growth may be partly due to the dual role of human capital in development. In his analysis of the relationship between human capital and inequality, Tinbergen (1975) suggested that inequality is ultimately determined by the opposing effects that technology and education exert, respectively, on the demand for and supply of skilled labor, and hence on the relative wage. He stipulated that the relationship between growth and inequality is determined by the “race between technological development and education” (1975, p. 97). Tinbergen’s statement has not been formalized and the task of this paper is to model both effects explicitly to shed light on the remarkably diverse empirical relationship between human capital and inequality.

In this paper, we explicitly model endogenous human capital and technology to highlight that the relationship between growth and inequality is indeed complex due to offsetting supply and demand effects. In our model, the direct effect of greater supplies of human capital is to lower the relative wage, and hence, inequality. However, we also highlight that human capital accumulation indirectly generates more innovations, which in turn increase the demand for skilled workers to absorb new technologies into production. As a result, our model predicts a non-monotonic relationship between educational attainment and inequality, which may help to explain why cross-country analyses of income inequality tend to find that school enrollment rates have little explanatory power.²

In modeling human capital accumulation and technical change, we focus on three essential features. First, we explicitly introduce costs and externalities associated with skilled labor supply, and examine how both relate to learning-by-doing and R&D intensity.³ Second, we endogenize the determinants of the degree of skill-bias in labor demand. Specifically, we endogenize the complementarity between technology, and skilled and unskilled labor. Third, we differentiate between deliberate R&D and serendipitous learning-by-doing. R&D is potentially the more productive means of innovation, but it is also more costly and it requires an adequate number of researchers to yield sufficient returns and justify R&D investment. As a result, the model determines endogenously which countries rely

¹ Cross-country evidence on the effect of growth on inequality and on that of inequality on growth is inconclusive (see, for example, Anand and Kanbur, 1993a; Deininger and Squire, 1998; Forbes, 2000), while historical and recent time series shows a diversity of experiences (Williamson, 1991, 1999; Gottschalk and Smeeding, 1997). For a review see, Aghion et al., (1999).

² See Bourguignon and Morrisson (1998, Table 3) and Breen and García-Peñalosa (2000).

³ Rather than focusing on parental effects in education (as Galor and Tsiddon, 1996, for example), we are concerned with group externalities in education, following the growing literature on external effects within schools and the role of “social capital” in human capital accumulation. See Tamura (1991, 1996), Galor and Moav (2000b) and Benabou (1996a,b, 2000) for models with externalities at the school level, and Borjas (1995) for related evidence.

only on learning or also on R&D in order to provide a possible rationale for the threshold effects that abound in the development literature.

The results derived in the paper attract attention to parameters that are central to the supply and demand of human capital, but which have been absent from previous empirical analyses of the inequality and growth relationship. Our results mirror Tinbergen's (1975) hypothesis that the pattern of relative wages along the development path depends on the strength of the demand for skills exerted by technology relative to the supply of skills generated by education. Our model emphasizes that whether a country experiences rising or falling inequality as the growth rate increases depends crucially on (a) the externality (social returns) in education, (b) the evolution of the direct cost of education, (c) the elasticity of substitution in production between skilled and unskilled, and (d) the relative productivities and costs of learning-by-doing versus R&D. Neither of these variables has thus far been included in the regressions that attempt to untangle the relationship between inequality and growth across or within countries. For example, since it is likely that the use of advanced technologies lowers the elasticity of substitution of skilled and unskilled in production, the product mix of a country should also enter as an important determinant into growth and inequality regressions.

Our second result is the endogenous emergence of poverty traps. Poverty traps are usually explained by the presence of positive externalities, such as threshold effects in education (e.g., Azariadis and Drazen, 1990), endogenous fertility decisions (e.g., Becker et al., 1990), coordination failures (e.g., Acemoglu, 1996), or external effects associated with human capital investment (e.g., Tamura, 1996).⁴ Our model provides another possible mechanism: the interdependence of the supply and demand for skilled labor when technical change is skill-biased. In contrast to previous work, where agents are assumed to be identical, our framework shows that being in a poverty trap has implications about both aggregate income and the distribution of income. In our model, development thresholds are endogenously generated, since the move from learning to R&D occurs only when the income generated from R&D justifies the factor payments to the sector. With few skilled workers, research output is small, costs of implementing new technology are high, and the benefits to the final good production are reduced. In terms of skill complementarity, the benefits generated by a small R&D sector are even further eroded as unskilled labor can easily adapt to the slow rates of technical change.

The previous literature on inequality and growth falls into several different classes. The early literature stipulates imperfect mobility between distinct sectors (from agriculture to industry), which affects the distribution of labor incomes.⁵ In the last decade, the impact of initial inequality on growth rates has been examined

⁴ See Azariadis (1996) for a survey on the literature on poverty traps.

⁵ See Kuznets (1955) and Harris and Todaro (1970).

by papers that emphasize the constraints to investment (in human or physical capital) imposed by capital market imperfections, or the impact of inequality on socio-political (in)stability and redistribution.⁶ More recently, and motivated by the experience of the US and a number of other OECD countries, interest has shifted towards the effect of growth on distribution. In particular, the rate (or direction) of technical change is seen as a major determinant of the relative wage between educated and non-educated workers.⁷

However, the joint determination the rate of technological change and the stock of educated workers has received little attention. One exception is Galor and Tsiddon (1996), who argue that in the presence of externalities in the accumulation of human capital, both at the aggregate and the family level, the initial distribution of income determines both aggregate income and the distribution of human capital—and therefore of earnings. Closest to our work are Galor and Moav (2000a) and Gould et al. (2000), who also maintain that it is not the ex ante distribution of income, but rather the technology-driven demand for labor that is central to explaining inequality and growth. As in our model, they assume that technological change erodes the aggregate stock of human capital due to its effect on the productivity of uneducated workers. As the number of educated workers increases, the rate of technical change accelerates due to externalities associated with human capital. Since skilled and unskilled labor are perfect substitutes, this process implies that the rate of technological progress, the number of educated workers, and the skill premium grow together during the convergence to the (unique) steady state. Although this may be a suitable description of recent trends in certain industrial countries, in a broader sample, the relationship between educational attainments and wage inequality is ambiguous, as countries with significantly different levels of human capital exhibit similar returns to education.⁸ Our paper explores precisely the reasons why a non-monotonic relationship between the supply of skilled workers and the skill premium may be observed.⁹

The structure of the paper is as follows. Section 2 presents the model, specifying the relative demand for labor, the supply of skills, and technological change. Section 3 describes the general equilibrium and stationary states, and Section 4 shows the possible patterns of inequality and growth and how they depend on parameter values. We then discuss our results in the light of empirical evidence, and examine possible policy options. Section 5 concludes.

⁶ See Galor and Zeira (1993), Banerjee and Newman (1993), Aghion and Bolton (1997), and Chiu (1998), on models with credit market imperfections, and Perotti (1993), Alesina and Rodrik (1994), and Persson and Tabellini (1994) for a political economy analysis.

⁷ See Eicher (1996), Greenwood and Yorukoglu (1997), Acemoglu (1998), and Caselli (1999).

⁸ See Acemoglu (1999) and Chiu (1998).

⁹ Acemoglu (1998) argues that an increase in the supply of educated workers can have a non-monotonic effect on the skill premium, as it induces firms to produce technologies that complement educated labor and hence changes in the *direction* of technical change.

2. Production structure

2.1. Final and intermediate goods

A competitive final goods sector produces one homogeneous output using human capital and a variety of intermediate inputs. The basic production structure of the final good is based on Romer (1990), with output being produced according to

$$Y_t = \sum_{i=1}^{D_t} n(i)_t^{1-\delta} H_t^\delta, \quad (1)$$

where D represents the number of different intermediate goods used in production, $n(i)$ is the quantity of the i th intermediate good employed, and H is the skill-adjusted stock of labor in the economy. Technological change takes the form of an expansion of the number of different intermediate goods available.

The intermediate goods sector is competitive, and each intermediate good requires one unit of capital, k , to transform a new technology into a new intermediate good. Profit maximization in the intermediate goods sector implies the usual symmetric use of inputs $n(i)_t = n_t$, which allows us to rewrite Eq. (1) as¹⁰

$$Y_t = D_t n_t^{1-\delta} H_t^\delta. \quad (2)$$

Our aim is to provide additional structure to the absorption process that differentiates skilled and unskilled labor. The two types of labor differ not only in terms of productivities, but also in their technological capabilities. Previous growth models stipulate exogenous productivity differentials between skilled and unskilled workers; we endogenize these differentials. We posit that technology is not equally complementary with skilled and unskilled labor, but that skilled workers possess a greater capacity to absorb new technologies and to better handle increased technological change. Exactly how complementary technology is with the respective types of labor will be a function of the rate of technological change itself. That is, the greater the speed of technological change, the relatively more productive skilled labor becomes, compared to unskilled labor. To generate such endogenous relative productivities, we assume that the skill-adjusted stock of labor can be disaggregated according to the following CES function:

$$H_t = \left(\frac{D_{t-1}}{D_t} U_t^{-\alpha} + (S_t^P)^{-\alpha} \right)^{-1/\alpha}, \quad (3)$$

where S_t^P denotes skilled labor employed in production and U_t unskilled labor. We restrict the degree of substitutability between the two types of labor and assume

¹⁰ See the Appendix A for the complete intermediate firm problem.

$0 > \alpha > -1$. The resulting elasticity of substitution, $\phi = 1/(1 + \alpha)$, falls in the interval $(1, \infty)$, implying that skilled and unskilled labor in production are imperfect substitutes.

Eq. (3) also implies that the relative shares of skilled and unskilled in the total effective labor force (or in the total product) are a function of the rate of technological change. This assumption is akin to the Nelson and Phelps (1966) argument that greater skills allow for faster adoption of technology. It also receives strong support from empirical studies, such as Bartel and Lichtenberg (1987), who show that the relative demand for skilled workers declines with the age of the plant and equipment, and that technology enters labor demand non-neutrally. The production structure thus incorporates the notion that not only the absolute, but also the *relative* productivities of skilled to unskilled labor change with the level of development, or with the rate of progress observed in an economy.

From Eqs. (1) and (3), the labor demand can be derived as a function of the rate of technological change and the relative wage of skilled to unskilled labor, ω_t :

$$\omega_t \equiv \frac{w_t^S}{w_t^U} = \left(\frac{U_t}{S_t^P} \right)^{1+\alpha} \frac{D_t}{D_{t-1}}. \quad (4)$$

Eq. (4) shows that, on the production side, the relative wage is determined by two standard factors: relative factor supplies and relative productivity. The latter is, however, determined by technological change. An increase in the relative supply of skilled workers lowers the relative wage, while an increase in the rate of technological change raises it. Depending on the strength of each factor, the effects of an increase in technological change may well outweigh the effects of concurrent increases in the skilled labor force.

2.2. Factor supplies

This section outlines the incentives to invest in education, given the relative returns to skilled and unskilled labor. Agents live for two periods, work only when young and, for simplicity, consume only when old. Let S_t denote the total number of skilled workers in the economy, and U_t the number of unskilled workers. We normalize the size of the population to unity, which implies the labor constraint

$$U_t + S_t = 1. \quad (5)$$

Skilled workers can be employed either in production, S_t^P , or in research, S_t^R .

When new technologies are introduced, agents must learn to work with these technologies to become skilled labor. Hence, at the start of their working lives, agents have to decide whether to invest in education or to remain unskilled. Agents possess perfect foresight and skills, which are acquired only through

formal education. We assume that agents differ in their abilities to learn, a , and that these abilities are distributed uniformly, $a \in [0,1]$.¹¹

The cost of education takes the following form, $c_t w_t^U/a$. That is, two components determine the cost of education. First, there is a direct cost $c_t w_t^U$, which is proportional to the unskilled wage and therefore increases as the economy grows.¹² For simplicity, education is instantaneous. In addition, more able individuals can learn faster/better and therefore incur a lower cost, captured by a in the denominator.

We postulate that the direct cost of education is a function of the number of agents being educated, so that $c_t = c[S_t]$. More specifically, we assume that it decreases in the number of agents seeking schooling, $c'[\cdot] < 0$. This assumption may account for fixed costs in the education process, such as physical structures or the cost of taking teachers to rural areas. Alternatively, one could motivate the declining marginal cost of education as the result of externalities in the education process.¹³ It has become standard to assume in growth models that a greater aggregate stock of human capital increases the skills acquired from a given educational investment. We reverse this relationship and argue that a greater stock of human capital makes it less costly to attain a given level of skills. For simplicity, we assume a specific functional form for the education cost, $c[S_t] = \rho S_t^{-\sigma}$, which incorporates a direct cost, ρ , and a measure of the externality, σ .¹⁴

To allow for differential taxation of skilled and unskilled, we impose an income tax of τ only on skilled wages. The income of a skilled worker born at time t can be written as her net wage income minus the education cost¹⁵

$$Y_t^S = (1 - \tau) w_t^S - \frac{\rho S_t^{-\sigma} w_t^U}{a}. \quad (6)$$

Agents choose to invest in skills if the income in Eq. (6) exceeds that of remaining unskilled, $Y_t^U = w_t^U$. Equality between these two expressions gives the level of ability of the agent that is indifferent between investing in education and working as unskilled: $a_t^* = \rho S_t^{-\sigma} (\omega_t(1 - \tau) - 1)^{-1}$. The uniform ability distribution, i.e.

¹¹ If skills were to influence ability (as, for example, in Tamura, 1991), the labor supply function derived below would not be impacted qualitatively. This assumption would generate results that are equivalent to our discussion of stronger education externalities (see below).

¹² Any measure of the direct cost of education would do, as long as the cost grows proportional to income in equilibrium. If we replaced, for example, w_t^U , with w_t^S , Eq. (6) below would simply change to $\omega_t(1 - \tau - \rho S_t^{-\sigma}/1 - S_t)^{-1}$.

¹³ See Coleman (1990) for a discussion of social capital and its impact on educational attainment, Borjas (1995) for evidence of externalities at the school level, and Psacharopoulos and Woodhall (1985) for evidence that initial years of schooling are usually the most cost effective and productive in terms of educational expenditures.

¹⁴ As we will show in Appendix B.1, $1 + \alpha \geq \sigma$ is required for stability.

¹⁵ See Appendix A for a description of the capital market equilibrium.

$S_t = 1 - a_t^*$, together with the labor constraint Eq. (5), allow us to express the relative wage as a function of the number of skilled workers,

$$\omega_t = \left(1 + \frac{\rho S_t^{-\sigma}}{1 - S_t} \right) (1 - \tau)^{-1}. \quad (7)$$

The above inverse labor supply equation gives the relative wage needed to induce S workers to invest in skills. The relative wage first declines and then rises in the stock of skilled labor. The initial decline reflects the decrease in the cost of education as more agents opt for education. Subsequently, the rising opportunity and effort costs dominate to force an increase in the relative wage to elicit a greater supply of skilled labor. The relative wage equation thus highlights the effects of increasing returns to education at different stages of development. For low levels of development, the abundance of unskilled labor keeps the opportunity cost low, which combines with high returns to education and large spillovers to provide strong incentives to invest in education. As the stock of skilled workers rise, so do the opportunity and effort costs, which eventually outweigh the effects of the education externality.

Expressed in the wage–labor space, (S, ω) the labor supply function, Eq. (7), shifts upwards as the direct cost of education increases, ρ and its minimum occurs at $\tilde{S}_t = \sigma/(1 + \sigma)$. Hence, an increase in the externality moves the minimum to the right, implying that stronger externalities in education prolong the decline in relative wages. The differential tax rate that is levied on skilled workers shifts the curve up, as it increases the relative wage to induce an equal amount of skilled to seek education. These findings pertaining to the externality, the tax, and the direct cost of education are summarized in Proposition 1.

Proposition 1 (Labor Supply). *Externalities in education, σ , generate a U-shaped relationship between the relative wage and the supply of skilled labor. The greater the externality, the more prolonged the initial decline of the relative wage. Increases in the direct cost of education, ρ or in the differential tax on skilled labor, τ , require higher relative wages for each level of skilled labor supply.*

2.3. Technological change

Ever-new technological blueprints are employed in the intermediate goods sector, together with a unit of capital, to produce a new type of intermediate good that is then used by the final good sector. There are two possible ways of generating new technologies. First, via learning-by-doing (henceforth, LBD); second, through deliberate and costly investment in research and development (R&D).

Learning-by-doing takes place as skilled workers serendipitously discover new types of intermediate goods during the production process, according to

$$\left. \frac{D_t}{D_{t-1}} \right|_{\text{LBD}} = 1 + \gamma S_{t-1}, \quad \gamma > 0. \quad (8)$$

The exclusive reliance on LBD is thought to be limited to the early stages of development when skilled labor is perhaps too scarce to allow for a dedicated research and development activity. Lamoreaux, et al. (1999) present several historical summaries that testify to the importance of both learning and deliberate R&D across firms and countries. We incorporate the important distinguishing features of learning and deliberate R&D by determining when a country switches endogenously from learning to deliberate R&D. We posit that the endogenous threshold depends on whether a sufficiently large number of (potential) researchers has been attained.

We follow Shell (1967) and Grossman and Helpman (1991, Section 2.4) and assume that research is financed by a public entity that raises revenues through tax collections, τ . Any (more complex) means of R&D financing is feasible as long as it retains the proportionality between the total stock of skilled labor and the shares of labor allocated in production and research. Otherwise, balanced growth would not be possible.¹⁶ There is strong evidence for the importance of publicly funded R&D, especially in developing countries (Rustichini and Schmitz, 1991, provide numerous examples).¹⁷ When S_t^R researchers are employed, the economy produces technological blueprints according to

$$\left. \frac{D_t}{D_{t-1}} \right|_{\text{R\&D}} = (1 + \gamma S_{t-1}) \beta S_{t-1}^R, \quad \beta > 1. \quad (9)$$

In Eq. (9), we posit that technical change is an amalgam of LBD and research effort.¹⁸ Hence, learning does not cease when R&D is undertaken, but it continues to contribute to the technology output. We know from Jones (1995) that the

¹⁶ Privately financed R&D could also be introduced. With private R&D, the joint determination of R&D activity (profit streams) and the incentives to invest in education generate far more complicated skilled labor demand functions than the ones derived below. Qualitatively, the results would, however, be similar.

¹⁷ There is clear evidence that the share R&D, which is publicly funded is extremely high in developing countries. For example, in 1990, it was 95% in Mexico, 87% in India, 51% in Italy, and 45% in the US (UNESCO, 1999, Table 3.3). From a historical point of view, the first research institutions were probably the academies established by Frederick of Prussia and Catherine of Russia in the 18th century. Major research labs like the MIT (1969), Johns Hopkins (1876) the Reichsanstalt (1895) and the British National Physics Lab (1902) were also initially publicly funded.

¹⁸ The results of the model do not depend on the assumption of exogenous taxation. Instead of taxation determining the share of skilled workers in research, one could assume this fraction to be constant. As shown in the previous footnote, public finance is an important determinant of R&D, especially in developing nations.

specification of the accumulation functions that generate the endogenous factor are crucial to the results of the model. Hence, we augment the common reduced form R&D sector to combine learning and directed research. We will discuss below how the results depend on our technology specification.

More importantly, however, is the assumption that a sufficiently large number of skilled researchers, S_t^R , is required to generate a rate of technological change that exceeds pure LBD. Consistent with the motivation for Eq. (8), Eq. (9) reflects that R&D is not necessarily sensible for all types of economies. For low levels of skilled labor, R&D will not be profitable—not just in terms of final output but also in terms of the generated rate of technical change. Only after a country is sufficiently developed in terms of its supply and demand for skilled labor will deliberate R&D be done. As R&D becomes economically feasible, the dedicated research effort generates a crucial advantage over pure LBD: it leads to greater advances in knowledge.

Having specified the mechanics of technical change, we can write the labor constraint for skilled workers when R&D is undertaken as $S_t^P + S_t^R = S_t$. If no R&D is done, all skilled labor work in production.

We assume that the government undertakes all R&D, and that the blueprints are put in the public domain and can be used at no cost. Research is financed by tax revenues, and the fiscal budget is always balanced. The budget constraint is then $\tau w_t^S S_t = w_t^S S_t^R$. Any excess revenues at the end of the period are classified as fiscal waste.

Given the budget constraint and the skilled labor market constraint, we find that the number of skilled workers that contribute to R&D and to production is given by

$$S_t^R = \tau S_t \quad (10)$$

$$S_t^P = (1 - \tau) S_t. \quad (11)$$

We can now utilize the equations for technological change under LBD and R&D, Eqs. (8) and (9), and substitute for the division of skilled labor, Eqs. (10) and (11), into Eq. (4) to derive the inverse relative labor demands under the two regimes. That is,

$$\omega_t|_{\text{LBD}} = (1 + \gamma S_{t-1}) \left(\frac{1 - S_t}{S_t} \right)^{1+\alpha}, \quad (12)$$

$$\omega_t|_{\text{R\&D}} = \beta \tau \frac{(1 + \gamma S_{t-1}) S_{t-1}}{(1 - \tau)^{1+\alpha}} \left(\frac{1 - S_t}{S_t} \right)^{1+\alpha}, \quad (13)$$

Eqs. (12) and (13) imply that the demand for skilled labor is a lagged function of its supply, as the relative wage is decreasing in the current stock of skilled labor but increasing in the last period's stock. The reason for this is that a greater proportion of skilled labor in period $t - 1$ results in faster technological change,

which means that the productivity of skilled labor is growing more rapidly than that of unskilled labor. This raises the demand for skills at t , and therefore the wage ratio for any given supply.

3. General equilibrium and stationary states

General equilibrium in the goods and factor markets is attained by equating the labor supply, given in Eq. (7), to the labor demand, Eqs. (12) and (13), which renders two differential equations in S_t and S_{t-1} . The exact expressions for these equations are given in Appendix B.¹⁹ In what follows, we impose the restriction that $1 + \alpha > \sigma$, that is, the education externality is not too strong given the elasticity of substitution between the two types of labor. This ensures that S_t is increasing in the previous period's stock of skills.

The equilibrium is best expressed in (S, ω) space, which relates relative wages and income inequality to the level of development and economic growth. Consider the steady state behavior of the model. In steady state, $S_{t-1} = S_t = S$, and equilibrium is given by the intersection of the labor supply function with the steady state labor demand. This yields S^* as a function of the parameters of the model, as shown in Appendices A and B. Once the equilibrium stock of skilled labor is obtained, it uniquely determines the degree of wage inequality and the rate of growth of the economy. Relative wages are given by the supply of labor function. To obtain the rate of output growth, note that in steady state, all inputs except the number of intermediate goods available are constant. The steady state growth rate is then given by

$$\frac{Y_t - Y_{t-1}}{Y_t} = \frac{D_t - D_{t-1}}{D_t} = \begin{cases} \gamma S^* & \text{LBD} \\ (1 + \gamma S^*) \beta \tau S^* - 1 & \text{R\&D} \end{cases}$$

and hence uniquely determined by the level of human capital in the economy.

Imposing the steady state condition, $S_{t-1} = S_t = S$, allows us to depict the relative labor demand functions in the (ω, S) space. Labor demand is downward sloping if LBD is the source of technical change.²⁰ However, when deliberate R&D effort is used in the economy, the labor demand becomes log concave and intersects the horizontal axis at $S = 0$ and $S = 1$. The demand for labor under R&D is initially upward sloping since more researchers raise the marginal product of skilled labor in output *and* allow for more R&D, which again improves the productivity of skilled labor in production. Demand cannot be upward sloping throughout, since unskilled labor eventually becomes sufficiently scarce to exert downward pressure on the relative wage.

¹⁹ Stability and existence are also proven in Appendix B.

²⁰ From Eq. (12), $\partial \omega / \partial S < 0$ for $S = 0$, and $\partial \omega / \partial S < 0$ for all $S \in [0, 1]$ if $\gamma < 4(1 + \alpha) / \alpha^2$.

R&D labor demand reaches its maximum at a level of the skilled labor supply $\tilde{S} = ((1 - \alpha) - 1/\gamma + (((1 - \alpha) - 1/\gamma)^2 - 8\alpha/\gamma)^{1/2})/4$. This implies that increased productivity in learning, γ , prolongs the upward sloping section of the relative demand curve, since more skilled workers generate sufficiently greater technological change to justify prolonged relative wage increases. A higher elasticity of substitution between skilled and unskilled (that is, a lower α), has the same effect, as it slows down the rate at which the scarcity of unskilled labor reduces the relative wage.

The intersection between the LBD and R&D labor demand curves implies a development threshold. No R&D is undertaken until the productivity of skilled workers in the R&D regime starts to exceed that in the LBD regime. The critical level of skilled labor necessary to equalize the productivities is $\tilde{S} = (1 - \tau)^{1+\alpha}/\beta\tau$. This shows that the development threshold decreases in the productivity of researchers and in the tax rate.²¹ An economy with more productive researchers thus finds deliberate R&D rewarding for lower levels of skilled labor. Equivalently, an economy that diverts a greater share of income to finance research allocates a relatively larger share of its skilled labor force to the R&D sector, which renders R&D attractive at lower levels of development.

Proposition 2 (Labor Demand). *Research requires an adequate quantity of sufficiently productive skilled workers, else the country must rely on pure learning-by-doing to develop new technologies. Both learning and research are skill intensive. Relative demand for skilled labor increases in the learning productivity, γ , in the funding for research, τ , and in the productivity of skilled workers in research β .*

Labor demand is downward sloping and log concave under learning and R&D, respectively. Greater learning productivity, γ , or higher elasticity of substitution between skilled and unskilled, ϕ , prolong the upward sloping segment of the relative demand curve under R&D.

The switch from learning to deliberate R&D occurs earlier if the share of income devoted to financing research, τ , and the productivity of researchers, β , increases.

The aggregate labor demand function is a tilted *S* shape as seen in Fig. 1. The figure shows three distinct phases of development. The examination of each phase establishes intuition for the tilted *S* shape of the economy-wide labor demand. In the early stages of development, the stock of skilled is small and LBD is the only

²¹ Alternatively, the government could choose to start doing research when the stock of skilled labor is high enough to make the output of the R&D sector equal to that obtained under learning-by-doing. From Eqs. (8) and (9), this occurs when S is $\bar{S} = 1/\beta\tau > \tilde{S}$. If this were the threshold at which R&D starts, none of the results in Propositions 2 and 3 would change, the only difference being that there would be a discontinuity in the steady state demand function.

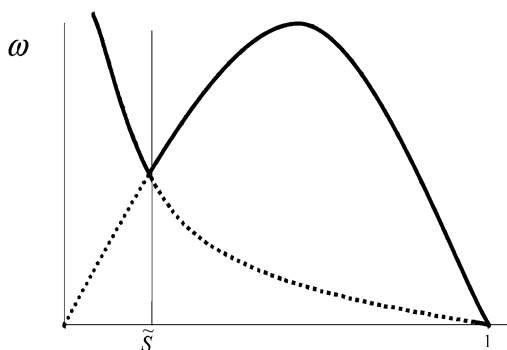


Fig. 1. Labor demand.

form of technical change. At this stage of development, unskilled workers are relatively productive in the final goods sector, compared to skilled labor and the positive effects of technological change are weak. Thus, the labor supply effect dominates and more skilled labor is associated with lower relative wages.

Economies that are more technologically advanced and that possess a sufficiently large stock of skilled labor (phase two) surpass the development threshold and switch endogenously to a dedicated R&D sector. At this stage of development, the active R&D sector produces significantly greater technical change, causing the technology-driven demand for skilled labor to outweigh the labor supply effect. Hence, due to the strong technology–skill complementarity in production, the relative wage initially rises *together* with the stock of skilled labor.

Countries in advanced stages of development (phase three) find that the increasing scarcity of unskilled labor exerts ever-stronger downward pressure on the relative wage to mute the effects of skill-biased technical change. To rule out an equilibrium where all workers in the economy invest in skills, the relative wage declines to zero as the number of skilled workers approaches unity. Once labor supply is added, these three stages of development will be associated with three possible equilibria.

4. Human capital, inequality and growth

4.1. Possible equilibria and wage profiles

It is convenient to examine the possible equilibria and wage time profiles in Fig. 2(a–e). These figures depict the steady state labor demand and labor supply functions, hence the intersections between the two represent possible steady state

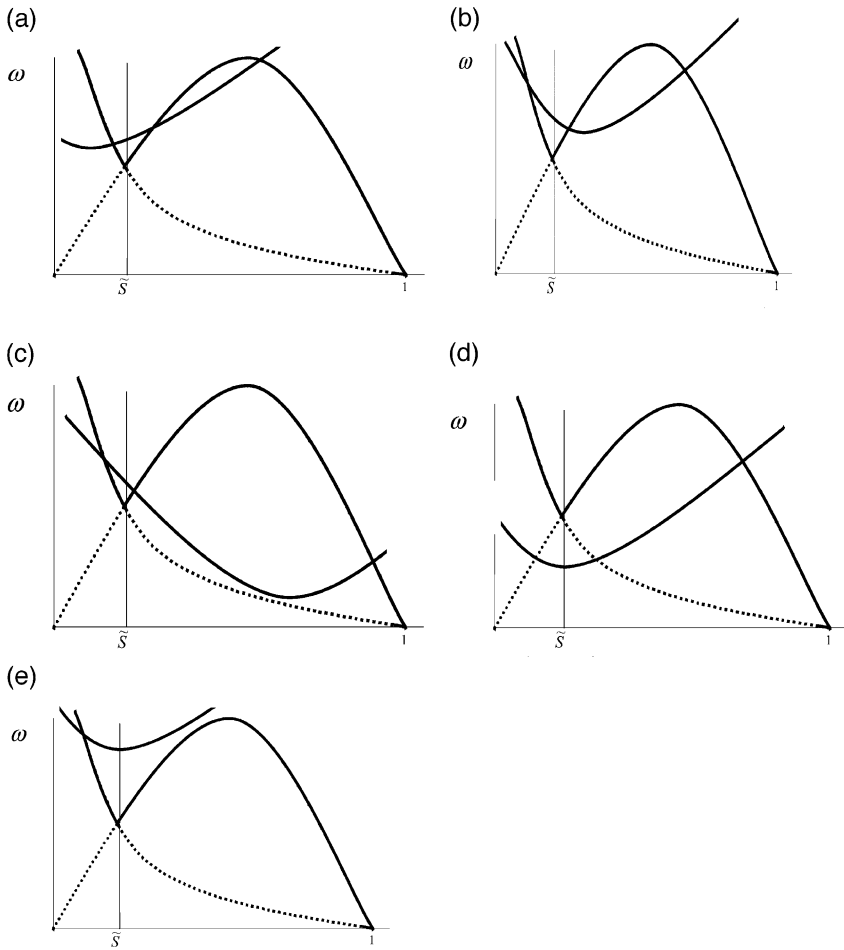


Fig. 2. (a) Rising inequality. (b) De- and increasing inequality. (c) Decreasing inequality. (d) Unique R&D equilibrium. (e) Unique LBD equilibrium.

equilibria. Note, however, that the economy is always on the labor supply function, as it represents the wage required at time t given the supply of skills in that period. Hence, the development process will consist of movements along this curve until a steady state equilibrium is reached.

Four classes of equilibria can be identified. The first two categories consist of equilibria Fig. 2(a) and (c), where greater levels of human capital and growth are associated with monotonic increases (decreases) in inequality. Two conditions combine to allow declining relative wages to be associated with equilibria that feature successively higher growth rates. The first condition is a prolonged decline

of the labor supply function; the second, an early decline of the relative demand for skilled labor under the R&D regime. A strong externality in education allows for the former, while a low degree of substitution and low learning productivity accomplishes the latter. The two conditions that combine to generate increasing relative wages are exactly opposite to those necessary for the previous case. A shortened decline of the labor supply function (due to a weak externality in education) and a late decline of the relative demand for skilled labor under the R&D regime (because of a high degree of substitution and great learning productivity) suffice.

A third pattern of inequality is shown in Fig. 2(b). Here the relationship between inequality and growth reverses as the endogenous stock of skilled labor increases. A low growth equilibrium is associated with low equality, a medium growth equilibrium shows increased equality, but the high-growth equilibrium finally exhibits high levels of inequality. This situation is observed for intermediate values of the externality in education, the elasticity of substitution, and the extent of LBD.

Finally the fourth class of equilibria is shown in Fig. 2(d) and (e). In both cases, the economy exhibits a unique equilibrium with (without) R&D. Each equilibrium is attained independently of the initial conditions. If R&D is conducted (Fig. 2(d)), the country moves toward the unique stable equilibrium by skipping the pure learning stage in its entirety. If, instead, the economy converges to the pure LBD equilibrium, R&D is never performed, no matter how great the initial level of skilled labor may have been. The existence of unique equilibria depends on the direct cost of education, ρ , the externality in education, σ , (increases in σ or decreases in ρ shift the labor supply function down to rule out the LBD equilibrium), and on the productivity in research, β , (which not only shifts the labor demand, but also reduces the development threshold, \tilde{S} , and renders R&D attractive at lower levels of human capital). We can summarize these findings and state in conjunction with Appendix B:

Proposition 3 (Inequality and growth). *The economy exhibits, at most, three equilibria.*

(a) *Sufficiently low (high) costs of education coupled with strong (weak) externalities in education and high (low) research productivities generate unique, stable high-growth (poverty-trap) equilibria.*

(b) *Sufficiently strong (weak) externalities in education and low (high) degrees of substitution between skilled and unskilled in production generate multiple equilibria that exhibit monotonically decreasing (increasing) inequality.*

(c) *Intermediate values for the education externality and for the elasticity of substitution in production imply initially declining inequality along the development path, but eventually rising inequality as growth and human capital accumulation increase sufficiently.*

4.2. *Significance of the results*

Research productivity and the direct cost of education are crucial for determining not only the character of an equilibrium (high-growth or poverty-trap) but also whether multiple equilibria can exist. A country with low costs of education and high R&D sector productivity may skip the pure LBD stage in its entirety and move to a unique R&D equilibrium, independent of the initial human capital stock. High direct costs of education, in contrast, and low research productivity, makes it unlikely for countries to surpass the LBD stage. Intermediate ranges of these parameters imply multiple equilibria that occur in triplets of low, medium and high-growth.²²

If multiple equilibria are observed, the externality in education and the elasticity of substitution between skilled and unskilled determine the relation between successively higher growth equilibria and the relative wage. High (low) externalities in education and a low (high) substitutability of skilled and unskilled workers in production generate equilibria where successively higher growth rates are associated with ever-lower (greater) inequality. Multiplicity results in poverty traps, where countries are trapped in a no-R&D equilibrium, even though a high-growth equilibrium would be feasible for the economy's parameter values. Only if the initial stock of labor exceeds the level associated with the unstable, middle equilibrium, does the country converge to the stable R&D equilibrium. If the initial level of skilled labor is not sufficiently high, the country reverts to the development trap in which only LBD generates technical change. With multiplicity, history matters dramatically, as initial conditions determine whether the country finds itself with an active research sector or not. It renders development path-dependent, since countries with similar technological parameters may now gravitate to either the low or high-growth equilibrium.

Multiplicity emerges as the result of two features of our economy: skill-biased technical change and the fact that new knowledge is generated by skilled labor. Essentially, a greater supply of skilled workers accelerates technical change, which in turn increases the relative demand for these workers in order to absorb the new technology. Because demand is high, there are enough incentives to invest in education and the greater stock of skilled labor is supported by equilibrium wages. The economy thus finds itself in a virtuous cycle. Alternatively, the economy can be stuck in a low-growth trap, where a low relative wage, caused by the fact that slow technical change implies a small demand for educated labor, generates few incentives to further invest in skills. These features of the model thus formalize Tinbergen's (1975) hypothesis that the pattern of relative wages along the devel-

²² In the case of multiple equilibria, Appendix B proves that only the odd numbered equilibria are stable.

opment path depends on the strength of the demand for skills exerted by technology and the supply of skills generated by education.

Unlike in Shell (1967) who modeled the public provision of technology, an increase in publicly funded R&D expenditures does not unambiguously increase economic growth. As in previous models that incorporate productive government spending (e.g., Barro, 1990), the tax in our model has two opposing effects on growth. Higher taxes affect the provision of new productive technology, but also present additional disincentives to accumulate the crucial resource that drives economic growth: human capital. Because revenues are generated through a tax on skilled wages, a change in the tax rate affects both the supply and the demand for skills. A higher tax rate increases the *proportion* of educated workers employed in the research sector, thus raising the rate of technical change and shifting upwards the labor demand function (see Proposition 2). At the same time, a higher tax reduces the net income of skilled workers. The incentives to invest in skills are diminished and the *stock* of skilled workers falls, shifting downwards the labor supply (see Proposition 1). Consequently, the total number of researchers, and hence the growth rate, may be greater or smaller than under the lower tax rate. In other words, if research expenditures are financed through a progressive labor income tax, a higher tax rate may reduce R&D expenditure because of its effect on the supply of researchers.

It is important to note the role played by the functional forms of the technology generating functions in our results. The implications are remarkably robust, however; even if LBD is absent ($\gamma = 0$), the qualitative results can be replicated. In this case, the labor demand function simply shifts downward, and the possibility of attaining multiple steady states is preserved. If, however, deliberate R&D is absent from the model, labor demand slopes downward and multiple steady states can be ruled out. If R&D were absent but the rate of LBD increased in the stock of skilled labor, $\gamma'[S] > 0$, then sufficiently large spillovers from skilled labor to learning would exert upward pressure on the labor demand, to generate qualitatively equivalent equilibria in the propositions discussed above.²³

Aside from alternative specifications of the R&D function, there exists an extensive literature on the impact of openness on a country's technological capacities. Van Elkan (1996), Lai (1995, 1998), as well as Eicher (1999a,b), have shown that international diffusion or imitation add additional dynamics that may inhibit or accelerate catch-up to the world technology frontier. While a complete analysis of the issue of international trade is beyond the scope of the paper, we conjecture that the same dynamics may influence the above model to affect the selection of a particular equilibrium.

²³ $\gamma'[S] > 0$ does not receive support in the literature, however, because it would imply accelerated rates of technical change in the past century (see Jones, 1995). Hence we maintain $\gamma'[S] = 0$ and introduce deliberate R&D.

5. Conclusion

There is no clear empirical regularity that describes the evolution of inequality along the development process, either within or across countries. Recent dual-economy models have provided a possible explanation. Expanding the original Kuznets argument to allow for intra-sectoral inequality, yields the possibility of inequality patterns different from the traditional inverse-U shaped relationship (see Anand and Kanbur, 1993b; Fields, 1993). This paper has presented an alternative mechanism based on the dual role of human capital. We have argued that the stock of educated workers in an economy determines both the degree of income inequality and the rate of growth, and that the parameters of the demand for and the supply of labor are crucial determinants of whether inequality increases or decreases as an economy accumulates human capital.

The driving force of the model is a production function where the relative productivity of skilled to unskilled labor changes with the rate of technical change. New technologies are in turn generated by skilled workers, which implies that the relative demand for labor, and hence the skill premium, are not monotonically decreasing in the stock of skills in the economy. When we pair this demand function with a supply of labor function, we find, first, that multiple equilibria are possible, and, second, that as a country accumulates skills, inequality may increase, decrease, or follow a U-shaped path. The trajectory followed by a particular country will depend on the direct cost of education, the extent of externalities in the education process, and the elasticity of substitution between skilled and unskilled workers in production.

Of course, we make no claim that this is the only, or even the main, determinant of inequality. We simply believe that it is an important part of the story. This is particularly so, given that the “source” of growth seems to have changed substantially. In the words of Williamson (1991, p. 90) “the mode of accumulation in the nineteenth century appears to have been much more heavily directed towards conventional capital formation, while the mode of accumulation in the twentieth century seems to have been much more heavily directed towards human capital accumulation”.

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Appendix A. The intermediate good sector and capital accumulation

New technologies for intermediate goods are public goods generated either via LBD or via tax-financed R&D. Differentiating Eq. (1) with respect to $n(i)$, the inverse demand function for good i , is $p_{it} = (1 - \delta) n(i)_t^{-\delta} H_t^{-\delta}$. Intermediate goods last for one period, and one unit of capital, k , is required to produce one unit of intermediate good. Production cost is thus $1 + r_t$, where r_t is the interest rate. Perfect competition implies marginal cost pricing, hence the amount of good i produced at t is $n(i)_t^* = (1 - \delta/1 + r_t)^{-\delta} H_t$, which is the same for all types of intermediaries, i.e. $n(i)_t^* = n_t^* \forall i$. The aggregate stock of capital is then $K_t \equiv n_t^* D_t$.

Since individuals work when young and consume when old, all net labor income is saved, and total labor income is given by $(1 - S_t)w_t^u + \int_{a^*}^1 [(1 - \tau)w_t^S - \rho S_t^{-\sigma} w_t^u / a] da$. Integrating, and since $w_t^S = \omega_t w_t^u$, we can express savings as

$$Z_t = (1 - S_t)w_t^u + (1 - \tau)(1 - a_t^*) \omega_t w_t^u - \rho S_t^{-\sigma} \log \frac{1}{a_t^*} w_t^u.$$

Substituting for the relative wage from Eq. (6) and using the fact that the unskilled wage is given by $w_t^u = \delta n_t^{1-\delta} H_t^{\delta+\alpha} U_t^{-\alpha-1} D_{t-1}$, we have

$$Z_t = \delta(1 - S_t)^{-\alpha-1} \left(\frac{1 - \delta}{1 + r_t} \right)^{(1-\delta)/\delta} \times H_t^{1+\alpha} D_{t-1} \left[1 + \rho S_t^{-\sigma} \left(\frac{S_t}{1 - S_t} - \log \frac{1}{1 - S_t} \right) \right].$$

Capital market equilibrium requires that total savings be equal to the aggregate capital stock, that is $K_t = Z_t$, which implies

$$\begin{aligned} & (1 + r_t) \frac{\alpha}{1 - \alpha} (1 - S_t)^{-\alpha-1} \left[1 + \rho S_t^{-\sigma} \left(\frac{S_t}{1 - S_t} - \log \frac{1}{1 - S_t} \right) \right] \\ & = H_t^{-\alpha} \frac{D_t}{D_{t-1}}. \end{aligned}$$

The right-hand side of this equation is a function of S_t and S_{t-1} (through H_t and D_t/D_{t-1} , respectively). Since S_{t-1} is given and S_t is determined by the labor market equilibrium that does not depend on r_t (see below), this equation defines the equilibrium interest rate at time t as a function of the current and the previous period's supply of skills.

Appendix B. Existence and dynamic behavior

Define

$$\Psi(S_t) \equiv \frac{1}{1-\tau} \left(1 + \frac{\rho}{(1-S_t)S_t^\sigma} \right) \left(\frac{S_t}{1-S_t} \right)^{1+\alpha}.$$

Substituting the inverse supply function into the labor demand functions (Eqs. (12) and (13)), we obtain the first order difference equations that govern the dynamics of the stock of skilled labor in the economy for the LBD and R&D cases, respectively:

$$1 + \gamma S_{t-1} = \Psi(S_t), \tag{A2.1}$$

$$\frac{S_{t-1}}{\tilde{S}} (1 + \gamma S_{t-1}) = \Psi(S_t). \tag{A2.2}$$

B.1. Part I: Dynamics of the equilibria

Differentiating, we have

$$\frac{\partial \Psi}{\partial S_t} = \frac{\rho(1 + \alpha - \sigma) + (1 + \alpha)(1 - S_t)S_t^\sigma + \rho(1 + \sigma)S_t}{(1 - \tau)} \frac{S_t^{\alpha - \sigma}}{(1 - S_t)^{3 + \alpha}}.$$

Note that $1 + \alpha \geq \sigma$ is a necessary and sufficient condition for $\partial \Psi / \partial S_t > 0$ in the interval $[0,1]$. Since the left-hand sides of both Eqs. (A2.1) and (A2.2) are increasing in S_{t-1} , the restriction $1 + \alpha \geq \sigma$ implies that $\partial S_t / \partial S_{t-1} > 0$ both under LBD and R&D.

In order to examine the dynamics of the model, we depict the right- and left-hand sides of Eqs. (A2.1) and (A2.2) graphically in Fig. 3. Under the assumption $1 + \alpha \geq \sigma$, the function $\Psi(S_t)$ has the following properties:

- (i) $\partial \Psi / \partial S_t > 0$ in the interval $[0,1]$,
- (ii) $\Psi(S_t)$ is first concave and then convex,
- (iii) $\Psi(S_t = 0) = 0$ and $\Psi(S_t = 1) = \infty$,
- (iv) higher values of ρ and σ shift $\Psi(S_t)$ upwards.

During the LBD phase, the left-hand side of Eq. (A2.1) is a linear function of S_{t-1} , $f(S_{t-1}) \equiv 1 + \gamma S_{t-1}$. The LBD equilibrium occurs at the value of S , for which $f(S_{t-1}) = \Psi(S_t)$. The two functions always cross once (further intersections are ruled out by the assumption that γ is not too large, i.e. $\gamma < 4(1 + \alpha) / \alpha^2$). Only if the intersection occurs for a value of S less than \tilde{S} does the LBD equilibrium exist. In the R&D phase, the left-hand side of Eq. (A2.2) is a convex function of S_{t-1} , $h(S_{t-1}) \equiv S_{t-1}(1 + \gamma S_{t-1}) / \tilde{S}$. The functions $h(S_{t-1})$ and $\Psi(S_t)$ cross either twice or not at all in the interval $(0,1)$. If these intersections exist, they will only be an equilibrium if they occur for values S_{t-1} greater than \tilde{S} .

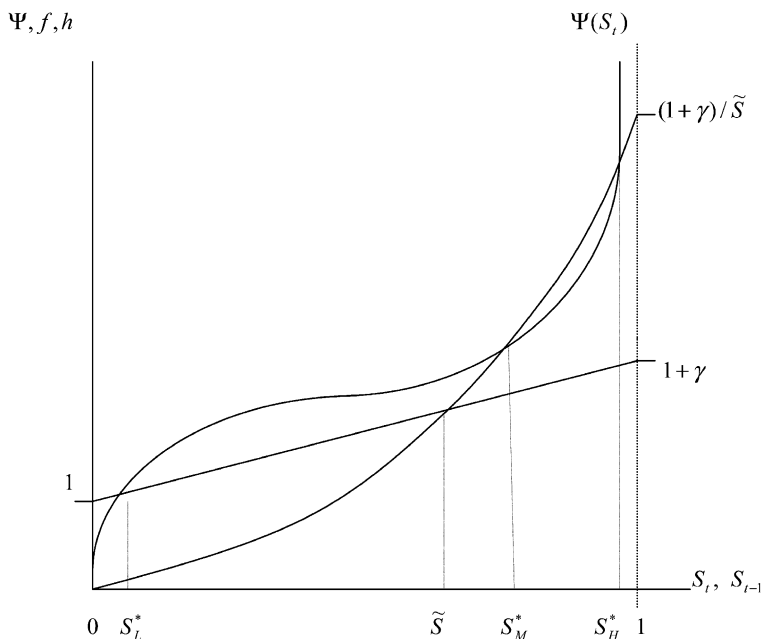


Fig. 3. Stability.

There can thus exist three possible equilibria: a low-growth trap in the LBD phase and a pair of equilibria in the intermediate and advanced development phase. Fig. 3 represents these three possible intersections. It is straightforward to assess the stability of the equilibria, if they exist, from the figure. We can see that the LBD equilibrium will be stable, while in the R&D phase, the first equilibria will be unstable and the second one stable.

B.2. Part II: Existence of the equilibria

Fig. 3 allows us to examine when the various equilibria would exist. A condition for the existence of the LBD equilibrium (R&D equilibria) is that the direct cost of education be high (low) enough (see below). A reduction in the cost of education shifts down $\Psi(S_t)$. Hence, for very low ρ , the LBD intersection occurs to the right of \tilde{S} and the LBD equilibrium does not exist. A very high cost of education implies that the functions $\Psi(S_t)$ and $h(S_{t-1})$ do not intersect, and the R&D equilibria do not exist. Similarly, a strong education externality (low value of σ) shifts down $\Psi(S_t)$, implying that a sufficiently weak (strong) externality is required for the LBD equilibrium (R&D equilibria) to exist. A high research productivity, β , makes the $h(S)$ function steeper and moves the threshold \tilde{S} to the left. As a result, the intersection S_L^* occurs for a value of S greater than \tilde{S} and the

low-growth equilibrium does not exist. A low value of β implies that the intersections S_M^* and S_H^* occur for a value of S smaller than \tilde{S} and the medium and high-growth equilibria do not exist.

It is not possible to obtain precise existence conditions for the equilibria from the differential equations governing the behavior of S_t . However, we can obtain such conditions from the steady state supply and demand functions. By inspection of the demand and supply functions as depicted in Fig. 2(a–e), we can state the following properties:

(a) A necessary condition for the existence of multiple equilibria is that the labor demand function has an upward-sloping section. This will occur if the intersection between the two wage demand curves occurs before the maximum of the log concave curve. That is, if $\tilde{S} < \hat{S}$, which implies

$$\frac{\gamma (1 - \tau)^{1+\alpha}}{\beta \tau} < \frac{(1 - \alpha)\gamma - 1 + (((1 - \alpha)\gamma - 1)^2 - 8\alpha\gamma)^{1/2}}{4}. \tag{A2.3}$$

(b) The necessary conditions for existence of a LBD equilibrium are

- the labor supply must lie below the steady state labor demand curve at $S = 0$, which for $1 + \alpha \geq \sigma$ always holds, and
- the labor supply must lie above the steady state labor demand curve at the point where LBD ceases, \tilde{S} . This condition can be expressed as

$$\rho > (1 - \tilde{S})\tilde{S}^\sigma \left((1 + \gamma\tilde{S})(1 - \tau) \left(\frac{1 - \tilde{S}}{\tilde{S}} \right)^{1+\alpha} - 1 \right). \tag{A2.4}$$

(c) The necessary condition for the existence of an R&D equilibrium is that the labor supply function be below the steady state labor demand function at some point in the interval $(\hat{S}, 1)$. A sufficient condition for this is that the supply function be below the demand function at the maximum of the latter. That is,

$$\rho < (1 - \hat{S})\hat{S}^\sigma \left((1 + \gamma\hat{S})(1 - \tau) \left(\frac{1 - \hat{S}}{\hat{S}} \right)^{1+\alpha} \frac{\hat{S}}{\tilde{S}} - 1 \right). \tag{A2.5}$$

These three conditions have intuitive interpretations. Eq. (A2.3) says that in order to have multiple equilibria, the difference between the productivity of R&D and that of LBD must be large enough relative to the elasticity of substitution between the two types of labor. That is, the behavior of the economy on the two phases must be “different enough”. Eqs. (A2.4) and (A2.5) imply that the direct cost of education determines the possible type of equilibria. A LBD (or low-growth) equilibrium exists only if the cost of education is sufficiently high, relative to the

externality and the productivities of skilled labor in generating technological change. Similarly, an R&D equilibrium exists only if the direct cost of education is sufficiently low. Intuitively, this means that if education is very cheap, no economy will be locked into a low-growth trap, while if it is very expensive, no economy will be able to reach a high-growth equilibrium. Also, a high productivity of researchers β (which raises \bar{S}) and a strong externality (i.e. a low σ) increase the right-hand side of both Eqs. (A2.4) and (A2.5), making it less likely for a LBD equilibrium and more likely for an R&D equilibrium to exist.

References

- Acemoglu, D., 1996. A microfoundation for social increasing returns in human capital accumulation. *Quarterly Journal of Economics* 111, 779–804.
- Acemoglu, D., 1998. Why do new technologies complement skills? Directed technical change and wage inequality. *Quarterly Journal of Economics* 113, 1055–1089.
- Acemoglu, D., 1999. Patterns of Skill Premia. Mimeo MIT.
- Aghion, P., Bolton, P., 1997. A trickle-down theory of growth and development with debt overhang. *Review of Economic Studies* 64, 151–172.
- Aghion, P., Caroli, E., García-Peñalosa, C., 1999. Inequality and economic growth: the perspective of the new growth theories. *Journal of Economic Literature* 37, 1615–1660.
- Alesina, A., Rodrik, D., 1994. Distributive politics and economic growth. *Quarterly Journal of Economics* 109, 465–490.
- Anand, S., Kanbur, S.M.R., 1993a. Inequality and development: a critique. *Journal of Development Economics* 41, 19–43.
- Anand, S., Kanbur, S.M.R., 1993b. The Kuznets process and the inequality-development relationship. *Journal of Development Economics* 40, 25–52.
- Azariadis, C., 1996. The economics of poverty traps part one: complete markets. *Journal of Economic Growth* 1, 449–486.
- Azariadis, C., Drazen, A., 1990. Threshold externalities in economic development. *Quarterly Journal of Economics* 105, 501–526.
- Banerjee, A., Newman, A.F., 1993. Occupational choice and the process of development. *Journal of Political Economy* 101, 274–298.
- Barro, R., 1990. Government spending in a simple model of endogenous growth. *Journal of Political Economy* 98, 103–126.
- Bartel, A.P., Lichtenberg, F.R., 1987. The comparative advantage of educated workers in implementing new technology. *Review of Economics and Statistics* 69, 1–11.
- Becker, G.S., Murphy, K.M., Tamura, R., 1990. Human capital, fertility, and economic growth. *Journal of Political Economy* 98, S12–S37.
- Benabou, R., 1996a. Equity and efficiency in human capital investment: the local connection. *Review of Economic Studies* 63, 237–264.
- Benabou, R., 1996b. Heterogeneity, stratification and growth: macroeconomic implications of community structure and school finance. *American Economic Review* 86, 548–609.
- Benabou, R., 2000. Unequal societies: income distribution and the social contract. *American Economic Review* 90, 96–129.
- Borjas, G., 1995. Ethnicity, neighborhoods, and human capital externalities. *American Economic Review* 85, 365–390.
- Bourguignon, F., Morrisson, C., 1998. Inequality and development: the role of dualism. *Journal of Development Economics* 57, 233–257.

- Breen, R., García-Peñalosa, C., 2000. Income Inequality and Macroeconomic Volatility: an Empirical Investigation, GREQAM, mimeo.
- Caselli, F., 1999. Technological revolutions. *American Economic Review* 89, 78–102.
- Chiu, W.H., 1998. Income inequality, human capital and economic performance. *Economic Journal* 108, 44–59.
- Coleman, J., 1990. *Foundations of Social Theory*. Harvard Univ. Press, Cambridge.
- Deininger, K., Squire, L., 1998. New ways of looking at old issues: inequality and growth. *Journal of Development Economics* 57, 259–287.
- Eicher, T.S., 1996. Interaction between endogenous human capital and technological change. *Review of Economic Studies* 63, 127–144.
- Eicher, T.S., 1999a. Training, adverse selection and appropriate technology: development and growth in a small open economy. *Journal of Economic Dynamics and Control* 23, 727–746.
- Eicher, T.S., 1999b. Trade, development and converging growth rates: dynamic gains from trade reconsidered. *Journal of International Economics* 48, 179–198.
- Fields, G.S., 1993. Inequality in dual economy models. *Economic Journal* 103, 1228–1235.
- Forbes, K., 2000. A reassessment of the relationship between inequality and growth. *American Economic Review* 90, 869–887.
- Galor, O., Moav, O., 2000a. Ability based technological transition, wage inequality and economic growth. *Quarterly Journal of Economics* 115, 469–497.
- Galor, O., Moav, O., 2000b. *Das Human Capital*, Brown University mimeo.
- Galor, O., Tsiddon, D., 1996. Income distribution and growth: the Kuznets hypothesis revisited. *Economica* 63, S103–S117.
- Galor, O., Zeira, J., 1993. Income distribution and macroeconomics. *Review of Economic Studies* 60, 35–52.
- Gottschalk, P., Smeeding, T.M., 1997. Cross-national comparisons of earnings and income inequality. *Journal of Economic Literature* 35, 633–687.
- Gould, E., Moav, O., Weinberg, B.A., 2000. Precautionary demand for education, inequality, and technological progress, mimeo.
- Greenwood, J., Yorukoglu, M., 1997. 1974. *Canergie–Rochester Conference Series on Public Policy* 46, 49–95.
- Grossman, G., Helpman, E., 1991. *Innovation and Growth in a Global Economy*. MIT Press, Cambridge.
- Harris, J.R., Todaro, M.P., 1970. Migration, unemployment and development. *American Economic Review* 60, 126–142.
- Jones, C., 1995. R&D-based models of economic growth. *Journal of Political Economy* 103, 759–784.
- Kuznets, S., 1955. Economic growth and income inequality. *American Economic Review* 45, 1–28.
- Lai, E., 1995. The product cycle and the world distribution of income: a reformulation. *Journal of International Economics* 39, 369–382.
- Lai, E., 1998. International intellectual property rights protection and the rate of product innovation. *Journal of Development Economics* 55, 133–153.
- Lamoreaux, N.R., Raff, D.M.G., Temin, P. (Eds.), 1999. *Learning by Doing in Markets, Firms and Countries*. National Bureau of Economic Research and University of Chicago Press, Chicago.
- Nelson, R., Phelps, E., 1966. Investments in humans, technological diffusion, and economic growth. *American Economic Review* 61, 69–75.
- Perotti, R., 1993. Political equilibrium, income distribution, and growth. *Review of Economic Studies* 60, 755–776.
- Persson, T., Tabellini, G., 1994. Is inequality harmful for growth? Theory and evidence. *American Economic Review* 84, 600–621.
- Psacharopoulos, G., Woodhall, M., 1985. *Education for Development*. Oxford Univ. Press, Oxford.
- Romer, P.M., 1990. Endogenous technological change. *Journal of Political Economy* 98, S71–S102.
- Rustichini, A., Schmitz, J.A., 1991. Research and imitation in long-run growth. *Journal of Monetary Economics* 27, 271–292.

- Shell, K., 1967. A model of inventive activity and capital accumulation. In: Shell, K. (Ed.), *Essays on the Theory of Optimal Economic Growth*. MIT Press, Cambridge.
- Tamura, R., 1991. Income convergence in an endogenous growth model. *Journal of Political Economy* 99, 522–540.
- Tamura, R., 1996. Regional economies and market integration. *Journal of Economic Dynamics and Control* 20, 825–845.
- Tinbergen, J., 1975. *Income Distribution: Analysis and Policies*. North-Holland, Amsterdam.
- UNESCO, 1999. *Statistical Yearbook*. UNESCO Publishing, New York.
- Van Elkan, R., 1996. Catching up and slowing down: learning and growth patterns in an open economy. *Journal of International Economics* 41, 95–111.
- Williamson, J.G., 1991. *Inequality, Poverty and History*. Blackwell, Oxford.
- Williamson, J.G., 1999. Globalization and the labor market: using history to inform policy. In: Aghion, P., Williamson, J.G. (Eds.), *Growth, Inequality and Globalization*. Cambridge Univ. Press, Cambridge.