Income Distribution and Skilled Biased Technological Change*

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Abstract

This paper develops a model of growth based on a critical interplay between human capital accumulation and technological change. The "direction" of technological change is skilled biased by assumption, but its occurrence is endogenous, and determined by an intentional, profit-oriented decision taken by Schumpeterian innovators.

A property of the dynamic equilibrium of the model is of featuring an education-technology race, in which the accumulation of human capital triggers the spread of highly efficient but skilled biased technologies. In turn the latter generates potentially deep transformations in the wage structure and in the distribution of income. In particular, consistently with the evidence on the recent experience of many industrialized countries, skilled wages can increase and unskilled wages can fall, both in *absolute* terms, rather then just relative ones. The pauperisation suffered by the unskilled on impact may be long lasting and substantially slow down the pace of the diffusion of the new technologies if, as the model assumes, a market for financing human capital investments does not exist. At the limit, it may be such to impede to a number of dynasties of workers to ever become educated and to forbid a full scale upgrading of the aggregate production structure of the economy.

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1 Introduction

This paper is concerned with the dynamic general equilibrium relations between technological change, inequality and human capital accumulation. Its basic motivation is of shedding some new light on the transformations which have been observed in recent years both in the productive structure and in the distribution of income in many advanced economies. These phenomena of deep change are arguably intimately connected with each other and ought therefore to be analyzed in a unified framework. Yet, much of the existing theoretical literature on the issue has failed to do so, treating as "exogenous" important pieces of the picture.[1] Conversely, I will deal with an economy where:

- technological change is endogenous and takes place reflecting profitability incentives, on the base of a precisely micro-founded market mechanism.
- The supply of human capital is also endogenous, and shaped by the assumption of the inexistence of a perfect credit market for financing individual educational expenditures.

The emphasis of the paper is on the linkage between the distribution of income and growth obtaining in an economy where credit market imperfections coupled with non-convexities constraint the individual ability to undertake human capital investments, as in the seminal paper of Galor and Zeira (1993). Two key differences with respect to that paper are the endogeneity of technological progress, and the introduction of a framework where the latter has non trivial implications for the distribution of factors income, which is in turn critical for the subsequent dynamics of the economy. Hence, the model also sheds some light on the yet relatively unexplored topic of the relations between credit market imperfections and technological change.

The importance of the linkage in question is suggested by some of main stylized facts of the recent macroeconomic history of many developed economies. Let me review here these facts briefly.

[1] For example, Caselli (1999) does not explain the occurence of "technological revolutions" in his economy. Aghion and Howitt (1998, ch. 8) and Aghion (1998) present converesly a model of endogenous diffusion of a skilled biased General Purpose Technology, but postulate an ad hoc supply dynamics of skilled labor.

Three exceptions are vice versa the paper of Galor and Tsiddon (1997), of Galor and Moav (2000) and of Eicher and García-Penalosa (2001).

Income inequality has increased visibly in the United States and in other industrialized countries over the last three decades. This fact is highlighted clearly by a large number of statistics including the Gini coefficient, which has increased in the United States of 1.07 in percentage terms over the period $1979-1993$ (Gottschalk (1997)). Positive percentage increments in the Gini coefficient over same period have also been observed in the U.K. (1.80), Japan (0.84), Germany (0.53), France (0.40) and elsewhere.

At the base of the observed process of increasing income inequality lays a sharp divergence of the earnings of the most and of the least skilled workers.[2] That is, an increasing wage inequality appears to have been the driving force behind the overall trend documented. In the United States for example, the gap between the top and bottom deciles in the wage distribution has increased since 1970 to 1995 by as much as 30% (Topel (1997)).

Two parallel forces seem to have acted behind this increasing earnings divergence. On the one hand, the wages of the workers at the top of the skills distribution have increased persistently, on the other those of the workers at the bottom of it have also fallen in absolute terms, rather than just in relative ones. Quantitatively, the absolute earning loss at the bottom has been often remarkable, reaching the peak again in the Unites States, where real wages have fallen of more than 20% since 1970 up to today. Indeed, the pauperisation suffered by low earnings workers has affected even median wages, which in the United States have fallen themselves in absolute terms by 5% over the period $1970-1989$ (Juhn et al. (1993)), while average wages have stagnated.

While a number of different factors has been identified to lie at the roots of this process,[3] a major role seems to have been played by the diffusion

[2] Inequality has also sharply increased *within* educational groups (e.g. Juhn et al. (1993)). This fact has been interpreted by recognizing that new technologies are both skill *and* ability biased (e.g. Bartel and Sicherman (1999)). Therefore their diffusion is also conductive to an increment of the premium granted to unobservable individual characteristics. However, this paper will be concerned only with the interplay of technological change and between group wage inequality.

[3] An alternative hypothesis refers to the increasing trade with unskiled labor abundant underdeveloped countires, which would tend to reduce the price of skilled labor also in the developed world. There are however several empirical problems with this hypotesis (for a brief discussion see Johnson (1997)). An other possible explanation refers to widely observed transformations in labor market institutions such as deunionization and the erosion of the real value of minimum wages (e.g. DiNardo et al. (1996)). However, this is perhaps more a complementary story than an alternative to the technology-based hypothesis. In fact, it may be argued that deunionization itself is not independent from technological change. This could be so since the distorsions caused by rigid wage setting institutions

of "skilled biased" technologies, which has persistently taken place over the last three decades in virtually all advanced economies. A new technology may be defined as skilled biased (relatively to some existing benchmark) if skilled workers are necessarily required to operate with it, a requirement not imposed by the old technology.[4] The spread of skilled biased technologies is thus naturally associated to an increment in the demand for skilled labor and to a fall in the demand for unskilled labor. Therefore, holding constant the relative factors supply, it may well be conductive to a higher relative price for skilled labor (that is, to a greater skill premium) and possibly even to an absolute reduction of the price for unskilled labor. In recent times, the most obvious form of skilled biased technological change has been represented by the diffusion of computers and other Information Technology devices including robots, which have complicated many tasks that used to be routine ones (e.g. Berman et al. (1994), Autor et al. (1998)). But, more generally, one can think to any transformation, including organizational ones,[5] increasing the complexity and the homogeneity of the working environment.

The skilled biased technological change hypothesis is appealing also because it is consistent with the large variations in the relative supply of skilled and unskilled labor observed. In all advanced economies the share of highly educated workers (say with a university degree) has continuously increased while the fraction of low education workers (those with a high school diploma or less) has systematically fallen during the past decades. The picture is thus that of an ongoing increment in the aggregate human capital stock, which makes it very difficult to explain the observed earnings dynamics abstracting from a substantial shift in the relative labor demand.

Some authors (e.g. Acemoglu (1998)) have indeed recently gone one step further, by arguing that the factor bias of technological change is to be regarded as at least partly endogenous, depending on the relative factors supply. When technological progress is driven by market incentives and

may be exacerbated in a "new economy" envirnonment, and hence their redistributive scope of may be substabtially cut down.

[4]A more general definition can be given in terms of skills-tasks specificity. If a technology is viewed as a combination of skills-specific tasks, a new technology will be skilled biased if skilled workers become necessary to perform tasks which used to be performed by the unskilled. See Jonhson (1997) for a careful discussion of the various non skills-neutral forms of technological change.

[5]Aghion (1998) discusses the relations between skilled biased technological change and organizational transformations. Important examples of links between the two are represented by an increasing segregation of workers by skills (a point formalized by Kremer and Maskin (1996)), by a higher decerentralization of decision making and by a lower degree of specialization by task of the part of workers.

subject to fixed costs, market size effects play a central role in *directing* it. An increment in the relative supply of human capital would increase the profits accruing to an innovator introducing a new skilled labor intensive technology, thereby stimulating the overall R&D effort in this direction. And it would thus raise the (endogenous) bias of technological progress toward skilled labor. In this perspective, the large upward trend in the supply of skilled labor observed at least since the 1960's would be a crucial causal antecedent of the technological and productive transformations observed later.

In this paper, I develop a similar point, considering an economy where both the supply of human capital and technological progress are jointly endogenous and critically affect each other. The dynamics of the aggregate human capital supply is shaped, and slowed down, by the inability of households to have access to sources of external finance, due to the inexistence of a credit market for educational expenditures. The macroeconomic relevance of credit market imperfections has been repeatedly stressed by several papers of the growth literature flourished in the 1990's. Important examples include the contributions of Banrejee and Newman (1993), Galor and Zeira (1993), Perotti (1993), Saint-Paul and Verdier (1993), Bénabou (1996a,b) and Aghion and Bolton (1997). All of these papers point out that the joint dynamics of growth and of the distribution of income depend critically on the degree of access to the credit market on the part of households. All of them however consider a growth process based only on factors' accumulation and abstract from endogenous technological change. In my economy vice versa, credit market imperfections do not only impede to relatively poor households to invest in human capital. They also tend to delay technological change as R&D investments are discouraged by the aggregate shortage of human capital. This is so again because of a market size effect: the cost of R&D borne by an innovator can be recovered only when the related profits are large enough, namely when enough workers can operate with the new technology invented. In my model an economy starts replacing across sectors of production a given status quo technology with a more efficient one (in the total factor productivity sense) only *after* it has accumulated a sufficiently large stock of human capital (if it can do so at all). This is necessary as the new technology, which could be either a common General Purpose Technology or a sector specific technology with standardized productivity, is by assumption intensive in skilled labor.[6] In other words, a substantial

[6] A related model of technology adoption is also the one discussed by Aghion and Howitt (1998, ch. 8). These authors are there concerned with the diffusion of a skilled biased

human capital accumulation appears as a "pre-requisite" for a technological revolution to start taking place.

It is well known that in presence of credit market imperfections, the distribution of income can become critical for human capital investment and therefore in allowing or not allowing technological change to ever take place when this is endogenous. In my economy, it appears to be determinant also in shaping the medium-long run dynamics and the overall extent of the diffusion of the new technology, after this has started to take place. An important result of my paper is in fact that unskilled wages may (though they need not) fall in *absolute* terms, rather then just in relative ones, consistently with the actual recent experience of many countries. This is perhaps the most interesting distributive implication of skill biased technological change in general equilibrium, and its macroeconomic relevance can be critical in presence of credit market imperfections. In fact, a large enough wage drop can prevent an entire dynasty of workers (linked by some form of intergenerational altruism) to be ever able to invest in education, despite the existence of a significant skill premium. Since the overall diffusion of new technologies will depend on the ability of the supply of human capital to follow-up, this pauperisation effect of skilled biased technological change may have profound implications for the long run configuration of the economy. This could involve the adoption of the new technology in all sectors of production and the convergence of the distribution of income to a perfectly egalitarian one, having all dynasties of workers ultimately afforded to invest in education. But it may also display the convergence to a dual form, featuring a permanent segmentation of the population into a class of rich/skilled and of poor/unskilled and an heterogenous aggregate production structure, where the relatively obsolete technology has not been completely discarded.

I demonstrate also that the process of diffusion of a new technology may be very non-smooth, whatever its long-run outcome is. That is, I show that for the cross-sectoral spread of the new technology to increase without discontinuity, the aggregate human capital supply must increase from period to period (in a discrete time OLG setting) by a large enough amount, because of the indivisibilities related to R&D, which in general may well not be the case. Otherwise, the aggregate production structure exhibits no change. A corollary of this is that the interplay between an endogenous human capital

General Purpose Technology in an economy where the supply of skilled labor increases constantly over time *by assumption*. As we shall argue, not allowing for possible feedback effects on the distribution of income of technological change is a potentially serious limit of their analysis.

supply and endogenous technological change can generate a cyclical pattern for wage inequality as represented by the skill premium. During the periods separating different waves of innovation the skills premium falls because: (*i*) some workers become rich enough to invest in education, (*ii*) the level of the aggregate demand for skilled labor is lower due to the absence of R&D activities. Both of these effects tend to depress the skill premium and (*i*) also to let unskilled wages to increase in absolute terms.

This result looks interesting since the cyclically of wage inequality and of the skill premium is an other important stylized fact of the post-war economic history of the United States (e.g. Autor et al. (1998)) as well as of other developed economies.

This paper is organized as follows. Section 2 describes the production structure (2.1), and the R&D process (2.2) in its static aspects primarily. Sections 3 and 4 describes the dynamic setup of the model and deals with the growth process. Section 5 discusses the main results, section 6 deals informally with political economy issues and section 7 concludes. All proofs are to be found in the appendix or after each statement.

2 The Basic Environment

2.1 Production

The model is based on the Aghion and Howitt (1992, 1998) model of growth through creative destruction, which is extended to allow for heterogeneity in the labor force in terms of skills or education levels, for a form of technological change biased toward skilled labor (or human capital) and embedded into a discrete time OLG setting. Growth in this economy will take place in terms of dynastic accumulation of wealth, of diffusion of education or human capital *and* of adoption over time of high productivity but skilled biased technologies. A strong interplay will be found to exist between the three of them.

In the section I will describe the production structure of the economy and the innovation process at a point in time, treating as a given parameter the human capital endowment. The analysis will thus be static for the most part but an eye to the dynamics of the economy will be first given toward the end of the section.

A unique final good is produced through a continuum of intermediate goods of unitary measure. Intermediate goods are manufactured with a linear production technology. The final good is produced through the intermediate goods with a decreasing returns to scale technology and there is no complementarity between them. The aggregate production function can then be represented as

$$Y = \int_0^1 Y(i)\, di = \int_0^1 A^i x^\alpha (i)\, di \tag{1}$$

where $x(i)$ indicates the quantity of labor which is allocated to the manufacturing of the intermediate good i.[7] Two linear production technologies are (or can be) available for intermediate goods manufacturing. One is intensive in skilled labor and indexed by a productivity coefficient $\left(A^h\right)^{\frac{1}{\alpha}}$, the other one is skills-neutral and indexed by $\left(A^l\right)^{\frac{1}{\alpha}}$. The skilled labor intensive technology requires specifically skilled workers but is more efficient in the sense that $A^h = \gamma A^l$ with $\gamma \in (1, \infty)$. All workers can operate with the skills-neutral technology. Workers do supply inelastically a number of efficiency units of labor standardized to one if unskilled and, if skilled, equal to some $\phi^{\frac{1}{\alpha}} > 1$ regardless of where they work.

Let $\theta \in [0, 1]$ indicate the Lebesgue measure of the set of sectors of production adopting the skills-neutral technology. There is no loss of generality, given the symmetry of the model, in assuming that goods indexed with $i \in [0, \theta]$, are manufactured with the unskilled labor intensive technology ($A^i = A^l$) and that goods indexed with $i \in (\theta, 1]$ are manufactured with the skilled labor intensive one ($A^i = A^h$). The value of θ is taken as given for the time being, but it will be made endogenous shortly as a result of a profit-oriented innovation activity. θ can also be naturally interpreted as an index of the intensity in unskilled labor of the aggregate production structure, and therefore of the strength of the relative labor demand. Hence, the aggregate production function (1) can also be represented as

$$Y = \int_0^\theta A^l x^\alpha (i)\, di + \int_\theta^1 A^h x^\alpha (i)\, di. \tag{2}$$

In absence of innovation, all intermediate goods are sold at the competitive price equal to the respective marginal productivity of labor. Let N and L indicate respectively the measure of the set of all workers of the set of

[7] The presence of a fixed factor of producion with supply normalized to unity is implicit in (1). In what follows, I will ignore completely this factor, asssuming that is owned entirely by foreigners "rentiers".

the unskilled. It is clear that skilled and unskilled labor shall be allocated symmetrically across sectors of production, so that $x(i) = \frac{L}{\theta}$ if $i \in [0, \theta]$ and $x(i) = \frac{N-L}{1-\theta}$ if $i \in (\theta, 1)$.[8] Hence, the wage rate rewarding unskilled labor will be equal to

$$w^u(L;\theta) = \alpha A^l \left(\frac{L}{\theta}\right)^{\alpha-1} \tag{3}$$

and the wage rate rewarding skilled labor will read

$$w^s(L;\theta) = \alpha A^h \left(\frac{N-L}{1-\theta}\right)^{\alpha-1} \phi. \tag{4}$$

Because of diminishing marginal returns, the unskilled (skilled) wage rate increases as the number of sectors adopting the technology complementing raw labor (human capital) increases.

Obviously, variations of the endowments of skilled and unskilled labor, which must always be equal in absolute value because of the normalization of the population size, generate, for a given value of θ, variations in factors prices of opposite sign. Thus, for instance, as L decreases, the skill premium $\sigma \equiv \frac{w^s}{w^u}$ decreases. But again, this is a result which holds for a stationary aggregate production technology. We will see shortly that when a variation of the relative endowment of the two labor types triggers a variation of θ, the picture can change radically.

2.2 R&D and Technological Change

To start with, all sectors of production operate with the low productivity, skills neutral technology (hence $\theta_0 = 1$) which is given and characterizes the status quo production structure of the economy.

A new technology is introduced in those sectors where an innovator performs the required R&D activity. This can either be interpreted as directed to the implementation at the sectoral level of a unique General Purpose Technology (e.g. computers and other IT devices) or to the invention of a new technology specific for the manufacturing of an intermediate good. In

[8] I have implicitly assumed that workers are perfectly segregated in relation to their human capital endowment. In principle, this needs not to be true. However, I do restrict the attention to a parametrization of the model such that γ is high enough to let this be the case whenever $\theta \in [0, 1)$. If $\theta = 1$, all workers are employed in old technology firms and the pair of wages reads $w^u(N;1) = \alpha A^l (N)^{\alpha-1}$ and $w^s(N;1) = \alpha A^l (N)^{\alpha-1} \phi$.

any case, innovation takes place in each sector at the most once, and the productivity level of all new technologies invented is standardized and equal to $\left(A^h\right)^{\frac{1}{\alpha}}$. Also, it is an activity intensive in skilled labor, and the workers who engage in it are drawn away from production.

At the aggregate level, technological progress can in principle take place on the full scale, but may turn out to be ultimately only partial (and at the limit not to occur at all). As we shall see more precisely shortly, the overall extent of the cross-sectoral technological upgrading will be determined by its joint interaction with human capital accumulation. The latter in fact makes R&D profitable, but is in turn affected by it as the wage structure, and thus the distribution of income and individual educational opportunities, may be radically altered by the spread of skills-non neutral innovations.

A given and fixed number of skilled workers, equal to F, is required for R&D to take place in one sector and be successful.[9] Innovators become local monopolists and acquire the right to set the price of the good manufactured by them.[10] I introduce the *ad hoc* assumption that monopoly rents last for one period only (in an infinite horizon-discrete time setup), say because the existing patent system grants only a limited degree of protection. After that, the rent is dissipated and the good is again priced competitively.

Facing the inverse demand schedule $p\left(x\left(i\right)\right) = \alpha A^h x^{\alpha-1}\left(i\right)$, and taking the level of the skilled wage rate as given, an innovator solves a profit-maximization problem formalized as

$$\max_{x(i)} \pi\left(x\left(i\right)\right) = \max_{x(i)} \alpha A^h x^{\alpha}\left(i\right) - w^s x\left(i\right).$$

As standard, the solution of this problem involves the charging of a price equal to a fixed mark-up over the variable cost of production and implies that the level of gross monopoly profits is equal to the familiar expression

[9] The diffusion of the high productivity technology across sectors corresponds to a form of "horizontal" innovation. So the R&D process has a form which combines elements of both the Aghion and Howitt (1992) and the Romer (1990) model.

Also, by assuming that R&D, if undertaken, is always successful I ignore the (Poisson) uncertainty which characterizes growth in the Aghion and Howitt model.

[10] I am assuming implicitly that innovations are "drastic" (i.e. bring about a substantial productivity improvement). Hence, each innovator drives off the market the incumbent producer charging the unconstrained monopoly price given that, at that price, the latter would make non positive profits if it remained active. In the appendix of the paper I describe under which condition this is actually true. Basically this involves the existence of an upper bound for the skill premium, and thus also constraint the extent of the wage inequality observable.

$$\pi = \frac{1-\alpha}{\alpha} x_n^s w^s$$

where $x^{s,n}$ is the symmetric equilibrium level of employment in a sector which has just experienced the replacement of the old technology.

Clearly, innovation will be profitable only as long as the resulting gross profits exceed the related R&D cost, namely as long as

$$\frac{1-\alpha}{\alpha} x^{s,n} w^s \geq F w^s \Longleftrightarrow x^* \equiv \frac{\alpha}{1-\alpha} F \leq x_n^s. \tag{5}$$

Since the right hand side of the last weak inequality is bounded from above by $N-L$, the economy will not experience any technological change as long as its endowment of skilled labor is not at least as large as $x^* \equiv \frac{\alpha}{1-\alpha} F$;[11] equivalently, the economy may experience innovation if

$$L \leq N - \frac{\alpha}{1-\alpha} F \tag{6}$$

x^* is increasing in F, quite obviously, and in α. The more elastic is the intermediate goods demand, the lower is, *ceteris paribus*, the rent appropriated by an innovator. Hence, the stronger will the market size effect have to be in order for R&D to be enough profitable.

This preliminary result highlights a first sense in which a critical interplay between the accumulation of human capital and technological progress characterizes this economy. A larger human capital endowment eventually triggers a spread of advanced technologies across sectors of production, by means of a market size effect. When there are enough skilled workers around R&D becomes profitable since firms can earn enough monopoly rents out of it to cover the implied costs and earn non negative profits.

Two other things are noteworthy in (6). First of all, the skilled wage does not appear in it, and is therefore irrelevant in determining whether or not innovation will take place. But also the productivity index A^h does not appear in (6). Hence, an economy may remain stuck with a relatively

[11] A very similar threshold is derived in Matsuyama (1999), where the market size effect refers however to the resources base of the economy in terms of output. Sorensen (1999) demonstrates that R&D is not performed in a model of endogenous technological change and endogenous human capital accumulation until the stock of the latter is not large enough. However, that paper considers skills neutral innovation and ignores the interplay between growth and changes in the wage structure, which is the focus of mine.

obsolete aggregate production structure no matter how high the potential productivity gains from innovation could be, simply because of poverty of human capital.

2.2.1 When Does R&D Take Place?

(6) is only a necessary, but *not* sufficient condition for innovation to take place, as the subsequent analysis shows.

Let's start by assuming that some R&D does indeed take place in the economy at some point in time. By virtue of the free entry condition usually postulated, the pure profits accruing to innovators will be driven down to zero, which means that in equilibrium the weak inequality (6) will hold as equality, so that $x^{s,n} = \frac{\alpha}{1-\alpha}F$. Also, the wage rate earned by the skilled will have to be equal across both old and new skilled labor intensive sectors of production, which means that $\alpha A^h \left(x^{s,o}\right)^{\alpha-1} = \alpha^2 A^h \left(x^{s,n}\right)^{\alpha-1}$. Hence, $x^{s,o} = \frac{\beta}{1-\alpha}F$, with $\beta \equiv \alpha^{\frac{\alpha}{\alpha-1}} > 1$. In order to ensure the existence of an equilibrium with R&D, I impose the following parametric restriction.

Assumption 1 $\frac{\beta}{1-\alpha}F < N$.

Notice that $x^{s,o} > x^{s,n}$. The demand for labor of innovating sectors is, for any value of the wage rate, lower (due to monopoly pricing distortions) than that coming from sectors which had innovated before. Hence, employment in the former sectors must be lower in equilibrium for the wage arbitrage condition to hold.

At this point, some more notation and an explicit time index are useful to introduce. Let Δ_t indicate the (endogenous, and possibly equal to zero) measure of the set of sectors which experience technological progress at time t and let $\Omega_t \equiv \{s \in (0,t] : \Delta_s > 0\}$.

If $t \in \Omega_t$ the *total* number of skilled workers employed in manufacturing can be decomposed into the number of them employed in sectors having previously experienced innovation ($i \in (\theta_{t-1}, 1]$), or

$$X_t^{s,o} \equiv (1-\theta_{t-1})\, x^{s,o} = (1-\theta_{t-1})\, \frac{\beta}{1-\alpha}F$$

and into the number of them employed in sectors where innovation takes place at t, which is equal to

$$X_t^{s,n} \equiv \Delta_t x^{s,n} = \Delta_t \frac{\alpha}{1-\alpha} F.$$

Finally, the number of skilled workers employed in R&D is determined residually as $X_t^{s,r} = N - L_t - (X_t^{s,o} + X_t^{s,n})$. Since it takes F skilled workers to innovate in one sector, $X_t^{s,r} = \Delta_t F$; thus the measure of the set of sectors which will benefit from a productivity improvement, as a function of the state variables θ and L, will be equal to

$$\Delta_t\left(\theta_{t-1}, L_t\right) = \max\left\{0, \min\left\{(1-\alpha)\frac{N-L_t}{F} - \left(1-\theta_{t-1}\right)\beta, \theta_{t-1}\right\}\right\}. \quad (7)$$

Combining expressions (7) and (6), we can state the necessary and sufficient condition for having some R&D in equilibrium.

Proposition 1 *(Necessary and sufficient condition for R&D to take place at time t)*

$$\Delta_t\left(\theta_{t-1}, L_t\right) > 0 \Longleftrightarrow N - L_t > \frac{F}{1-\alpha}\max\left\{\alpha, \left(1-\theta_{t-1}\right)\beta\right\}.$$

In essence, proposition 1 tells us that a positive level of R&D is sustainable at t provided that the stock of skilled labor available at that time is sufficiently large relatively to the measure of the set sectors implementing the advanced technology at time $t-1$. If that is not the case, all of the stock of skilled labor is employed in manufacturing. This is basically a consequence of the indivisibility which characterizes R&D. If the demand for skilled labor coming from manufacturing is sufficiently strong relative to its supply, the point-in-time equilibrium features no innovation.

Proposition 1 has an important corollary which provides a first characterization of the dynamic linkage between technological change and human capital accumulation.

Corollary 1 (Technological Change versus Human Capital Race).

If $\Delta_t \in (0, \theta_{t-1})$ *and* $\frac{L_t - L_{t+1}}{\Delta_t} > C$, *where* C *is some constant, then* $\Delta_{t+1} = 0$.

Proof. See Appendix. ■

Corollary 1 gives us a more precise idea of the critical interplay present in this economy between the accumulation of human capital and (skilled biased) technological progress. A wave of innovations is induced by a critical increment of the aggregate stock of human capital. When this happens, the relatively inefficient, unskilled labor intensive technology is abandoned in a continuum of positive measure of sectors. In turn, holding constant the human capital endowment, innovation cannot continue in the future (assuming that it has not yet exhausted already the array of its potential "targets") because of the resulting *shortage* of human capital supply, relatively to the needs of *new* aggregate production structure. That is, to the higher new level of demand for skilled labor coming from the greater number of sectors or intermediate good producers adopting technologies complementing human capital. This higher level of demand absorbs the existing mass of skilled workers entirely, and leaves none of them for more R&D. The indivisibility characterizing the R&D process imply that a new spread of innovations is possible only provided that the number of skilled workers increases in parallel (and sufficiently) to the upgrading of the aggregate production structure.

In this sense, the model features a technology-human capital race: for economic growth to be a self-sustained process, the two of them, technological progress and human capital accumulation, must proceed together, "hand in hand". Otherwise, if any of the two fails to keep up with the other, the virtuous circle stops working.[12]

2.2.2 The Impact of Innovation on the Wage Structure

In this economy, the distributive effects of technological change will be crucial for their static and dynamic implications. We can start assessing them by analyzing how the wage structure changes as R&D takes place in some sectors. Since the set of sectors still adopting technologies intensive in unskilled labor at time $t \in \Omega_t$ has a measure of $\theta_t = \theta_{t-1} - \Delta_t$, the pair of wages at that time reads

$$w_t^u = \alpha A^l \left(\frac{L_t}{\theta_{t-1} - \Delta_t} \right)^{\alpha - 1} \tag{8}$$

[12] The concept of "education-technology race" was first introduced by Tinbergen (1975).Yet, while in Tinbergen (see pp.154-5) education acts as the inequality depressing agent while technological change acts as the inequality boosting agent, in my model to role of the two of them cannot be separated in these terms, as it will be more clear in the following.

and

$$w_t^s = \alpha A^h \left(\frac{\beta}{1-\alpha} F \right)^{\alpha-1} \phi. \tag{9}$$

Notice that the skilled wage is indeed equal to a (identical) constant whenever there is innovation, while the unskilled wage depends on L and θ.

A straightforward comparison of (3) with (9) and of (4) with (10) reveals that

$$w_t^s > w_{t-1}^s \Longleftrightarrow F < \frac{1-\alpha}{\beta} \frac{N - L_{t-1}}{1-\theta_{t-1}} \qquad \text{if } t-1 \notin \Omega_{t-1} \tag{10}$$

$$w_t^s = w_{t-1}^s \qquad \text{if } t-1 \in \Omega_{t-1} \tag{11}$$

$$w_t^u < w_{t-1}^u \Longleftrightarrow F < (1-\alpha) \frac{N - L_t}{\frac{L_{t-1} - L_t}{L_{t-1}} \theta_{t-1} + (1-\theta_{t-1}) \beta}. \tag{12}$$

The next proposition summarizes the most interesting implication of these last results.

Proposition 2 *If* $t \in \Omega_t$, $t-1 \notin \Omega_{t-1}$ *and*

$$F < \min \left\{ \frac{1-\alpha}{\beta} \frac{N - L_{t-1}}{1-\theta_{t-1}}, (1-\alpha) \frac{N - L_t}{\frac{L_{t-1} - L_t}{L_{t-1}} \theta_{t-1} + (1-\theta_{t-1}) \beta} \right\}$$

skilled wages increase and unskilled wages falls, both in absolute terms as: (i) the endowment of skilled labor increases; (ii) the endowment of unskilled labor decreases by the same amount; (iii) skilled biased technological progress takes place in some sectors using low productivity, unskilled labor intensive technologies.

While the number of unskilled workers shrinks ("shortage effect") whenever $\Delta > 0$, the number of sectors hiring them also does so ("compression effect"); which of the two effects will prevail will depend on which variation will be proportionally higher. It turns out that, if F is relatively small, the demand for unskilled labor falls proportionally more than its supply does: as a result, the number of unskilled per sector actually increases. Diminishing marginal returns make up for the rest. Under a similar condition, the demand for skilled labor increases proportionally more than its supply does and, as a result, the skilled wage raises.

On top of this, the unskilled wage (next result) is always increasing at the margin in L. Conditionally on technological change taking place, unskilled wages are higher the *more* workers remain uneducated. This result reflects the fact that at the margin, over the range consistent with positive R&D, the compression effect always dominates over the shortage effect. Similarly, skilled wages increase at the margin at time $t+1$ with the number of skilled workers at t if $\Delta_t > 0$ and $\Delta_{t+1} = 0$.

Result 1 *(i) If $t \in \Omega_t$, the inequality $\partial w_t^u / \partial L_t \geq 0$ is true for any value of θ_{t-1} and of L_t. (ii) If $t \in \Omega_t$ and $t+1 \notin \Omega_{t+1}$, the inequality $\partial w_{t+1}^s / \partial L_t \leq 0$ is also identically true.*

Proof. See Appendix. ■

Notice however that none of the two inequalities (11) and (12) needs to hold a priori. Therefore, it is in principle possible that unskilled wages may *increase* and that the skill premium may *decrease* as some sectors adopt more efficient, skilled biased technologies. In other words, it is *not* a general result that skilled biased technological change as such causes a (relative or absolute) reduction of the earnings of the unskilled. Its effects on the wage structure depend on the composition between the labor shortage effect and the compression effect. Which of them will prevail is a priori ambiguous and depends ultimately on the balance between demand and supply forces.[13]

Proposition 2 (coupled with corollary 1) has an important implication for the dynamics of wage inequality, which is expressed next. Suppose that the aggregate supply of human capital is (weakly) increasing over time (as it will be the case indeed) and suppose that at time $t+1$ the economy has

[13] Acemoglu (1998) derives a result of similar flavor, through a completely different mechanism. In his model, skilled and unskilled labor are complementary factors of production in a CES technology. The effect of a variation of the relative supply of them on wages depends in that setup on the value of the elasticity of factors substitution. Depending on the value of this parameter, the skill premium can either fall or increase as the relative endowment of skilled labor increases. A second difference between my theory and Acemoglu's one is that I also do derive implications for the behavior of the absolute level of wages, rather then for the skill premium only.

not yet adopted the new technology completely. Then, we can remark the following implication of the model.

Result 2 *If $t \in \Omega_t$ and $t+1 \notin \Omega_{t+1}$ inequality, as measured by the skill premium, falls between time t and time $t+1$.*

Proof. See Appendix. ■

Since no R&D is performed at $t+1$, and since R&D is intensive in skilled labor, the aggregate demand for the latter falls, and so does the relative wage.[14] However, this does not mean that the unskilled wage will have to increase (in fact it may well remain constant), and more generally that the reduction in inequality observed at a point in time should signal the convergence to an egalitarian steady state.[15] The model is indeed perfectly consistent with a transitional dynamics featuring a progressive (or at least a cyclical) *reduction* of wage inequality but nonetheless converging to a polarized long run configuration (an example will be given in next section).

Finally, we can state one last result concerning the existence of a limit to the extent of wage inequality possibly observable in the economy.

Result 3 *As long as $L > 0$, the adoption of the new technology is only partial and the skill premium is bounded from above by a finite constant which increases with γ.*

Proof. See Appendix. ■

Basically, this result tells us that the potential impact of technological progress on wage inequality is in some way limited. In particular, it tells us that an extreme outcome such as the full scale adoption of the new technology, in absence of the acquisition of human capital by *all* households, is not possible in this economy. If that was the case, the unskilled wage would be zero,[16] and therefore the skill premium would be infinite. This cannot occur however as the skill premium is necessarily bounded from above. The existence of such upper bound is determined by the fact that, as the unskilled

[14] The possibility of observing a cyclical dynamics in wage inequality arises also in Galor and Tsiddon (1997) model. The mechanics driving my and of their result is indeed formally quite similar. However, while they do postulate that their productivity index is a piecewise constant function of the average level of human capital of the economy (which "jumps" infrequently) I derive a similar proposition as an equilibrium outcome.

[15] Thus one can argue that the reduction in inequality observed by some over the last few years is not necessarily a piece of evidence against the two-tiers society hypothesis.

[16] It is clear from equation (6) that, as long as $L > 0$, $\lim_{\theta \to 0} w^u(L, \theta) = 0$.

wage approaches an arbitrarily low value, it is always more profitable to use the unskilled labor intensive technology in some sectors of production. Therefore there is no incentive to perform any R&D beyond some point and the unskilled wage cannot fall "too much" in turn. In other words, in this economy the magnitude of wage inequality is constrained by profitability incentives. Such upper bound increases with γ: the higher is productivity improvement brought about by innovation, the higher is the degree of "admissible" inequality.

I turn now to the precise description of the intertemporal structure of the economy, of households' preferences and to the derivation of the human capital accumulation under credit market imperfections, following in part closely Galor and Zeira (1993).

3 Setup and Preferences

The economy has an overlapping generation (OLG) structure and an infinite duration. It is small and open and agents can lend money in an international capital market at a given interest rate $R > 0$. They cannot borrow however, because of some imperfection existing in the credit market.[17] The economy is populated by a continuum of measure N of dynasties, indexed by $i \in [0, N]$. Individuals live for two periods. In the first period of life, the young age, they may get educated (acquire human capital) and in the second period, the adult age, they work and generate a unique child.[18] Hence there is no population growth and every new cohort is also made up by a measure N continuum of agents. For simplicity again, and with no loss of generality, consumption takes place during the second period of life only, the adult age. Agents also draw utility, in the second period of life, from a bequest left to their child.[19]

Without loss of generality, the generation that is adult at time 0 is assumed to be made up entirely by unskilled workers.

[17] A variety of stories could be provided to justify the existence of this market imperfection, which essentially does not enable agents to borrow against their future income. The risk of debt repudiation or incentives problems in the guise of moral hazard of the borrower are only some of them. Since the assumption is completely standard, I will no go any further in accounting for its microfoundation in terms of first principles.

[18] The generation that is old at time 0 is assumed with no loss of generality to be made up entirely by uneducated workers.

[19] That is, intergenerational altruism is of the "warm glow type", rather then pure dynastic à la Barro.

Assuming separability of preferences and log utility, and letting $\delta \in (0,1)$ index the relative importance of consumption and bequest in individual welfare, the optimization problem of the member of dynasty i born at time t is formalized as

$$\max_{e_t^i, c_{t+1}^i, b_{t+1}^i} u\left(c_{t+1}^i, b_{t+1}^i\right) = \delta \ln\left(c_{t+1}^i\right) + (1-\delta) \ln\left(b_{t+1}^i\right)$$

s.t.

$$c_{t+1}^i + b_{t+1}^i \leq \left(a_{t+1}^i + w_{t+1}^i\right)$$

$$a_{t+1}^i = R\left(b_t^i - e_t^i d_t^i\right) \tag{13}$$

$$a_{t+1}^i \geq 0 \tag{14}$$

$$a_0^i \geq 0 \; given \tag{15}$$

$$w_0^i = w_0^u, \; \forall \; i \tag{16}$$

where d indicates the (constant across time and dynasties) cost of education acquisition in units of income and e is a dichotomous variable assuming the value of 1 if the agent invest in education and of 0 otherwise so that

$$w_{t+1}^i = \begin{cases} w_{t+1}^s \text{ if } e_t^i = 1 \\ w_{t+1}^u \text{ if } e_t^i = 0 \end{cases}$$

Notice that, as households cannot borrow, their stock of assets is constrained to be always non negative (14). (15) reflects the assumption that all dynasties start out with an exogenously given wealth endowment, which is initially distributed across them over the interval $\left[0, \bar{a}_0\right]$ according to a given measure function μ_0 so that

$$\frac{1}{N} \int_{\left\{0 \, \leq \, a \, \leq \, \bar{a}_0\right\}} \mu_0\left(da\right) = 1.$$

Lastly, (16) formalizes the assumption that all the workers who are adult at time 0 are unskilled.

The optimization problem solved by households can be broken down in two pieces: first maximizing lifetime income (i.e. making the optimal career choice) and then maximizing utility given income. The second part of the problem has the straightforward solution

$$c_{t+1}^{i}=\delta\left(a_{t+1}^{i}+w_{t+1}^{i}\right) \tag{17}$$

$$b_{t+1}^{i}=(1-\delta)\left(a_{t+1}^{i}+w_{t+1}^{i}\right). \tag{18}$$

The first part of the problem, income maximization, consists in the optimal allocation of the inheritance between savings and educational expenditures and is in fact a non-convex decision. A (credit unconstrained) worker will invest in education provided that the net return, the skilled versus unskilled wage differential, exceeds the cost of human capital acquisition, or if

$$\frac{w_{t+1}^{s}-w_{t+1}^{u}}{R}\geq d. \tag{19}$$

4 Dynamics of the Wealth and Skills Distribution

The dynamic equation describing the evolution of dynasty's i assets and bequests can be obtained by combining equations (14) and (18); they read

$$a_{t+1}^{i}=R\left((1-\delta)\left(a_{t}^{i}+w_{t}^{i}\right)-e_{t}^{i}d_{t}\right) \tag{20}$$

$$b_{t+1}^{i}=(1-\delta)R\left(b_{t}^{i}-e_{t}^{i}d_{t}\right)+(1-\delta)w_{t+1}^{i}. \tag{21}$$

The following set of parametric restrictions is imposed.

Assumption 2 $a^{*}\equiv\left(\frac{d}{1-\delta}-w_{0}^{u}\right)$ *is such that* $\mu_{0}\left((0,a^{*}]\right)>0$.

Assumption 3 $(1-\delta)R<1$.

Assumption 2 ensures the existence of a set of strictly positive measure of dynasties which are credit constrained at time zero (that is, the children of some adults at time zero cannot invest in education). Assumption 3 ensures that the wealth of, and bequest passed by, each dynasty converges to a finite long run level (the first order difference equations (20) and (21) have a stable equilibrium).

It would not be possible to describe analytically the dynamics of the model for a generic initial distribution of wealth. Thus, I choose to focus on one simple case, of which an explicit analysis is possible. This example I provide is intended to show how the impact of skilled biased technological change on the wage structure may cause inequality to persist in the long run in an economy where, if technology remained stationary, the latter would have vanished in steady state.

4.1 Example: a Three Classes Economy

I consider the case of an economy with an initial wealth distribution concentrated in three mass-points, corresponding to the endowments of three social classes: the poor, the middle class and the rich. Let P, M and W indicate the measure of the three classes respectively as of time 0 and a_0^p, a_0^m and a_0^r denote their respective initial wealth. I assume that the both the poor and the middle class are not *initially* rich enough to invest in education while the rich are so and that $W < x^* < M + W$. That is, there are not enough rich at time zero to fuel alone any technological change but the rich and the middle class combined (if educated) could do so. Also, I assume if the wage structure remained stationary, every dynasty would eventually afford to invest in education.[20]

It will be apparent from the subsequent analysis that the following restriction is sufficient to guarantee that it is always efficient (that is, for any equilibrium wage structure) for workers to invest in education in this economy

$$\frac{(\phi - 1)\, w_0^u}{R} > d. \tag{22}$$

The economy experiences basically two different growth regimes.

[20] Formally, this is so if the asymptotic level of bequest corresponding to the initial unskilled wage exceeds the education cost, of if

$$\frac{(1-\delta)\, w_0^u}{1-(1-\delta)\, R} > d$$

which I assume to be the case.

4.1.1 Regime I

The economy operates initially with a stationary aggregate production technology. It goes through a first growth phase which is in essence based only on the dynastic accumulation of assets and on the acquisition of human capital by the rich alone. This initial regime stops when the middle class has become rich enough to invest in education, namely at the (first) time $T+1$ such that $M+W \geq \int_{\{a^* \leq a\}} \mu_T(da) \geq x^*$. As long as that does not happen, wage inequality does non vary (the skill premium remains equal to ϕ).

4.1.2 Regime II

The economy enters in its second growth regime once the middle class has accumulated enough assets to invest in education. When this happens, a technological revolution starts taking place across sectors of production. We can then distinguish between two different types of medium-long run outcomes.

(1) The diffusion of the advanced technology is complete if the poor are themselves rich enough to invest in education at time $T+1$, or if $N = \int_{\{a^* \leq a\}} \mu_T(da)$. In this case, the old technology is completely dropped-off once and forever. To see this, notice first of all from (7) that $\lim_{L \to 0} \Delta(\theta, L) = \theta$: if all workers acquire education, the aggregate production structure can benefit of the full scale adoption of new technology. And therefore all workers do earn a salary equal to $w^s_{T+1} = \alpha A^h N^{\alpha-1} \phi > \alpha A^l N^{\alpha-1} \phi$. This is the unique equilibrium of the model. In fact, if one individual worker deviated from it, he would earn an unskilled salary equal to zero (since he would be unemployed) and this would not clearly be profitable. Conversely, as long as (22) holds, each worker will strictly prefer to invest in education anyway rather than remaining uneducated.

Over time, the economy converges to a steady state where all dynasties have accumulated an identical stock of assets equal to the stationary equilibrium of the dynamic equation (20), or

$$a^s_\infty = \frac{(1-\delta) R}{1-(1-\delta) R} \alpha A^h N^{\alpha-1} \phi - \frac{d}{1-(1-\delta) R}.$$

Clearly, this event is more likely to happen the lower is the initial difference in the wealth endowment of the poor and of the middle class. The larger is such an initial gap, the more likely it is that the poor will remain behind the middle class when this affords to invest in education. In this sense, we recover in this economy a version of the proposition according to which "equality is good for growth".

(2) If the initial wealth gap between the poor and the middle class is indeed relatively large, the former will (at least temporarily) remain unable to invest in education, and will remain stuck in the residual unskilled labor intensive sectors, with technological change taking place at $T+1$ only partially (recall the point made in result 3, section 2). The production structure and the labor market of the economy assume then a segmented form, which reflects the skills heterogeneity among the workers. Notice that it is *always* the case the unskilled wage is lower at time $T+1$ then at time T since $\Delta_{T+1}(1,P) = (1-\alpha)\frac{N-P}{F}$ and

$$w^u(\theta_{T+1},P) = \alpha A^l \left(\frac{P}{1-\Delta_{T+1}(1,P)}\right)^{\alpha-1} < w^u(1,N) \Longleftrightarrow \frac{F}{1-\alpha} < N. \tag{23}$$

which is always true (by implication of assumption 1).

Since $L_{T+1} = L_{T+1+J} = P$ for some $J \geq 1$, corollary 1 of section 2 tells us that there will not be any innovation for some (possibly infinite) time after T. Whether J will be indeed finite of infinite will depend critically on the way the wage structure is affected by the first wave of technological progress. We can distinguish two sub-cases.

Proposition 3 $\exists$ *a positive constant* Γ *such that:*

(2i) *if* $P < \Gamma$*, initially poor dynasties remain credit constrained for ever;*

(2ii) *if* $P > \Gamma$*, within a finite time, initially poor dynasties can invest in education.*

Proof. See Appendix. ■

Basically, in case (2i) the wage loss suffered by the poor is so large not to enable (any of) them to ever invest in education. Their dynastic accumulation of assets converges to a long run level such that the corresponding bequest is lower than the cost of education. As a result, initially poor dynasties remain credit constrained and end up working as unskilled forever. And the distribution of wealth converges to the two-points ergodic distribution $\{P, M+W\}$ concentrated at

$$a_{\infty}^{u}=\frac{(1-\delta)\,R}{1-(1-\delta)\,R}\alpha A^{l}\left(\frac{P}{1-\Delta}\right)^{\alpha-1}-\frac{d}{1-(1-\delta)\,R}$$

$$a_{\infty}^{s}=\frac{(1-\delta)\,R}{1-(1-\delta)\,R}\alpha A^{h}\left(\frac{M+W}{\Delta}\right)^{\alpha-1}\phi-\frac{d}{1-(1-\delta)\,R}.$$

Notice that the skill premium falls between $T+1$ and $T+2$ ($\sigma_{T+2} < \sigma_{T+1}$), remaining constant thereafter. This is so as no innovation takes place at $T+2$, and therefore the demand for skilled labor is lower. Therefore, the fall in wage inequality that the economy experiences is a purely transitory event and inequality persists in the long run. In case ($2ii$) instead, the wage loss of the poor is not strong enough to impede to the process of dynastic accumulation of assets to go far enough to allow at some point all workers to acquire education. If that ever happens, the long run configuration of the economy is identical to the one obtaining in case (1), since it is clear that the unique (static) equilibrium of the economy will involve the acquisition of education by everybody. Crucially, inequality persists in the long run if the poor are relatively *few* to start with. Indeed, we know already that the compression effect always dominates at the margin over the shortage effect (result 1), and therefore the wage loss suffered by the poor is in general equilibrium actually higher the less they are, despite the diminishing marginal returns technology.

In sum, we conclude that the form of the initial distribution of wealth plays a key role in shaping the long run behavior of the economy, when technological progress does ever take place. It does so by influencing the timing and extent of technological change. Two conditions seem to make the event of persistence of inequality more likely to occur. The poor must be sufficiently below the middle class in terms of initial wealth (likelihood of being in case (2)) and they must be relatively few (likelihood of being in subcase ($2i$)). In other words, holding constant the average aggregate initial level of wealth, an economy starting with a relatively small number of very poor dynasties, seems more likely to converge to a dual long run configuration where both old and new technologies coexist and where only a fraction of the workers are educated.

5 Discussion

Standard human capital theory predicts that a higher skill premium, whatever its cause, should unambiguously trigger a higher spread of education at the aggregate level. Moreover, the higher skill premium should itself be expected to fall over time due to the resulting process of quantity adjustment. Finally, along with the skill premium, the associated inequality of earnings across the skills spectrum should also be expected to revert to the mean. The core message of this paper appears to be in sharp contrast with this conventional wisdom. In particular, the paper argues that such wisdom may be incorrect if two key conditions are met: (i) credit markets are imperfect, and (ii) unskilled wages fall in absolute terms relative to skilled wages (so that the skill premium is actually higher for two parallel reasons) as a result of technological change.

Given the dramatic transformations in the wage structure induced by skilled biased technological change over the past thirty years, and in particular the substantial absolute fall of the earnings of a large fraction of the population, it is not unreasonable to speculate that the ability of many households to undertake costly human capital investments must have sharply deteriorated. In other words, the high skill premia granted by skill biased technologies may not generate the boom in human capital investments they should in a world with perfect credit markets, because of the pauperizing effect played by the same technologies on the earnings of a relatively large fraction of the population. In turn, inequality may also not be expected to revert to the mean following a major diffusion of skilled biased technologies.

A number of recent empirical contributions provide evidence consistent with the main message of this paper. In particular, Acemoglu and Pishcke (2000) document the existence of a substantial income elasticity in households educational investments.[21] For example, they document that in the U.S. over the period $1982-1992$ the rate of enrollment in four-year college programs has increased sensibly only for the households in the fourth quartile of the distribution of income. But the same has remained roughly constant over the same period for the households in the first and second quartile. Interestingly, they also find that even relatively rich households may not have been completely immune to credit constraints, thus providing important evidence in favor of the main hypothesis of this paper. Since their results are based on U.S. data and since the U.S. are normally thought to

[21] Partly different conclusions have been however obtained by other recent empirical investigations of the relevance of credit constraints such as the paper of Shea (2000).

have the most efficient credit market of the world, their results should a fortiori be corroborated across countries as well.

One other piece of evidence not inconsistent with the conclusions of my model is provided by Card and Lemieux (2000), who document a substantial slowdown in the rate of growth of educational attainments in post-1950 U.S. cohorts, in spite of the high skilled premia of the 1980's and 1990's.

6 On Redistribution, Education and The Rise of Fiscal Conservatism

The 1980's and 1990's have seen not only a spectacular rise of wage inequality but also a parallel fall in the extent of the fiscal redistribution of resources promoted by the governments of many advanced economies. This second trend stands obviously in sharp contrast with the opposite one toward welfare state expansion observed over the 1960's and 1970's. At a first sight, the two parallel processes may perhaps appear as difficult to be explained jointly in the light of the conventional, median-voter based theory of public decision making in a democracy. Yet, this impression is not correct. As Saint-Paul and Verdier (1996) and Saint-Paul (2001) convincingly argue, within such a framework it is *not* necessarily true that *any* mean preserving spread in the distribution of income will increase the political support for fiscal redistribution. In fact, what critically matters in this sense (if the median voter theorem is assumed as the benchmark) is the distance between the median and the mean income, rather than simply the absolute level of the former. If a higher overall inequality is primarily due to a pauperisation of the poor, it is perfectly possible that the median voter (or some other pivotal voter if the political system is biased in some way) may become *richer* relatively to the mean voter, and hence support less redistribution rather than more. While skilled biased technological change increases dramatically the importance of education, it may well also contribute to cut-down the political support for those redistributive public policies aimed, *inter alia*, to promote the accumulation of human capital among the poor. This can happen in our model if the critical voter at some point in time is thought to be the member of a dynasty which has afforded to invest in education, but is endowed with a relatively low wealth. If technological change affects the wage structure in a way such the skill premium increases enough, so that wage income becomes a sufficiently more important component of total income than financial wealth, such a pivotal voter may well decide to favor a lower degree of redistributive taxation than otherwise. In turn, to the extent that redistribution affects positively human capital accumulation (as it typically does when credit markets do not function properly), the fiscal conservatism of the median voter may in fact not allow relatively poor households to be ever able to escape an ultimate poverty trap. We can thus identify one other channel, represented by a change in the social attitude toward fiscal redistribution, through which skilled biased technological change could cause wage and income inequality to persist over time.

7 Conclusions

This paper has presented a model of growth through endogenous technological change, human capital and wealth accumulation in an environment where credit markets are imperfect. The key message of the paper is that the distribution of income in an economy can be critical both in allowing technological change to ever take place or not and both in shaping the extent of the diffusion of new technologies. If technological change is skilled biased and if credit markets are imperfect, its general equilibrium effects on the wage structure can be critical for the long run performance of the economy. These have been found to depend themselves on the distribution of income which determines how many workers can invest in education, and therefore affects the profitability of R&D. The earning loss suffered by the unskilled due to the skill bias of innovation, has been found to be actually higher the fewer are they. This looks as a quite striking result in the light of the assumption of diminishing marginal returns to labor. Basing on it, it has been argued that multiple long run configurations are possible depending on initial conditions. In particular, an economy where poverty is initially concentrated in relatively few dynasties of workers, is more likely to converge to a dual or polarized long run equilibrium, in terms of both technological diffusion and wealth distribution. Finally, the model predictions have been found to be consistent with some recent empirical contributions documenting a substantial income elasticity in households' educational expenditures.

8 Appendix

8.1 Drastic versus Non Drastic Innovations

Innovations are drastic (see also on this the appendix of ch. 2 of Aghion and Howitt (1998)) when an innovator can charge the unconstrained monopoly price and drive the incumbent producer out of the market. Aghion and Howitt demonstrate that this is so as long as γ exceeds a certain constant. In our economy things are somewhat more complicated as the old and the new technologies use different types of labor, and therefore are associated to cost functions that depend on different wages.

Let $C^i(w^u, Y(i))$ indicate the cost of purchasing $Y(i)$ units of the intermediate good i manufactured with the low productivity technology; since $Y(i) = A^l x^\alpha(i)$, it is the case that

$$C^i(w^u, Y(i)) = w^u x(i) = w^u \left(\frac{Y(i)}{A^l}\right)^{\frac{1}{\alpha}}.$$

Vice versa, the cost of producing $Y(i)$ units of intermediate good i manufactured with the new technology if the unconstrained monopoly price ($p(i) = \frac{w^s}{\alpha}$) is charged reads

$$C^i(p(i), Y(i)) = p(i)\, x(i) = \frac{w^s}{\alpha}\left(\frac{Y(i)}{A^h}\right)^{\frac{1}{\alpha}}. \tag{24}$$

Hence, the innovator of sector i technology will be able to drive the incumbent off the market charging the unconstrained monopoly price if

$$C^i(w^u, Y(i)) \geq C^i(p(i), Y(i)) \Longleftrightarrow \gamma \geq \alpha^{-\alpha}\left(\frac{w^s}{w^u}\right)^{\alpha} \Longleftrightarrow \frac{w^s}{w^u} \leq \gamma^{\frac{1}{\alpha}}\alpha. \tag{25}$$

The difference between (25) and the corresponding condition derived by Aghion and Howitt is that the skill premium now matters in determining whether an innovation is drastic or not. Since the left hand side of (25) does not depend on γ, the condition will hold (as long as $w^u \neq 0$) for some γ large enough, which I assume to be always the case in equilibrium. Notice that if (25) did not hold, the innovator would charge the highest price allowing it to drive the incumbent off the market and serve alone all the demand. Namely the price $\overline{p} = \gamma^{\frac{1}{\alpha}} w^u$ which is such that $C^i(w^u, Y(i)) = C^i(\overline{p}, Y(i))$. The free entry condition (6) would then assume the form

$$F = \left(\gamma^{\frac{1}{\alpha}} \frac{w^u}{w^s} - 1\right) x_n^s \tag{26}$$

which again imposes a restriction in terms of an upper bound for the skill premium, for any value of x_n^s. The bottom-line remains thus unchanged: wage inequality is constrained by the profitability of different technologies.

8.2 Proof of Corollary 1

Let's assume that $\Delta_{t+1}(\theta_t, L_{t+1}) > 0$. Then

$$\begin{aligned}
\Delta_{t+1} &= (1-\alpha)\frac{N - L_{t+1}}{F} - (1 - \theta_{t-1} + \Delta_t)\beta \\
&= (1-\beta)\Delta_t + (1-\alpha)\frac{L_t - L_{t+1}}{F}.
\end{aligned}$$

Hence,

$$\Delta_{t+1}(\theta_t, L_{t+1}) > 0 \Longleftrightarrow \frac{L_t - L_{t+1}}{\Delta_t(\theta_{t-1}, L_t)} > C$$

with $C \equiv \left(\frac{1-\beta}{1-\alpha} F\right)$.

8.3 Proof of Result 1

(i):

$$\frac{\partial w^u}{\partial L} = \alpha(\alpha-1)A^l \left(\frac{L}{\theta - \Delta}\right)^{\alpha-2} \frac{\theta - (1-\alpha)\frac{N}{F} + (1-\theta)\beta}{(\theta-\Delta)^2} > 0$$

since, by virtue of assumption 1,

$$\beta - (1-\alpha)\frac{N}{F} \leq 0 \leq \theta(\beta - 1)$$

(ii):

$$\frac{\partial w^s}{\partial L} = (\alpha-1)A^h \left(\frac{N-L}{1-\theta+\Delta(\theta,L)}\right)^{\alpha-2} \frac{(1-\theta)(\beta-1)}{(1-\theta+\Delta(\theta,L))^2} < 0.$$

8.4 Proof of Result 2

By virtue of proposition 4, $\Delta_{t+1} = 0$. also $w_t^u \leq w_{t+1}^u$ since some children of unskilled can get educated while "downward mobility" is not possible in this economy. Since $\Delta_{t+1} = 0$, $w_{t+1}^s = \alpha A^h \left(\frac{N-L_{t+1}}{1-\theta_t+\Delta_t}\right)^{\alpha-1}$. Hence $w_{t+1}^s < w_t^s$ even if $L_{t+1} = L_t$ and so $\sigma_{t+1} < \sigma_t$.

8.5 Proof of Result 3

Suppose no. Then the unskilled wage would tend to zero, some workers being unskilled, and the skills premium would be infinite. As, a result, condition (25) (and (26) as well) would be violated.

8.6 Proof of Proposition 3

If the children of the poor at time T can never invest in education, the unskilled wage remains constant forever and equal to $w_{T+1}^u = \alpha A^l \left(\frac{P}{1-\Delta_T(P)}\right)^{\alpha-1}$. By result 1, this is known to be strictly decreasing in P. The long run level of bequest left by the poor-unskilled to their children converges to

$$b_\infty^u \left(\Delta_T \left(P\right), P\right) = \frac{\left(1-\delta\right) R}{1-\left(1-\delta\right) R} \alpha A^l \left(\frac{P}{1-\Delta_T \left(P\right)}\right)^{\alpha-1} \tag{27}$$

which must be strictly smaller than d. Let Γ be the unique solution to the equation $b_\infty^u \left(\Delta_T \left(P\right), P\right) = d$. Then $b_\infty^u \left(\Delta_T \left(P\right), P\right) < d$ whenever $P < \Gamma$. Conversely, if $P > \Gamma$, then in a finite time b^u will exceed d and therefore everyone will invest in education.

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