Growth with Quality-Improving Innovations: An Integrated Framework*

Philippe Aghion[†]and Peter Howitt[‡]

November 15, 2004

1 Introduction

Technological progress, the mainspring of long-run economic growth, comes from innovations that generate new products, processes and markets. Innovations in turn are the result of deliberate research and development activities that arise in the course of market competition. These Schumpeterian observations constitute the starting point of that branch of endogenous growth theory built on the metaphor of quality improvements, whose origins lie in the partial-equilibrium industrial-organization literature on patent races. Our own entry to that literature was the pre-publication version of chapter 10 of Tirole (1988).

We argued in Aghion and Howitt (1998) that by using Schumpeter's insights to develop a growth model with quality-improving innovations one can provide an integrated framework for understanding not only the macroeconomic structure of growth but also the many microeconomic issues regarding incentives, policies and institutions that interact with growth. Who gains from innovations, who loses and how much all depend on institutions and policies. By focusing on these influences in a model where entrepreneurs introduce new technologies that render previous technologies obsolete we hope to understand why those who would gain from growth prevail in some societies, while in others they are blocked by those who would lose.

In this chapter we show that the growth model with quality-improving innovations (also referred to as the "Schumpeterian" growth paradigm) is not only versatile but also simple and empirically useful. We illustrate its versatility by showing how it sheds light on such diverse issues as cross-country convergence, the effects of product-market competition on growth, and the interplay between growth and the process of institutional change. We illustrate its simplicity by building our analysis around an elementary discrete-time model. We illustrate its empirical usefulness by summarizing recent papers and studies that test

*Draft of chapter for the forthcoming Handbook of Economic Growth.

[†]Harvard University

[‡]Brown University

the microeconomic and macroeconomic implications of the framework and that address what might seem like empirically questionable aspects of the earliest prototype models in the literature.

The paper is organized as follows. Section 2 develops the basic framework. Section 3 uses it to analyze convergence and divergence patterns in the cross-country data. Section 4 analyses the interaction between growth and product market competition. Section 5 deals with the scale effect of growing population. Section 6 analyzes the interplay between institutional change and technological change, and section 7 provides some concluding remarks and suggestions for future research.

2 Basic framework

2.1 A toy version of the Aghion-Howitt model

Asked by colleagues to show them the simplest possible version of the quality-ladder model of endogenous growth which they could teach to second year undergraduate students, we came out with the following stripped-down version of Aghion-Howitt (1992).

Time is discrete, indexed by $t = 1, 2, ...$, and at each point in time there is a mass L of individuals, each endowed with one unit of skilled labor that she supplies inelastically. Each individual lives for one period and thus seeks to maximize her consumption at the end of her period.

Each period a final good is produced according to the Cobb-Douglas technology:

$$y = Ax^{\alpha}, \tag{1}$$

where x denotes the quantity of intermediate input used in final good production, and A is a productivity parameter that reflects the current quality of the intermediate good.

The intermediate good is itself produced using labor according to a simple one-for-one technology, with one unit of labor producing one unit of the current intermediate good. Thus x also denotes the amount of labor currently employed in manufacturing. But labor can also be employed in research to generate innovations.

Each innovation improves the quality of the intermediate input, from A to γA where $\gamma > 1$ measures the size of the innovation. Innovations result from research investment. More specifically, there is an innovator who, if she invests z units of labor in research, innovates with probability λz and thereby discover an improved version of the intermediate input.

The innovator enjoy monopoly power in the production of the intermediate good, but faces a competitive fringe who can produce a unit of the same intermediate good by using $\chi > 1$ units of labor instead of one. For $\chi < 1/\alpha$, this competitive fringe is binding which means that χw_t is the maximum price the innovator can charge without being driven out of the market. Her profit is thus equal to:

$$\pi_t = (\chi - 1) w_t x_t,$$

where $w_t x_t$ is the wage bill. This monopoly rent, however, is assumed to last for one period only, after which imitation allows other individuals to produce intermediate goods of the same quality.

The model is entirely described by two equations. The first is a *labor market clearing* equation, which states that at each period total labor supply L is equal to manufacturing labor demand x plus total research labor n, that is: $L = x_t + n_t$ for all t. The second is a *research arbitrage* equation which says that in equilibrium at any date t the amount of research undertaken by the innovator must equate the marginal cost of a unit of research labor with the expected marginal benefit. The marginal cost is just the manufacturing wage w_t. The expected benefit comes from raising the probability of success by $\lambda.1 = \lambda$, in which case she earns the monopoly profit π_t involved in producing the intermediate good for the final good sector. Thus the research arbitrage equation can be expressed as:

$$w_t = \lambda \gamma \pi_t. \qquad \text{(research arbitrage)}$$

where the factor γ on the right-hand side of the equation, simply stems from the fact that an innovation multiplies wages and profits by γ.

Using the fact that the allocation of labor between research and manufacturing, remains constant in steady-state, we can drop time subscripts. Then, substituting for π_t in the research arbitrage equation, dividing through by w, and using the labor market clearing equation to substitute for x, we obtain:

$$1 = \lambda \gamma (\chi - 1)(L - n)$$

which solves for the steady-state amount of research labor, namely:

$$n = L - \frac{1}{\lambda \gamma (\chi - 1)}.$$

The equilibrium expected rate of productivity growth in steady-state, is then simply given by:

$$g = \lambda n (\gamma - 1)$$

and it therefore depends upon the characteristics of the economic environment as described by the parameters λ, γ, χ, and L. In Section 2.3 below we interpret the comparative statics of growth with respect to all these parameters, and suggest preliminary policy conclusions.

The model is extremely simple, although at the cost of making some oversimplifying assumptions. In particular, we assumed only one intermediate sector, and that labor is the only input into research.. In the next sections we relax these two assumptions. We develop a slightly more elaborated version of the quality-ladder model that we then extend in several directions to capture important aspects of the growth and development process.

2.2 A generalization

There are three kinds of goods in the economy: a general-purpose good, a large number m of different specialized intermediate inputs, and labor. Time is discrete, indexed by $t = 1, 2, ...$, and there is a mass L of individuals, each endowed with one unit of skilled labor that she supplies inelastically.[1]

The general good is produced competitively using intermediate inputs and labor, according to the production function:

$$y_t = \left(\Sigma_1^m A_{it}^{1-\alpha} x_{it}^{\alpha}\right) (L/m)^{1-\alpha} \tag{2}$$

where each x_{it} is the flow of intermediate input i used at date t, and A_{it} is a productivity variable that measures the quality of the input. The general good is used in turn for consumption, research, and producing the intermediate inputs.

The expected growth rate of any given productivity variable A_{it} is:

$$g = E\left(A_{it}/A_{i,t-1}\right) - 1 \tag{3}$$

There is no i subscript on g because, as we shall see, all sectors are *ex ante* identical and hence will have the same productivity-growth rate. Likewise there is no t subscript because, as we shall also see, the system will go immediately to a constant steady-state expected growth rate.

Productivity growth in any sector i results from innovations, which create improved versions of that intermediate input. More precisely, each innovation at t multiplies the pre-existing productivity parameter $A_{i,t-1}$ of the best available input by a factor $\gamma > 1$. Innovations in turn result from research. If N_{it} units of the general good are invested at the beginning of the period, some individual can become the new "leading-edge" producer of the intermediate input with probability μ_{it}, where:[2]

$$\mu_{it} = \lambda f\left(n_{it}\right), \qquad f' > 0, f'' < 0, f\left(0\right) = 0,$$

and $n_{it} \equiv \frac{N_{it}}{\gamma A_{i,t-1}}$ is productivity-adjusted R&D expenditure in the sector. We divide by $\gamma A_{i,t-1}$, the targeted productivity parameter, to take into account the "fishing-out" effect - on average each quality improvement is harder to bring about than the previous one.

[1] The model we present here is a simplified discrete-time version of the Aghion-Howitt (1992) model of creative destruction, which draws upon Acemoglu-Aghion-Zilibotti (2002). Grossman and Helpman (1991) presented a variant of the framework in which the x's are final consumption goods and utility is log-linear. An early attempt at developing a Schumpeterian growth model with patent races in deterministic terms was presented by Segerstrom et al (1989). Corriveau (1991) developed an elegant discrete-time model of growth through cost-reducing innovations.

[2] More precisely, $f\left(n\right) = F\left(n, k\right)$ where k is some specialized research factor in fixed supply and F is a constant-returns function. Since there is free entry in research, the equilibrium price of k adjusts so that the expected profit of an R&D firm is zero. Since this price plays no role in the analysis of growth we suppress the explicit representation of k and deal only with the decreasing-returns function f. (Of course the constant-returns assumption can be valid only over some limited range of inputs, since F is bounded above by unity.)

Assume the time period is short enough that we may ignore the possibility of more than one successful innovator in the same sector. Then:

$$A_{it} = \left\{ \begin{array}{rl} \gamma A_{i,t-1} & \text{with probability } \lambda f\left(n_{it}\right) \\ A_{i,t-1} & \text{with probability } 1-\lambda f\left(n_{it}\right) \end{array} \right\} \tag{4}$$

According to (3) and (4) the expected productivity-growth rate in each sector can be expressed as the product of the frequency of innovations $\lambda f\left(n\right)$ and the incremental size of innovations $(\gamma - 1)$:

$$g = \lambda f\left(n\right)\left(\gamma - 1\right) \tag{5}$$

in an equilibrium where productivity-adjusted research is the same constant n in each sector. We assume moreover that the outcome of research in any one sector is statistically independent of the outcome in every other sector.

The model determines research n, and therefore the expected productivity-growth rate g, using a research arbitrage equation that equates the expected cost and benefit of research. The payoff to research in any sector i is the prospect of a monopoly rent π_{it} if the research succeeds in producing an innovation. This rent lasts for one period only, as all individuals can imitate the current technology next period. Hence the expected benefit from spending one unit on research is π_{it} times the marginal probability $\lambda f'\left(n\right)/\left(\gamma A_{i,t-1}\right)$:

$$1 = \lambda f'\left(n\right)\left(\pi_{it}/\left(\gamma A_{i,t-1}\right)\right)$$

To solve this equation for n we need to determine the productivity-adjusted monopoly rent π_{it}/A_{it} to a successful innovator. As before, we assume that this innovator can produce the leading-edge input at a constant marginal cost of one unit of the general good. But she faces a competitive fringe of imitators who can produce the same product at higher marginal cost χ, where $\chi \in (1, 1/\alpha)$[3] is an inverse measure of the degree of product market competition or imitation in the economy.[4]. Thus her monopoly rent is again equal to:

$$\pi_{it} = (p_{it} - 1)x_{it} = (\chi - 1)x_{it}. \tag{6}$$

A monopolist's output x_{it} will be the amount demanded by firms in the general sector when faced with the price χ; that is, the quantity such that χ equals the marginal product of the $i$the intermediate good in producing the general good:

$$\chi = \partial y_t/\partial x_{it} = \alpha\left(m x_{it}/A_{it}L\right)^{\alpha-1} \tag{7}$$

Hence:

$$\pi_{it} = \delta\left(\chi\right) A_{it}L/m \tag{8}$$

[3]It is easily verified that if there were no fringe then the unconstrained monopolist would charge a price equal to $1/\alpha$, but at that price the fringe could profitably undercut her because its unit cost is $\chi < 1/\alpha$.

[4]If no innovation occurs then some firm will produce, but with no cost advantage over the fringe because everyone is able to produce last period's intermediate input at a constant marginal cost of unity.

where

$$\delta(\chi) \equiv (\chi - 1)(\chi/\alpha)^{\frac{1}{\alpha-1}}, \; \delta'(\chi) > 0.$$[5]

Therefore we can write the research arbitrage equation, taking into account that $\gamma A_{i,t-1} = A_{it}$ because a monopolist is someone who has just innovated, as:

$$1 = \lambda f'(n)\, \delta(\chi)\, L/m \tag{9}$$

which we assume in this section has a positive solution.

The expected productivity growth rate is determined by substituting the solution of (9) into the growth equation (5). In the special case where the research-productivity function f takes the simple form:

$$f(n) = \sqrt{2n},$$

we have:

$$g = \lambda^2 \delta(\chi)(L/m)(\gamma - 1) \tag{10}$$

As it turns out, g is not only the expected growth rate of each sector's productivity parameter but also the approximate growth rate of the economy's per-capita GDP. This is because per-capita GDP is approximately proportional to the unweighted average of the sector-specific productivity parameters:[6]

$$A_t = \frac{1}{m} \sum_{i=1}^{m} A_{it}.$$

---

[5] To see that $\delta' > 0$ note that:

$$\chi \frac{d \ln(\delta(x))}{d\chi} = \frac{\chi}{\chi - 1} - \frac{1}{1-\alpha} > 0$$

where the last inequality follows from the assumption that $\chi < 1/\alpha$.

[6] To see this, note that GDP equals the sum of value added in the general sector and in the monopolized intermediate sectors. (There is no value added in the competitive intermediate sectors because their output is priced at the cost of the intermediate inputs. Also, we follow the standard national income accounting practice of ignoring the output (patents) of the research sector.) According to (7) the output of each monopolized sector ($i \in M_t$) at t is:

$$x_{it} = (\alpha/\chi)^{\frac{1}{1-\alpha}} (L/m) A_{it} \qquad (i \in M_t)$$

The output of each competitive sector ($i \in C_t$) at t is the amount demanded when its price is unity; setting $\chi = 1$ in (7) yields:

$$x_{it} = (\alpha)^{\frac{1}{1-\alpha}} (L/m) A_{it} \qquad (i \in C_t)$$

Substituting these into (2) and rearranging yields the following expression for per-capita GDP:

$$y_t/L = (\alpha/\chi)^{\frac{1}{1-\alpha}} \left(\frac{\#M_t}{m}\right)\left(\frac{1}{\#M_t} \sum_{i \in M_t} A_{it}\right) + \alpha^{\frac{1}{1-\alpha}} \left(\frac{\#C_t}{m}\right)\left(\frac{1}{\#C_t} \sum_{i \in C_t} A_{it}\right)$$

where $\#M_t$ is the number of monopolized sectors and $\#C_t$ the number of competitive sectors. By the law of large numbers, the fraction of sectors $\#M_t/m$ monopolized, i.e. the fraction in which there was an innovation at t, is approximately the probability of success in research in each sector: $\mu = \lambda f(n)$, and the fraction of sectors $\#C_t/m$ that are competitive is approximately $1 - \mu$. The average productivity parameter among monopolized sectors $\left(\frac{1}{\#M_t} \sum_{i \in M_t} A_{it}\right)$ is just γ times the average productivity parameter of those sectors last period; since innovations are spread randomly across sectors this is approximately γ times the average across all sectors last period: γA_{t-1}. Likewise the average productivity parameter

Since (a) all sectors have an expected growth rate of g, (b) the sectoral growth rates are statistically independent of each other and (c) there is a large number of them, therefore the law of large numbers implies that the average grows at approximately the same rate g as each component.

2.3 Alternative formulations

There are many other ways of formulating the basic model. We note two of them here for future reference. In the first one, as in the above toy model, the general good is used only for consumption, while skilled labor is the only factor used in producing intermediate products and research. The general good is produced by the intermediate inputs in combination with a specialized factor (for example unskilled labor) available in fixed supply. In this formulation, the growth equation is the same as (5) above, but with n being interpreted as the amount of skilled labor allocated to R&D. This version will be spelled out in somewhat more detail in section 5 below.

The other popular version is one with intersectoral spillovers, in which each innovation produces a new intermediate product in that sector embodying the maximum $\overline{A}_{t-1}$ of all productivity parameters of the last period, across all sectors, times some factor γ that depends on the flow of innovations in the whole economy. The idea here is that if a sector has been unlucky for a long time, while the rest of the economy has progressed, the technological progress elsewhere spills over into the innovation in this sector, resulting in a larger innovation than if the innovation had occurred many years ago. The model in section 3 below is a variant of this version.

2.4 Comparative statics on growth

Equation (10) delivers several comparative-statics results, each with important policy implications on how to "manage" the growth process:

1. Growth increases with the productivity of innovations λ and with the

across competitive sectors is the average across sectors that did not innovate, which is approximately A_{t-1}. Making these substitutions into the above expression for per-capita GDP yields:

$$y_t/L \simeq \left((\alpha/\chi)^{\frac{1}{1-\alpha}} \mu\gamma + \alpha^{\frac{1}{1-\alpha}} (1-\mu) \right) A_{t-1} \equiv \zeta A_{t-1}$$

Since labor is paid its marginal product in the general sector, the wage rate is:

$$w_t = \partial y_t / \partial L = (1-\alpha) y_t/L \simeq (1-\alpha) \zeta A_{t-1}$$

which is also per-capita value-added in the general sector. By similar reasoning, (8) implies that per-capita value added in monopolized intermediate sectors is:

$$(1/L) \sum_{i \in M_t} \delta(\chi) A_{it} L/m = \delta(\chi) \left(\frac{\# M_t}{m} \right) \left(\frac{1}{\# M_t} \sum_{i \in M_t} A_{it} \right) \simeq \delta(\chi) \mu\gamma A_{t-1}.$$

Therefore each component of per-capita GDP is approximately proportional to A_{t-1}. Since A_t grows at approximately the constant rate g thefore per-capita GDP is approximately proportional to A_t.

supply of skilled labor L: both results point to the importance of education, and particularly higher education, as a growth-enhancing factor. Countries that invest more in higher education will achieve a higher productivity of research activities and also reduce the opportunity cost of R&D by increasing the aggregate supply of skilled labor. An increase in the size of population should also bring about an increase in growth by raising L. This "scale effect" has been challenged in the literature and will be discussed in section 5 below.

2. Growth increases with the size of innovations, as measured by γ. This result points to the existence of a wedge between private and social innovation incentives. That is, a decrease in size would reduce the cost of innovation in proportion to the expected rents; the research arbitrage equation (9) shows that these two effects cancel each other, leaving the equilibrium level of R&D independent of size. However, equation (10) shows that the social benefit from R&D, in the form of enhanced growth, is proportional not to γ but to the "incremental size" $\gamma - 1$. When γ is close to one it is not socially optimal to spend spend as much on R&D as when γ is very large, because there is little social benefit; yet a laissez-faire equilibrium would result in the same level of R&D in both cases.

3. Growth is decreasing with the degree of product market competition and/or with the degree of imitation as measured inversely by χ. Thus patent protection (or, more generally, better protection of intellectual property rights), will enhance growth by increasing χ and therefore increasing the potential rewards from innovation. However, pro-competition policies will tend to discourage innovation and growth by reducing χ and thereby forcing incumbent innovators to charge a lower limit price. Existing historical evidence supports the view that property rights protection is important for sustained long-run growth; however the prediction that competition should be unambiguously bad for innovations and growth is questioned by all recent empirical studies, starting with the work of Nickell (1996) and Blundell et al (1999). In Section 4 we shall argue that the Schumpeterian framework outlined in this section can be extended so as to reconcile theory and evidence on the effects of entry and competition on innovations, and that it also generates novel predictions regarding these effects which are borne out by empirical tests.

3 Linking growth to development: convergence clubs

With its emphasis on institutions, the Schumpeterian growth paradigm is not restricted to dealing with advanced countries that perform leading-edge R&D. It can also shed light on why some countries that were initially poor have managed to grow faster than industrialized countries, whereas others have continued to fall further behind.

The history of cross-country income differences exhibits mixed patterns of convergence and divergence. The most striking pattern over the long run is the "great divergence" - the dramatic widening of the distribution that has taken place since the early 19th Century. Pritchett (1997) estimates that the proportional gap in living standards between the richest and poorest countries grew more than five-fold from 1870 to 1990, and according to the tables in Maddison (2001) the proportional gap between the richest group of countries and the poorest[7] grew from 3 in 1820 to 19 in 1998. But over the second half of the twentieth century this widening seems to have stopped, at least among a large group of nations. In particular, the results of Barro and Sala-i-Martin (1992), Mankiw, Romer and Weil (1992) and Evans (1996) seem to imply that most countries are converging to parallel growth paths.

However, the recent pattern of convergence is not universal. In particular, the gap between the leading countries as a whole and the very poorest countries as a whole has continued to widen. The proportional gap in per-capita income between Mayer-Foulkes's (2002) richest and poorest convergence groups grew by a factor of 2.6 between 1960 and 1995, and the proportional gap between Maddison's richest and poorest groups grew by a factor of 1.75 between 1950 and 1998. Thus as various authors[8] have observed, the history of income differences since the mid 20th Century has been one of "club-convergence"; that is, all rich and most middle-income countries seem to belong to one group, or "convergence club", with the same long-run growth rate, whereas all other countries seem to have diverse long-run growth rates, all strictly less than that of the convergence club.

The explanation we develop in this section for club convergence follows Howitt (2000), who took the cross-sectoral-spillovers variant of the closed-economy model described in section 2.3 above and allowed the spillovers to cross international as well as intersectoral borders. This international spillover, or "technology transfer", allows a backward sector in one country to catch up with the current technological frontier whenever it innovates. Because of technology transfer, the further behind the frontier a country is initially, the bigger the average size of its innovations, and therefore the higher its growth rate for a given frequency of innovations. As long as the country continues to innovate at some positive rate, no matter how small, it will eventually grow at the same rate as the leading countries. (Otherwise the gap would continue to rise and therefore the country's growth rate would continue to rise.) However, countries with poor macroeconomic conditions, legal environment, education system or credit markets will not innovate in equilibrium and therefore they will not benefit from technology transfer, but will instead stagnate.

This model reconciles Schumpeterian theory with the evidence to the effect

[7] The richest group was Western Europe in 1820 and the "Euopean Offshoots" (Australia, Canada, New Zealand and the United States) in 1998. The poorest group was Africa in both years.

[8] Baumol (1986), Durlauf and Johnson (1995), Quah (1993, 1997) and Mayer-Foulkes (2002, 2003).

that all but the poorest countries have parallel long-run growth paths. It implies that the growth rate of any one country depends not on local conditions but on global conditions that impinge on world-wide innovation rates. The same parameters which were shown in section 2.4 above to determine a closed economy's productivity-growth rate will now determine that country's relative productivity *level*. What emerges from this exercise is therefore not just a theory of club convergence but also a theory of the world's growth rate and of the cross-country distribution of productivity.

Before we develop the model we need to address the question of how our framework, in which growth depends on research and development, can be applied to the poorest countries of the world, in which, according to OECD statistics, almost no formal R&D takes place. The key to our answer is that because technological knowledge is often tacit and circumstantially specific,[9] foreign technologies cannot simply be copied and transplanted to another country no cost. Instead, technology transfer requires the receiving country to invest resources in order to master foreign technologies and adapt them to the local environment. Although these investments may not fit the conventional definition of R&D, they play the same role as R&D in an innovation-based growth model; that is, they use resources, including skilled labor with valuable alternative uses, they generate new technological possibilities where they are conducted, and they build on previous knowledge.[10] While it may be the case that implementing a foreign technology is somewhat easier than inventing an entirely new one, this is a difference in degree, not in kind. In the interest of simplicity our theory ignores that difference in degree and treats the implementation and adaptation activities undertaken by countries far behind the frontier as being analytically the same as the research and development activities undertaken by countries on or near the technological frontier. For all countries we assign to R&D the role that Nelson and Phelps (1966) assumed was played by human capital, namely that of determining the country's "absorptive capacity".[11]

3.1 A model of technology transfer

Consider one country in a world of h different countries. This country looks just like the ones described in the basic model above, except that whenever an innovation takes place in any given sector the productivity parameter attached to the new product will be an improvement over the pre-existing global leading-edge technology. That is, let $\overline{A}_{t-1}$ be the maximum productivity parameter over all countries in the sector at the end of period $t-1$; in other words the "frontier" productivity at $t-1$. Then an innovation at date t will result in a new version

[9] See Arrow (1969) and Evenson and Westphal (1995).

[10] Cohen and Levinthal (1989) and Griffith, Redding and Van Reenen (2001) have also argued that R&D by the receiving country is a necessary input to technology transfer.

[11] Grossman and Helpman (1991) and Barro and Sala-i-Martin (1997) also model technology transfer as taking place through a costly investment process, which they portray as imitation; but in these models technology transfer always leads to convergence in growth rates except in special cases studied by Grossman and Helpman where technology transfer is inactive in the long run.

of that intermediate sector whose productivity parameter is $A_t = \gamma \overline{A}_{t-1}$, which can be implemented by the innovator in this country, and which becomes the new global frontier in that sector. The frontier parameter will also be raised by the factor γ if an innovation occurs in that sector in any other country.

Therefore domestic productivity in the sector evolves according to:

$$\ln A_t = \left\{ \begin{array}{ll} \ln \overline{A}_{t-1} + \ln \gamma = \ln \overline{A}_t & \text{with probability } \mu \\ \ln A_{t-1} & \text{with probability } 1 - \mu \end{array} \right\}$$

where μ is the country's innovation rate:

$$\mu = \lambda f(n)$$

and the productivity-adjusted research n is defined as:

$$n \equiv N_t / \left(\gamma \overline{A}_{t-1} \right)$$

since the targeted productivity parameter is now $\gamma \overline{A}_{t-1}$.

Meanwhile, the global frontier advances by the factor γ with every innovation anywhere in the world.[12] Therefore:

$$\ln \overline{A}_t = \left\{ \begin{array}{ll} \ln \overline{A}_{t-1} + \ln \gamma & \text{with probability } \overline{\mu} \\ \ln \overline{A}_{t-1} & \text{with probability } 1 - \overline{\mu} \end{array} \right\} \tag{11}$$

where

$$\overline{\mu} = \Sigma_1^h \lambda^j f\left(n^j\right)$$

is the global innovation rate.[13] It follows from (11) that the long-run average growth rate of the frontier, measured as a difference in logs, is:[14]

$$\overline{g} = \overline{\mu} \ln \gamma \tag{12}$$

Assume there is no international trade in intermediates or general goods.[15] Then the costs and benefits of R&D are the same as in the previous model,

---

[12] Again we are assuming a time period small enough to ignore the possibility of simultaneous innovations in the same sector.

[13] A simpler version of the model would just have the frontier productivity grow at an exogenous rate $\overline{g}$. The model in this section has the advantage of delivering both an endogenous rate for productivity growth at the frontier and club convergence towards that frontier.

[14] The growth rate (12) expressed as a log difference is approximately the same as the rate (5) of the previous section which was expressed as a proportional increment, because the first-order Taylor-series approximation to $\ln\gamma$ at $\gamma = 1$ is $(\gamma - 1)$. We switch between these two definitions depending on which is more convenient in a given context.

[15] This is not to say that international trade is umimportant for technology transfer. On the contrary, Coe and Helpman (1995), Coe Helpman and Hoffmaister (1996), Eaton and Kortum (1996) and Savvides and Zachariadis (2004) all provide strong evidence to the effect that internation trade plays an important role in the international diffusion of technological progress. For a recent summary of this and other empirical work, see Keller (2002). Eaton and Kortum (2001) provide a simple "semi-endogenous" (see section 5 below) growth model in which endogenous innovation interacts with technology transfer and international trade in goods; in their model all countries converge to the same long-run growth rate.

except that the domestic productivity parameter A_t may differ from the global parameter $\overline{A}_t$ that research aims to improve upon. Each innovation will now change log productivity by:

$$\ln \overline{A}_{t-1} + \ln \gamma - \ln A_{t-1} = \ln \gamma + d_{t-1}$$

where

$$d_{t-1} \equiv \ln\left(\overline{A}_{t-1}/A_{t-1}\right)$$

is a measure of "distance to the frontier." As Gerschenkron (1952) argued when discussing the "advantage of backwardness," the greater the distance the larger the innovation. The average growth rate will again be the expected frequency of innovations times size:

$$g_t = \mu\left(\ln \gamma + d_{t-1}\right) \tag{13}$$

which is also larger the greater the distance to the frontier.

The distance variable d_t evolves according to:

$$d_t = \left\{ \begin{array}{cl} d_{t-1} & \text{with probability } 1-\overline{\mu} \\ \ln \gamma + d_{t-1} & \text{with probability } \overline{\mu}-\mu \\ 0 & \text{with probability } \mu \end{array} \right\}$$

That is, with probability $1-\overline{\mu}$ there is no innovation in the sector either globally or in this country, so both domestic productivity and frontier productivity remain unchanged; with probability $\overline{\mu}-\mu$ an innovation will occur in this sector but in some other country, in which case domestic productivity remains the same but the proportional gap grows by the factor γ; and with probability μ an innovation will occur in this sector in this country, in which case the country moves up to the frontier, reducing the gap to zero.

It follows that the expected distance $\widehat{d}_t$ evolves according to:

$$\widehat{d}_t = (1-\mu)\,\widehat{d}_{t-1} + (\overline{\mu}-\mu)\ln \gamma.$$

If $\mu > 0$ this is a stable difference equation with a unique rest point. That is, as long as the country continues to perform R&D at a positive constant intensity n its distance to the frontier will stabilize, meaning that its productivity growth rate will converge to that of the global frontier. But if $\mu = 0$ the difference equation has no stable rest point and $\widehat{d}_t$ diverges to infinity. That is, if the country stops innovating it will have a long-run productivity growth rate of zero because innovation is a necessary condition for the country to benefit from technology transfer.

More formally, the country's long-run expected distance d^* is given by:

$$d^* = \left\{ \begin{array}{ll} (\overline{\mu}/\mu - 1)\ln \gamma & \text{if } \mu > 0 \\ \infty & \text{if } \mu = 0 \end{array} \right\} \tag{14}$$

and its long-run expected growth rate g^*, according to (12), (13) and (14) is:

$$g^* = \left\{ \begin{array}{ll} \mu\left(\ln \gamma + d^*\right) = \overline{g} & \text{if } \mu > 0 \\ 0 & \text{if } \mu = 0 \end{array} \right\}$$

Each country's innovation rate μ is determined according to the same principles as before. In particular, it will be equal $\lambda f(n)$ where n is determined by the research-arbitrage equation (9) above, provided that a positive solution to (9) exists. For example if the research-productivity function f satisfies the Inada-like condition: $f'(0) = \infty$, as in the example used above to derive the growth equation (10), then there will always exist a positive solution to (9), so all countries will converge to the frontier growth rate.

But suppose, on the contrary, that this Inada-like condition does not hold, that instead: $f'(0) < \infty$. Then the research-arbitrage condition (9) must be replaced by the more general Kuhn-Tucker conditions:

$$1 \geq \lambda f'(n)\, \delta(\chi)\, L/m \qquad \text{with } n = 0 \text{ if the inequality is strict.} \tag{15}$$

That is, for an interior solution the expected marginal cost and benefit must be equal, but the only equilibrium will be one with zero R&D if at that point the expected marginal benefit does not exceed the cost. It follows that the country will perform positive R&D if:

$$\lambda\delta(\chi)\, L/m > 1/f'(0)\,, \tag{16}$$

but if condition (16) fails then there will be no research: $n = 0$ and hence no innovations: $\mu = 0$ and no growth: $g = 0$.

This means that countries will fall into two groups, corresponding to two convergence clubs:

1. Countries with highly productive R&D, as measured by λ, or good educational systems as measured by high λ or high L, or good property right protection as measured by a high χ, will satisfy condition (16), and hence will grow asymptotically at the frontier growth rate $\overline{g}$.

2. Countries with low R&D productivity, poor educational systems and low property right protection will fail condition (16) and will not grow at all. The gap d_t separating them from the frontier will grow forever at the rate $\overline{g}$.

3.2 World growth and distribution

Since the world growth rate $\overline{g}$ given by (12) depends on each country's innovation frequency $\mu^j = \lambda^j f\left(n^j\right)$, therefore world growth depends on the value for each country of all the factors described in section 2.4 above that determine μ^j. Thus any improvement in R&D productivity, education or property rights anywhere in the innovating world will raise the growth rate of productivity in all but the stagnating countries.

Moreover, the cross-country distribution of productivity is determined by these same variables. For according to (14) each country's long-run relative distance to the frontier depends uniquely on its own innovation frequency $\mu = \lambda f(n)$. Two countries in which the determinants of innovation analyzed in section 2.4 are the same will lie the same distance from the frontier in the long run and hence will have the same productivity in the long run. Countries with more productive R&D, better educational systems and stronger property right protection will have higher productivity.

3.3 The role of financial development in convergence

The framework can be further developed by assuming that while the size of innovations increases with the distance to the technological frontier (due to technology transfer), the frequency of innovations depends upon the ratio between the distance to the technological frontier and the current stock of skilled workers. This enriched framework (see Howitt and Mayer-Foulkes, 2002) can explain not only why some countries converge while other countries stagnate but also why different countries may display positive yet divergent growth patterns in the long-run. Benhabib and Spiegel (2002) develop a similar account of divergence and show the importance of human capital in the process. The rest of this section presents a summary of the related model of Aghion, Mayer-Foulkes and Howitt (2004) (AMH) and discusses their empirical results showing the importance of financial development in the convergence process.

Suppose that the world is as portrayed in the previous sections, but that research aimed at making an innovation in t must be done at period $t-1$. If we assume perfectly functioning financial markets then nothing much happens to the model except that the research arbitrage condition (9) has a discount factor β on the right-hand side to reflect the fact that the expected returns to R&D occur one period later than the expenditure.[16] But when credit markets are imperfect, AMH show that an entrepreneur may face a borrowing constraint that limits her investment to a fixed multiple of her accumulated net wealth. In their model the multiple comes from the possibility that the borrower can, at a cost that is proportional to the size of her investment, decide to defraud her creditors by making arrangements to hide the proceeds of the R&D project in the event of success.[17] They also assume a two-period overlapping-generations structure in which the accumulated net wealth of an entrepreneur is her current wage income, and in which there is just one entrepreneur per sector in each country. This means that the further behind the frontier the country falls the less will any entrepreneur be able to invest in R&D relative to what is needed to maintain any given frequency of innovation. What happens in the long run to the country's growth rate depends upon the interaction between this disadvantage of backwardness, which reduces the frequency of innovations, and the above-described advantage of backwardness, which increases the size of innovations. The lower the cost of defrauding a creditor the more likely it is that the disadvantage of backwardness will be the dominant force, preventing the country from converging to the frontier growth rate even in the long run. Generally speaking, the greater the degree of financial development of a country the

[16] For simplicity we suppose that everyone has linear intertemporal preferences with a constant discount factor β.

[17] The "credit multipler" assumed here is much like that of Bernanke and Gertler (1989), as modified by Aghion, Banerjee and Piketty (1999).

more effective are the institutions and laws that make it difficult to defraud a creditor. Hence the link between financial development and the likelihood that a country will converge to the frontier growth rate.

The following simplified account of AHM shows in more detail how this link between financial development and convergence works. Suppose that entrepreneurs have no source of income other than what they can earn from innovating. Then they must borrow the entire cost of any R&D project. Because there are constant returns to the R&D technology,[18] therefore in equilibrium that cost will equal the expected benefit, discounted back to today:

$$N_t = \mu\beta\pi_{t+1}$$

This is also the expected discounted benefit to a borrower from paying a cost cN_t today that would enable her to default in the event that the R&D project is successful. (There is no benefit if the project fails to produce an innovation because in that case the entrepreneur cannot pay anything to the creditor even if she has decided to be honest and therefore has not paid the cost cN_t). The entrepreneur will choose to he honest if the cost at least as great as the benefit; that is, if:

$$c \geq 1. \tag{17}$$

Otherwise she will default on any loan.

Suppose that $\beta\lambda\delta(\chi)L/m > 1/f'(0)$. This is the condition (16) above for positive growth, modified to take discounting into account. It follows that in any country where the incentive-compatibility constraint (17) holds then innovation will proceed as described in the previous section, and the country will converge to the frontier growth rate. But in any country where the cost of defrauding a creditor is less than unity no R&D will take place because creditors would rationally expect to be defrauded of any possible return from lending to an entrepreneur. Therefore convergence to the frontier growth rate will occur only in countries with a level of financial development that is high enough to put the cost of fraud at or above the limit of unity imposed by (17).

AHM test this effect of financial development on convergence by running the following cross-country growth regression:

$$g_i - g_1 = \beta_0 + \beta_f F_i + \beta_y \cdot (y_i - y_1) + \beta_{fy} \cdot F_i \cdot (y_i - y_1) + \beta_x X_i + \varepsilon_i \tag{18}$$

where g_i denotes the average growth rate of per-capita GDP in country i over the period 1960 - 1995, F_i the country's average level of financial development, y_i the initial (1960) log of per-capita GDP, X_i a set of other regressors and ε_i a disturbance term with mean zero. Country 1 is the technology leader, which they take to be the United States.

Define $\widehat{y}_i \equiv y_i - y_1$, country i's initial relative per-capita GDP. Under the assumption that $\beta_y + \beta_{fy} F_i \neq 0$ we can rewrite (18) as:

$$g_i - g_1 = \lambda_i \cdot (\widehat{y}_i - \widehat{y}_i^*)$$

[18] See footnote 2 above.

where the steady-state value $\widehat{y}_i^*$ is defined by setting the RHS of (18) to zero:

$$\widehat{y}_i^* = -\frac{\beta_0 + \beta_f F_i + \beta_x X_i + \varepsilon_i}{\beta_y + \beta_{fy} F_i} \tag{19}$$

and λ_i is a country-specific convergence parameter:

$$\lambda_i = \beta_y + \beta_{fy} F_i \tag{20}$$

that depends on financial development.

A country can converge to the frontier growth rate if and only if the growth rate of its relative per-capita GDP depends negatively on the initial value $\widehat{y}_i$; that is if and only if the convergence parameter λ_i is negative. Thus the likelihood of convergence will increase with financial development, as implied by the above theory, if and only if:

$$\beta_{fy} < 0. \tag{21}$$

The results of running this regression using a sample of 71 countries are shown in Table 1, which indicates that the interaction coefficient β_{fy} is indeed significantly negative for a variety of different measures of financial development and a variety of different conditioning sets X. The estimation is by instrumental variables, using a country's legal origins, and its legal origins[19] interacted with the initial GDP gap $(y_i - y_1)$ as instruments for F_i and $F_i\,(y_i - y_1)$. The data, estimation methods and choice of conditioning sets X are all take directly from Levine, Loayza and Beck (2000) who found a strongly positive and robust effect of financial intermediation on short-run growth in a regression identical to (18) but without the crucial interaction term $F_i\,(y_i - y_1)$ that allows convergence to depend upon the level of financial development.

TABLE 1 HERE

AHM shown that the results of Table 1 are surprisingly robust to different estimation techniques, to discarding outliers, and to including possible interaction effects between the initial GDP gap and other right-hand-side variables.

3.4 Concluding remark

Thus we see how Schumpeterian growth theory and the quality improvement model can naturally explain club convergence patterns, the so-called twin peaks pointed out by Quah (1996). The Schumpeterian growth framework can deliver an explanation for cross-country differences in growth rates and/or in convergence patterns based upon *institutional considerations.* No one can deny that such considerations are close to what development economists have been concerned with. However, some may argue that the quality improvement paradigm,

[19] See LaPorta et al. (1998) for a detailed explanation of legal origins and its relevance as an instrument for financial development.

and new growth theories in general, remain of little help for development policy, that they merely formalize platitudes regarding the growth-enhancing nature of good property right protection, sound education systems, stable macroeconomy, without regard to specifics such as a country's current stage of development. In Section 4 and 6 below we will argue on the contrary that the Schumpeterian growth paradigm can be used to understand (i) why liberalization policies (in particular an increase in product market competition) should affect productivity growth differently in sectors or countries at different stages of technological development as measured by the distance variable d; and (ii) why the organizations or institutions that maximize growth, or that are actually chosen by societies, also vary with distance to the frontier.

4 Linking growth to IO: innovate to escape competition

One particularly unappealing feature of the basic Schumpeterian model outlined in Section 2 is the prediction that product market competition is unambiguously detrimental to growth because it reduces the monopoly rents that reward successful innovators and thereby discourages R&D investments. Not only does this prediction contradict a common wisdom that goes back to Adam Smith, but it has also been shown to be (partly) counterfactual (e.g by Geroski (1994), Nickell (1996), and Blundell et al (1999))[20].

However, as we argue in this section, a simple modification reconciles the Schumpeterian paradigm with the evidence on product market competition and innovation, and also generates new empirical predictions that can be tested with firm- and industry-level data. In this respect the paradigm can meet the challenge of seriously putting IO into growth theory. The theory developed in this section is based on Aghion-Harris-Vickers (1997) and Aghion-Harris-Howitt-Vickers (2001), but cast in the discrete-time framework introduced above.

We start by considering an isolated country in a variant of the technology-transfer model of the previous section. This variant allows technology spillovers to occur across sectors as well as across national borders. Thus there is a global technological frontier that is common to all sectors, and which is drawn on by all innovations. The model takes as given the growth rate of this global frontier, so that the frontier $\overline{A}_t$ at the end of period t obeys:

$$\overline{A}_t = \gamma \overline{A}_{t-1},$$

where $\gamma > 1$.

In each country, the general good is produced using the same kind of technology as in the previous sections, but here for simplicity we assume a continuum

[20] We refer the reader to the second part of this section where we confront theory and empirics on the relationship between competition/entry and innovation/productivity growth.

of intermediate inputs and we normalize the labor supply at $L = 1$, so that:

$$y_t = \int_0^1 A_{it}^{1-\alpha} x_{it}^{\alpha} di,$$

where, in each sector i, only one firm produces intermediate input i using general good as capital according to a one-for-one technology.

In each sector, the incumbent firm faces a competitive fringe of firms that can produce the same kind of intermediate good, although at a higher unit cost. More specifically, we assume that at the end of period t, at unit cost χ, where we assume $1 < \chi < 1/\alpha < \gamma\chi$, a competitive fringe of firms can produce one unit of intermediate input i of a quality equal to $\min(A_{it}, \overline{A}_{t-1})$, where A_{it} is the productivity level achieved in sector i after innovation has had the opportunity to occur in sector i within period t.

In each period t, there are three types of sectors, which we refer to as type-j sectors, with $j \in \{0, 1, 2\}$. A type-j sector starts up at the beginning of period t with productivity $A_{j,t-1} = \overline{A}_{t-1-j}$, that is, j steps behind the current frontier $\overline{A}_{t-1}$. The profit flow of an incumbent firm in any sector at the end of period t, will depend upon the technological position of that firm with regard to the technological frontier at the end of the period.

Between the beginning and the end of the current period t, the incumbent firm in any sector i has the possibility of innovating with positive probability. Innovations occur step-by-step: in any sector an innovation moves productivity upward by the same factor γ. Incumbent firms can affect the probability of an innovation by investing more in R&D at the beginning of the period. Namely, by investing the quadratic R&D effort $\frac{1}{2}\gamma A_{i,t-1}\mu^2$ incumbent an firm i in a type-0 or type-1 sector, innovates with probability μ.[21] However, innovation is assumed to be automatic in type-2 sectors, which in turn reflects a knowledge externality from more advanced sectors which limits the maximum distance of any sector to the technological frontier.

Now, consider the R&D incentives of incumbent firms in the different types of sectors at the beginning of period t. Firms in type-2 sectors have no incentive to invest in R&D since innovation is automatic in such sectors. Thus

$$\mu_2 = 0,$$

where μ_j is the equilibrium R&D choice in sector j.

Firms in type-1 sectors, that start one step behind the current frontier at $A_{i,t-1} = \overline{A}_{t-2}$ at the beginning of period t, end up with productivity $A_t = \overline{A}_{t-1}$ if they successfully innovate, and with productivity $A_t = \overline{A}_{t-2}$ otherwise. In either case, the competitive fringe can produce intermediate goods of the same quality but at cost χ instead of 1, which in turn, as in section 2 above, the

[21] We thus depart slightly from our formulation in the previous sections: here we take the probability of innovation, not the R&D effort, as the optimization variable. However the two formulations are equivalent: that the innovation probability $f(n) = \mu$ is a concave function of the effort n, is equivalent to saying that the effort is a convex function of the probability.

equilibrium profit is equal to:[22]

$$\pi_t = A_t \delta(\chi),$$

with

$$\delta\left(\chi\right) = \left(\chi - 1\right)\left(\chi/\alpha\right)^{\frac{1}{\alpha - 1}}.$$

Thus the net rent from innovating for a type-1 firm is equal to

$$(\overline{A}_{t-1} - \overline{A}_{t-2})\delta(\chi)$$

and therefore a type-1 firm will choose its R&D effort to solve:

$$\max_{\mu}\{(\overline{A}_{t-1} - \overline{A}_{t-2})\delta(\chi)\mu - \frac{1}{2}\gamma\overline{A}_{t-2}\mu^2\},$$

which yields

$$\mu_1 = (1 - \frac{1}{\gamma})\delta(\chi).$$

In particular an increase in product market competition, measured as an reduction in the unit cost χ of the competitive fringe, will reduce the innovation incentives of a type-1 firm. This we refer to as the *Schumpeterian effect* of product market competition: competition reduces innovation incentives and therefore productivity growth by reducing the rents from innovations of type-1 firms that start below the technological frontier. This is the dominant effect, both in IO models of product differentiation and entry, and in basic endogenous growth models as the one analyzed in the previous sections. Note that type-1 firms cannot escape the fringe by innovating: whether they innovate or not, these firms face competitors that can produce the same quality as theirs at cost χ. As we shall now see, things become different in the case of type-0 firms.

Firms in type-0 sectors, that start at the current frontier, end up with productivity $\overline{A}_t$ if they innovate, and stay with their initial productivity $\overline{A}_{t-1}$ if they do not. But the competitive fringe can never get beyond producing quality $\overline{A}_{t-1}$. Thus, by innovating, a type-0 incumbent firm produces an intermediate good which is γ times better than the competing good the fringe could produce, and at unit cost 1 instead of χ for the fringe. Our assumption $\frac{1}{\alpha} < \gamma\chi$ then implies that competition by the fringe is no longer a binding constraint for an innovating incumbent, so that its equilibrium profit post-innovation, will simply be the profit of an unconstrained monopolist, namely:

$$\pi_t = \overline{A}_t \delta(1/\alpha).$$

On the other hand, a type-0 firm that does not innovate, will keep its productivity equal to $\overline{A}_{t-1}$. Since the competitive fringe can produce up to this quality level at cost χ, the equilibrium profit of a type-0 firm that does not innovate, is equal to

$$\pi_t = \overline{A}_{t-1}\delta(\chi).$$

[22] Imitation does not destroy the rents of non-innovating firms. We assume nevertheless that the firm ignores any continuation value in its R&D decision.

A type-0 firm will then choose its R&D effort to:

$$\max_{\mu}\{[\overline{A}_t\delta(1/\alpha) - \overline{A}_{t-1}\delta(\chi)]\mu - \frac{1}{2}\gamma\overline{A}_{t-1}\mu^2\},$$

so that in equilibrium

$$\mu_0 = \delta(1/\alpha) - \frac{1}{\gamma}\delta(\chi).$$

In particular an increase in product market competition, i.e a reduction in χ, will now have a fostering effect on R&D and innovation. This, we refer to as the *escape competition effect:* competition reduces pre-innovation rents of type-0 incumbent firms, but not their post-innovation rents since by innovating these firms have escaped the fringe. This in turn induces those firms to innovate in order to escape competition with the fringe.

4.1 Composition effect and the inverted-U relationship between competition and innovation

We have just seen that product market competition tends to have opposite effects on frontier and lagging sectors, fostering innovation by the former and discouraging innovation by the latter. In this section we consider the impact of competition on the steady-state aggregate innovation intensity

$$I = q_0\mu_0 + q_1\mu_1 \tag{22}$$

where q_j is the steady-state fraction of type-j sectors (recall that type-2 sectors do not perform R&D).

To get a non-trivial steady-state fraction of type-0 firms, we need that the net flows out of state 0 (which corresponds to type-0 firms that fail to innovate in the current period), be compensated by a net flow into state 0. We simply postulate such a flow into state 0, by assuming that at the end of any period t, with exogenous probability ε entry at the new frontier, that is by a type-0 firm with productivity level $\overline{A}_t$, occurs in a type-2 sector after the incumbent firm has produced. We then have the following flow equations describing the net flows into and out of states 0, 1 and 2:

$$\begin{aligned} q_2\varepsilon &= q_0(1-\mu_0); \\ q_0(1-\mu_0) &= q_1(1-\mu_1); \\ q_1(1-\mu_1) &= q_2\varepsilon; \end{aligned}$$

in which the left hand sides represents the steady-state expected flow of sectors that move into a state j and the right hand sides represent the expected outflow from the same state, for $j = 0, 1,$ and 2. This, together with the identity:

$$q_0 + q_1 + q_2 = 1,$$

implies that:

$$I = 1 - q_2(1 + 2\varepsilon),$$

where

$$q_2 = \frac{1}{1 + \frac{\varepsilon}{1-\mu_0} + \frac{\varepsilon}{1-\mu_1}}.$$

In particular, one can see that the overall effect of increased product market competition on I is ambiguous since it produces opposite effects on innovation probabilities in type-0 and type-1 sectors (i.e on μ_0 and μ_1). In fact, one can say more than that, and show that: (i) the Schumpeterian effect always dominates for γ sufficiently large; (ii) the escape competition effect always dominates for γ sufficiently close to one; (iii) for intermediate values of γ, the escape competition effect dominates when competition is initially low (with χ close to $1/\alpha$) whereas the Schumpeterian effect dominates when competition is initially high (with χ close to one). In this latter case, the relationship between competition and innovation is inverted-U shaped.

This inverted-U pattern can be explained as follows: at low initial levels of competition (i.e high initial levels of $\delta(\chi)$), type-1 firms have strong reason to innovate; it follows that many intermediate sectors in the economy will end up being type-0 firms in steady-state (this we refer to as the *composition effect* of competition on the relative equilibrium fractions of type-0 and type-1); but then the dominant effect of competition on innovation is the escape competition effect whereby more competition fosters innovation by type-0 firms. On the other hand, at high initial levels of competition, innovation incentives in type-1 sectors are so low that a sector will remain of type-1 for a long time, and therefore many sectors will end up being of type-1 in steady-state, which in turn implies that the negative Schumpeterian appropriability effect of competition on innovation should tend to dominate in that case.

4.2 Empirical predictions

The above analysis generates several interesting predictions:

1. Innovation in sectors in which firms are close to the technology frontier, react positively to an increase in product market competition;

2. Innovation reacts less positively, or negatively, in sectors in which firms are further below the technological frontier;

3. The average fraction of frontier sectors decreases, i.e the average technological gap between incumbent firms and the frontier in their respective sectors increases, when competition increases;

4. The overall effect of competition on aggregate innovation, is inverted-U shaped.[23]

These predictions have been confronted by Aghion et al (2002) with UK firm level data on competition and patenting, and we briefly summarize their findings in the next subsection.

[23]Although perhaps only the second part of the inverse U will be observable. See footnote ?? above.

4.3 Empirical evidence and relationship to literature

Most innovation-based growth models -including the quality improvement model developed in the above two sections- would predict that product market competition is detrimental to growth as it reduces the monopoly rents that reward successful innovators (we refer to this as the Schumpeterian effect of competition). However, an increasing number of empirical studies have cast doubt on this prediction. The empirical IO literature on competition and innovation starts with the pioneering work of Scherer (1965), followed by Cohen-Levin (1967), and more recently by Geroski (1994). All these papers point to a positive correlation between competition and growth. However, competition is often measured by the inverse of market concentration, an indicator which Boone (2000) and others have shown to be problematic: namely, higher competition between firms with different unit costs may actually result in a higher equilibrium market share for the low cost firm! More recently, Nickell (1996) and Blundell et al (1999) have made further steps by conducting cross-industry analyses over longer time periods and by proposing several alternative measures of competition, in particular the inverse of the Lerner index (defined as the ratio of rents over value added) or by the number of competitors for each firm in the survey. However, none of these studies would uncover the reason(s) why competition can be growth-enhancing or why the Schumpeterian effect does not seem to operate.

It is by merging the Schumpeterian growth paradigm with previous patent race models (in which each of two incumbent firms would both, compete on the product market and innovate to acquire a lead over its competitor), that Aghion-Harris-Vickers (1997), henceforth AHV, and Aghion-Harris-Howitt-Vickers (2001), henceforth AHHV, have developed new models of competition and growth with step-by-step innovations that reconcile theory and evidence on the effects of competition and growth: by introducing the possibility that innovations be made by incumbent firms that compete "neck-and-neck", these extensions of the Schumpeterian growth framework show the existence of an "escape competition"effect that counteracts the Schumpeterian effect described above. What facilitated this merger between the Schumpeterian growth approach and the patent race models, is that: (i) both featured quality-improving innovations; (ii) models with vertical innovations in turn were particularly convenient to formalize the notion of technological distance and that of "neck-and-neck" competition. A main prediction of this new vintage of endogenous growth models, is that competition should be most growth-enhancing in sectors in which incumbent firms are close to the technological frontier and/or compete "neck-and-neck" with one another, as it is in those sectors that the "escape competition" effect should be the strongest.

These models in turn have provided a new pair of glasses for deeper empirical analyses of the relationship between competition/entry and innovation/growth. The two studies we briefly mention in the remaining part of this section have not only produce interesting new findings; they also suggested a whole new way of confronting endogenous growth theories with data, one that is more directly grounded on serious microeconometric analyses based on detailed firm/industry panels.

The paper by Aghion-Bloom-Blundell-Griffith-Howitt (2002), henceforth ABBGH, takes a new look at the effects of product market competition on innovation, by confronting the main predictions of the AHV and AHHV models to firm level data. The prediction we want to emphasize here as it is very much in tune with our theoretical discussion in the previous subsections, is that the escape competition effect should be strongest in industries in which firms are closest to the technological frontier.

ABBGH considers a UK panel of individual companies during the period 1968-1997. This panel includes all companies quoted on the London Stock Exchange over that period, and whose names begin with a letter from A to L. To compute competition measures, the study uses firm level accounting data from Datastream; product market competition is in turn measured by one minus the Lerner index (ratio of operating profits minus financial costs over sales), controlling for capital depreciation, advertising expenditures, and firm size. Furthermore, to control for the possibility that variations in the Lerner index be mostly due to variations in fixed costs, we use policy instruments such as the implementation of the Single Market Program or lagged values of the Lerner index as instrumental variables. Innovation activities, in turn, are measured both, by the number of patents weighted by citations, and by R&D spending. Patenting information comes from the US Patent Office where most firms that engage in international trade register their patents; in particular, this includes 461 companies on the London Stock Exchange with names starting by A to L, for which we already had detailed accounting data. Finally, technological frontier is measured as follows: suppose a UK firm (call it i) belongs to some industry A; then we measure technological distance by the difference between the maximum TFP in industry A across all OECD countries (we call it TFP_F , where the subscript "F" refers to the technological frontier) and the TFP of the UK firm, divided by the former:

$$m_i = \frac{TFP_F - TFP_i}{TFP_F}.$$

Figure 1 summarizes our main findings.

$FIGURE$ 1 $HERE$

Each point on this figure corresponds to one firm in a given year. The upper curve considers only those firms in industries where the average distance to the technological frontier is less than the median distance across all industries, whereas the lower curve includes firms in all industries. We clearly see that the effect of product market competition on innovation is all the more positive that firms are closer to the technological frontier (or equivalently are more "neck-and-neck"). Another interesting finding that comes out of the Figure, is that the Schumpeterian effect is also at work, and that it dominates at high initial levels of product market competition. This in turn reflects the "composition effect" pointed out in the previous subsection: namely, as competition increases and neck-and-neck firms therefore engage in more intense innovation to escape competition, the equilibrium fraction of neck-and-neck industries tends to decrease (equivalently, any individual firm spends less time in neck-and-neck competition with its main rivals) and therefore the average impact of the escape competition effect decreases at the expense of the counteracting Schumpeterian effect. The ABBGH paper indeed shows that the average distance to the technological distance increases with the degree of product market competition. The Schumpeterian effect was missed by previous empirical studies, mainly as a result of their being confined to linear estimations. Instead, more in line with the Poisson technology that governs the arrival of innovations both, in Schumpeterian and in patent race models, ABBGH use a semi-parametric estimation method in which the expected flow of innovations is a piecewise polynomial function of the Lerner index.

4.4 A remark on inequality and growth

Our discussion of the effects of competition on growth also sheds light on the current debate on the effects of income or wealth inequality on growth. A recent literature[24] has emphasized the idea that in an economy with credit-constraints, where the poor do not have full access to efficient investment opportunities; redistribution may enhance investment by the poor more than it reduces incentives for the rich, thereby resulting in higher aggregate productive efficiency in steady-state and higher rate of capital accumulation on the transition path to the steady-state. Our discussion of the effects of competition on innovation and growth, hints at yet another negative effect of excessive wealth concentration on growth: to the extent that innovative activities tend to be more intense in sectors in which firms or individuals compete "neck-and-neck", taxing further capital gains by firms that are already well ahead of their rivals in the same sector, may enhance the aggregate rate of innovation by shifting the overall distribution of technological gaps in the economy towards a higher fraction of neck-and-neck sectors in steady-state.

More generally, having too many sectors in which technological knowledge and/or wealth are highly concentrated, may inhibit growth as it both, discourages laggard firms or potential entrants, and reduces the leader's incentives to innovate in order to escape competition given that the competitive threat coming from laggards or potential entrants is weak; the leader may actually prefer to invest her wealth into entry deterrence activities. These considerations may in turn explain why, following a high growth period during the industrial revolution in the 19th century, growth slowed down at the turn of the 20th century in France or England at the same time wealth distribution became highly concentrated: the high concentration of wealth that resulted from the industrial revolution, turned the innovators of the mid 19th century into entrenched incumbents with the power to protect their dominant position against competition by new potential entrants.[25]

[24] For example, see Galor-Zeira (1993), Banerjee-Newman (1993), and Aghion-Bolton (1997).
[25] See Piketty et al (2003).

5 Scale effects[26]

5.1 Theory

Jones (1995) has pointed out that the simple model of the preceding sections whereby increased population leads to increased growth, by raising the size of the market for a successful entrepreneur and by raising the number of potential R&D workers, is not consistent with post-war evidence. In the United States, for example, the number of scientists and engineers engaged in R&D has grown by a factor of five since the 1950s with no significant trend increase in productivity growth. This refutes the version of the basic model in which productivity growth is a function of skilled labor applied to R&D (section 2.3 above). Likewise, the fact that productivity-adjusted R&D has grown substantially over the same period rejects the version of the model presented in section 2 above in which productivity growth is a function of productivity-adjusted research.

5.1.1 The Schumpeterian (fully endogenous) solution

Schumpeterian theory deals with this problem of the missing scale effect on productivity growth by incorporating Young's (1998) insight that as an economy grows, proliferation of product varieties reduces the effectiveness of R&D aimed at quality improvement, by causing it to be spread more thinly over a larger number of different sectors.[27] When modified this way the theory is consistent with the observed coexistence of stationary TFP growth and rising R&D input, because in a steady state the growth-enhancing effect of rising R&D input is just offset by the deleterious effect of product proliferation.

The simplest way to illustrate this modification is to suppose that the number of sectors m is proportional to the size of population L. For simplicity normalize so that $m = L$.[28] Then the growth equation (10) becomes:

$$g = \lambda^2 \delta(\chi)(\gamma - 1) \tag{23}$$

It follows directly from comparing (23) with (10) that all the comparative-statics propositions of section 2.4 above continue to hold except that now the growth rate is independent of population size.

5.1.2 The semi-endogenous solution

Jones (1999) argues that this resolution of the problem is less intuitively appealing than his alternative semi-endogenous theory, built on the idea of diminishing returns to the stock of knowledge in R&D. In this theory sustained *growth* in R&D input is necessary just to maintain a given rate of productivity growth.

[26] This section drawson Ha and Howitt (2004).

[27] Variants of this idea have been explored by van de Klundert and Smulders (1997), Peretto (1998), Dinopoulos and Thompson (1998) and Howitt (1999).

[28] Thus, in contrast to Romer (1990) where horizontal innovations drive the growth process, here product proliferation eliminates scale effects whereas long-run growth is still ultimately driven by quality-improving innovations.

Semi-endogenous growth theory has a stark long-run prediction, namely that the long-run rate of productivity growth, and hence the long-run growth rate of per-capita income, depend on the rate of population growth, which ultimately limits the growth rate of R&D labor, to the exclusion of all economic determinants.

In Jones's formulation:

$$g = \lambda f(n) A^{\phi-1} (\gamma - 1), \qquad \phi < 1$$

where the R&D input n is measured by the number R&D workers in G5 countries. Except for the assumption of diminishing returns ($\phi < 1$) this is equivalent to the original formulation (5) above. In the special case where f takes a Cobb-Douglas form we have, in continuous time:

$$g \equiv \dot{A}/A = \lambda n^{\sigma} A^{\phi-1} (\gamma - 1)$$

so that:

$$\dot{g}/g = (1-\phi)(\gamma' g_n - g) \tag{24}$$

where $g_n = \dot{n}/n$ is the growth rate of R&D workers and $\gamma' = \sigma/(1-\phi)$.

This semi-endogenous model is compatible with the observation of positive trend growth in R&D input, because as long as $\phi < 1$ and the time path of g_n is bounded, the differential equation (24) yields a bounded solution for productivity growth. In particular, if g_n is constant, or approaches a constant, then

$$g \to \gamma' g_n$$

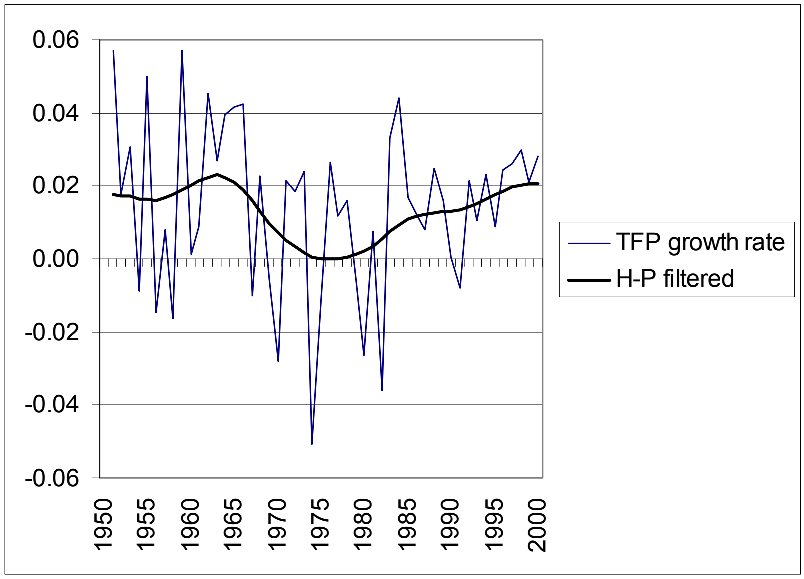
In the long run the growth rate of R&D labor cannot exceed the growth rate η of population, and in a balanced growth equilibrium it will equal η. Likewise, the growth rate of productivity-adjusted R&D expenditure will equal η along a balanced growth path. Hence the radical implication that the long-run growth rate of an economy will equal $\gamma'\eta$, independently of what fraction of society's resources are is assigned to knowledge creation. Policies to stimulate R&D will have at most transitory effects on productivity growth and, by extension, on per-capita income growth.

5.2 Evidence

These two competing approaches to reconciling R&D-based theory with the observed upward trend in R&D input offer a stark contrast. The Schumpeterian approach with product-proliferation effects retains all the characteristic comparative statics predictions of endogenous growth theory as outlined in section 2.4 above, while Jones's semi-endogenous theory denies all these predictions.

Fortunately the two competing approaches can also be tested using observed trends in productivity growth and R&D input. Specifically, the semi-endogenous model implies that the growth rate of productivity will track the growth rate

Figure 2: TFP growth rates, US, 1950-2000



of R&D input, whereas the Schumpeterian model implies that it will track the fraction of GDP spent on R&D.[29]

To derive this Schumpeterian implication note that, according to the growth equation (5), productivity growth depends on productivity-adjusted R&D per sector, n. Given the assumption $m = L$, if GDP per person grows asymptotically at the rate g then n will be proportional to the fraction of GDP spent on R&D.

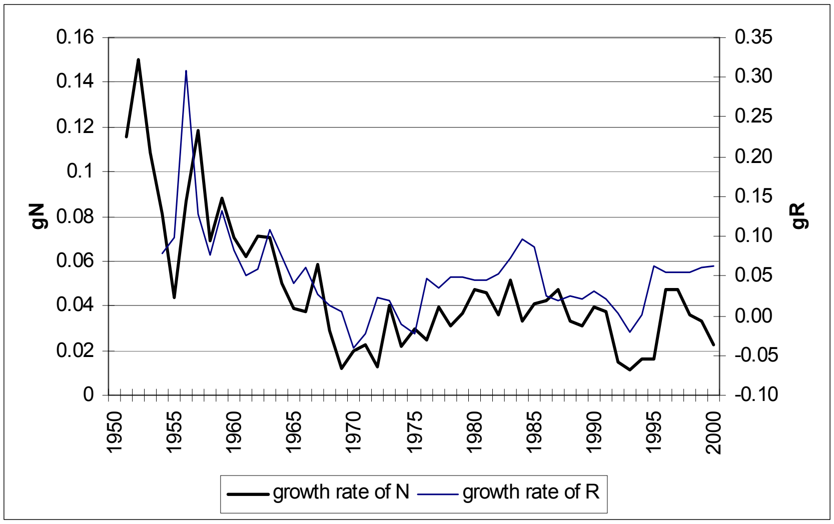
Figure 2 shows the growth rate of productivity in the United States from 1950 to 2000. There is no discernible trend. An Augmented Dickey-Fuller test rejects a unit root at the 1% significance level, confirming the stationarity of this series. Thus semi-endogenous theory implies that the growth rate of R&D input should also be trendless and stationary, whereas Schumpeterian theory implies that the R&D/GDP ratio should be trendless and stationary.

5.2.1 Results

Figure 3 shows that growth rates of the number of R&D workers in the G5 countries, N, and US R&D expenditure, R, appear to have a substantial negative trend, having fallen roughly fourfold since the early 1950s. The impression of

[29] Zachariadis (2003) shows that the fully-endogenous Schumpeterian theory without scale effects also passes a number of other tests using U.S. data. Specifically, he finds using two-digit industry level data that patenting, technological progress and productivity growth all depend upon the ratio of R&D expenditures to output, as implied by the fully endogenous theory.

Figure 3: Trend of growth rates for G5 R&D workers and US R&D expenditures



non-stationarity is supported by an Augmented Dickey-Fuller test, which fails to reject a unit root in g_N at the 5% level.

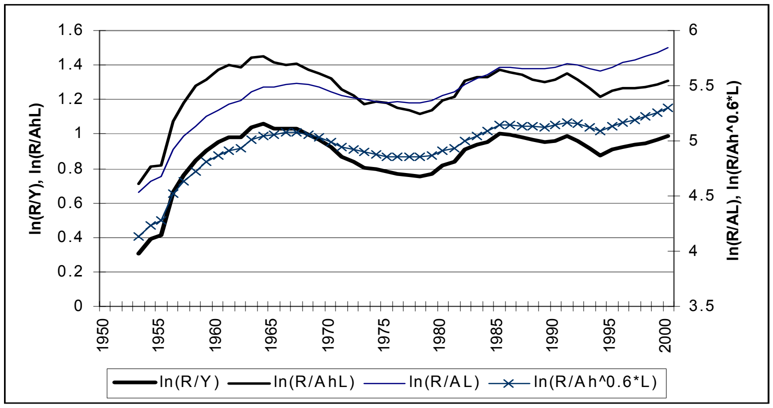
These findings are inconsistent with the implications of semi-endogenous growth theory.[30] Indeed they undermine the central proposition of semi-endogenous theory, because if productivity growth can be sustained for 50 years in the face of such a large fall in the growth rate of R&D labor then there is no reason to suppose that population growth limits productivity growth, except perhaps over a time scale of hundreds of years.

Figure 4 shows that the fraction of GDP spend on R&D in the US looks more or less stable with perhaps a small upward trend.[31] It is notable that ever since 1957, R&D as a percentage of GDP has been fluctuating between 2.1% and 2.9%, with similar movements as in productivity growth: downward trend for 1964-1975 and upward trend for 1975-2000. The stationarity of this

[30] The data on G5 R&D workers come from Jones, who had to guess at the non-US component from 1950 to 1965. However, Ha and Howitt (2004) consider a broader range of R&D measures. They also show that the formal cointegration predictions implied by semi-endogenous theory are not found in these data, even if attention is restricted to the post-1965 date, while the even tighter cointegration predictions implied by Schumpeterian theory are found. Ha and Howitt also conduct a calibration exercise and show that the semi-endogenous model fits the data of US productivity growth best when ϕ is almost equal to unity as in the fully endogenous model.

[31] There appears to be a more significant upward trend if we omit space and defense R&D, as is done by many researchers in the productivity literature on the grounds that they do not find spillovers from these components of R&D. However, this literature has not allowed for the very long lags with which we think federal R&D has its effects. Moreover, throwing out federal R&D would at times amount to throwing out about 70% of the total.

Figure 4: Trend of R&D intensity, US (log)



series is confirmed by an Augmented Dickey-Fuller test, which rejects a unit root at the 1% level. This is in conformity with the version of Schumpeterian theory presented above, adjusted to take into account the effects of product proliferation.

5.3 Concluding remarks

The scale effect whereby increased population should lead to increased productivity growth clearly refutes a simple interpretation of the model in section 2 above, in which L stands for the *number* of (skilled) individuals. However, we have shown in this section that even if we stick to this interpretation of L, a simple variant of the Schumpeterian model can be developed, which carries all the same long-run growth implications except for the scale effect. The rival semi-endogenous theory of Jones (1995), which denies endogenous growth in the very long run, is inconsistent with the observation that productivity growth can be sustained through half a century of falling growth in R&D labor. The analogous implication of amended Schumpeterian theory, namely that productivity growth can be sustained as long as society allocates a constant fraction of its resources to research, is consistent with the evidence.

Two brief remarks conclude this section. First, there is no evidence pointing to the absence of a scale effect at the world level or in small closed economies. That the stock of educated labor should affect technological convergence and productivity growth worldwide was first pointed out by Nelson and Phelps (1966). Second, if we replace L by Le^N, where e^N denotes the *quality* of the labor force as measured for example by the average number of years in schooling (so that more educated countries have more efficiency units of labor), then even if one eliminates scale effects by taking $L = m$, there will still remain a "level effect" embodied in the e^N term, whereby a higher average number of years of education N has a positive effect on growth. In the next section we show that increasing the fraction of highly educated workers and/or increasing the average number of years in schooling, have a positive impact on the rate of productivity growth, but the extent of which depends upon the country's distance to the world technology frontier: in particular, the closer a country is to the frontier, the higher is the effect of an additional year of higher education on its rate of productivity growth.

6 Linking growth to institutional change

6.1 From Schumpeter to Gerschenkron

By linking growth to innovation and entrepreneurship, and innovation incentives in turn to characteristics of the economic environment, new growth theories made it possible to analyze the interplay between growth and the design of policies and institutions. For example, the basic model developed in Section 2 suggested that long-run growth would be best enhanced by a combination of good property right protection (to protect the rents of innovators against imitation), a good education system (to increase the efficiency of R&D activities and/or the supply of skilled manufacturing labor), and a stable macroeconomy to reduce interest rates (and thereby increase the net present value of innovative rents). Our discussion of convergence clubs in Section 3 then suggested that the same policies or institutions would also increase a country's ability to join the convergence club.

Now, new growth theories may be criticized by development economists and policy makers, precisely because of the universal nature of the policy recommendations that appear to follow from them: no matter how developed a country or sector currently is, it seems that one should prescribe the same medicines (legal reform to enforce property rights, investment climate favorable to entrepreneurship, education, macrostability,..) to maximize the growth prospects of that country or sector.

However, in his essay on *Economic Backwardness in Historical Perspective,* Gerschenkron (1962) argues that relatively backward economies could more rapidly catch up with more advanced countries by introducing "appropriate institutions" that are growth-enhancing at an early stage of development but may cease to be so at a later stage. Thus, countries like Japan or Korea managed to achieve very high growth rates between 1945 up until the 1990s with institutional arrangements involving long-term relationships between firms and banks, the predominance of large conglomerates, and strong government intervention through export promotion and subsidized loans to the enterprise sector, all of which depart from the more market-based and laissez-faire institutional model pioneered and promoted by the US.

That growth-enhancing institutions or policies might change with a country's or sector's distance to the technological frontier, should not come as a total surprise to our readers at this point: in the previous section, we saw that competition could have opposite effects on innovation incentives depending on whether firms were initially closer to or farther below the fringe in the corresponding industry (it would enhance innovations in neck-and-neck industries, and discourage it in industries where innovating firms are far below the frontier). The same type of conclusion turns out to hold true when one looks at the interplay between countries' distance to the world technology frontier and "openness". Using a cross-country panel of more than 100 countries over the 1960-2000 period, Acemoglu-Aghion-Zilibotti (2002), henceforth AAZ, regress the average growth rate over a five year period on a country's distance to the US frontier (measured by the ratio of GDP per capita in that country to per capita GDP in the US) at the beginning of the period. Then, splitting the sample of countries in two groups, corresponding respectively to a high and a low openness group according to Frankel-Romer's openness indicator, AAZ show that average growth decreases more rapidly as a country approaches the world frontier when openness is low. Thus, while a low degree of openness does not appear to be detrimental to growth in countries far below the world frontier, it becomes increasingly detrimental to growth as the country approaches the frontier. AAZ repeat the same exercise using entry costs to new firms (measured as in Djankov et al (2001)) instead of openness, and they obtain a similar conclusion, namely that high entry costs are most damaging to growth when a country is close to the world frontier, unlike in countries far below the frontier.

In this section, we shall argue that Gerschenkron's idea of "appropriate institutions" can be easily embedded into our growth framework, in a way that can help substantiate the following claims:

1. different institution or policy design affects productivity growth differently depending upon a country's or sector's distance to the technological frontier;

2. a country's distance to the technological frontier affect the type of organizations we observe in this country (e.g, bank versus market finance, vertical integration versus outsourcing,..).

The remaining part of the section is organized as follows. We first describe the growth equation which AAZ introduce to embed the notion of "appropriate institutions" into the above growth framework. We then focus on the first question about the effects of institution design on productivity growth, by concentrating on the relationship between growth and the organization of education. Finally we briefly discuss the effects of distance on equilibrium institutions in a concluding subsection.

6.2 A simple model of appropriate institutions

Consider the following variant of the multi-country growth model of Section 3. In each country, a unique general good which also serves as numéraire, is produced competitively using a continuum of intermediate inputs according to:

$$y_t = \int_0^1 (A_t(i))^{1-\alpha} x_t(i)^{\alpha} \ di, \tag{25}$$

where $A_t(i)$ is the productivity in sector i at time t, $x_t(i)$ is the flow of intermediate good i used in general good production again at time t, and $\alpha \in [0, 1]$.

As before, ex post each intermediate good producer faces a competitive fringe of imitators that forces her to charge a limit price $p_t(i) = \chi > 1$. Consequently, equilibrium monopoly profits (gross of the fixed cost) are simply given by::

$$\pi_t(i) = \delta A_t(i)$$

where $\delta \equiv (\chi - 1) \chi^{-\frac{1}{1-\alpha}}$.

We still let

$$A_t \equiv \int_0^1 A_t(i) \, di$$

denote the average productivity in the country at date t, $\overline{A}_t$ the productivity at the world frontier which we assume to grow at the constant rate g from one period to the next, and $a_t = A_t / \bar{A}_t$ the (inverse) measure of the country's distance to the technological frontier at date t.

The main departure from the convergence model in Section 3, lies in the equation for productivity growth. Suppose that intermediate firms have two ways to generate productivity growth: (a) they can imitate existing world frontier technologies; (b) they can innovate upon the previous local technology. More specifically, we assume:

$$A_t(i) = \eta \bar{A}_{t-1} + \gamma A_{t-1}, \tag{26}$$

where $\eta \bar{A}_{t-1}$ and γA_{t-1} refer respectively to the imitation and innovation components of productivity growth. Imitations use the existing frontier technology at the end of period $(t-1)$, thus they multiply $\bar{A}_{t-1}$, whereas innovations build on the knowledge stock of the country, and therefore they multiply A_{t-1}.

Now dividing both sides of (26) by $\overline{A}_t$, using the fact that

$$\overline{A}_t = (1+g)\bar{A}_{t-1},$$

and integrating over all intermediate sectors i, we immediately obtain the following linear relationship between the country's distance to frontier a_t at date t and the distance to frontier a_{t-1} at date $t-1$:

$$a_t = \frac{1}{1+g}(\eta + \gamma a_{t-1}). \tag{27}$$

This equation clearly shows that the relative importance of innovation for productivity growth, increases as: (i) the country moves closer to the world technological frontier, i.e as a_{t-1} moves closer to 1, whereas imitation is more important when the country is far below the frontier, i.e when a_{t-1} is close to zero; (ii) a new technological revolution (e.g the ITC revolution) occurs that increases the importance of innovation, i.e increases γ.

This immediately generates a theory of "appropriate institutions" and growth: suppose that imitation and innovation activities do not require the same institutions. Typically, imitation activities (i.e η in the above equation (27)) will be enhanced by long-term investments within (large) existing firms, which in turn may benefit from long-term bank finance and/or subsidized credit as in Japan or Korea since 1945. On the other hand, innovation activities (i.e γ) require initiative, risk-taking, and also the selection of good projects and talents and the weeding out of projects that turn out not to be profitable. This in turn calls for more market-based and flexible institutions, in particular for a higher reliance on market finance and speculative monitoring, higher competition and trade liberalization to weed out the bad projects, more flexible labor markets for firms to select the most talented or best matched employees, non-integrated firms to increase initiative and entrepreneurship downstream, etc. It then follows from equation (27) that the growth-maximizing institutions will evolve as a country moves towards the world technological frontier. Far below the frontier, a country will grow faster if it adopts what AAZ refers to as *investment-based* institutions or policies, whereas closer to the frontier growth will be maximized if the country switches to *innovation-based* institutions or policies.

A natural question is of course whether institutions actually change when they should from a growth- (or welfare-) maximizing point of view, in other words how do equilibrium institutions at all stages of development compare with the growth-maximizing institutions? This question is addressed in details in AAZ, and we will come back to it briefly in the last subsection.

6.3 Appropriate education systems

In his seminal paper on economic development, Lucas (1988) emphasized the *accumulation* of human capital as a main engine of growth; thus, according to the analysis in that paper, cross-country differences in growth rates across countries would be primarily attributable to differences in *rates of accumulation* of human capital. An alternative approach, pioneered by Nelson-Phelps (1966), revived by the Schumpeterian growth literature[32], would instead emphasize the combined effect of the *stock* of human capital and of the innovation process in generating long-run growth and fostering convergence. In this alternative approach, differences in growth rates across countries would be mainly attributable to differences in *stocks* of human capital, as those condition countries' ability to innovate or to adapt to new technologies and thereby catch up with the world technological frontier. Thus, in the basic model of Section 2, the equilibrium R&D investment and therefore the steady-state growth rate were shown to be increasing in the aggregate supply of (skilled) labor L and in the productivity of research λ, both of which refer more to the *stock* and *efficiency* of human capital than to its rate of accumulation.

[32] For example, see Acemoglu (1996, 2002), Aghion-Howitt-Violante (2002) and Aghion (2002).

Now, whichever approach one takes, and the evidence so far supports the two approaches as being somewhat complementary, once again one may worry about growth models delivering too general a message, namely that more education is always growth enhancing. In this subsection we will try to go one step further and argue that the AAZ specification (summarized by the above equation (26), can be used to analyze the effects, not only of the total *amount* of education, but more importantly of the *organization* of education, on growth in countries at different stages of development..

This subsection, which is based on Vandenbussche-Aghion-Meghir (2003), henceforth VAM, focuses on one particular aspect of the organization of education systems, namely the mix between primary, secondary, and higher education. We consider a variant of the AAZ model outlined in the previous subsection, in which innovation requires highly educated labor, whereas imitation can be performed by both, highly educated and lower-skill workers. A main prediction emerging from this a model, is that the closer a country gets to the world technology frontier, the more growth-enhancing it becomes to invest in higher education. In the latter part of the subsection we confront this prediction with preliminary cross-country evidence.

6.3.1 Distance to frontier and the growth impact of higher education

There is again a unique general good, produced competitively using a continuum of intermediate inputs according to:

$$y = \int_0^1 A(i)^{1-\alpha} x(i)^{\alpha} di, \tag{28}$$

where $A\,(i)$ is the productivity in sector i, $x(i)$ is the flow of intermediate good i used in general good production, $\alpha \in [0, 1]$.

In each intermediate sector i, one intermediate producer can produce the intermediate good with leading-edge productivity $A_t\,(i)$, using general good as capital according to a one-for-one technology. As before, ex post each intermediate good producer faces a competitive fringe of imitators that forces her to charge a limit price $p\,(i) = \chi > 1$. Consequently, we have:

$$p(i) = \chi = \frac{\partial y}{\partial x},$$

so that equilibrium monopoly profits in each sector i are given by::

$$\pi\,(i) = (p(i) - 1)x(i) = \delta\pi(i) = \delta A(i)L$$

where $\delta = (\chi - 1)(\frac{\chi}{\alpha})^{\frac{-1}{1-\alpha}}$.

As in the previous subsection, intermediate firms can increase productivity, either by imitating frontier technologies or by innovating upon existing technologies in the country. Imitation can be performed by both types of workers, whereas innovation requires high education. More specifically, we focus on the following class of productivity growth functions:

$$A_t(i) - A_{t-1}(i) = u_{m,i,t}^{\sigma} s_{m,i,t}^{1-\sigma} \bar{A}_{t-1} + \gamma u_{n,i,t}^{\phi} s_{n,i,t}^{1-\phi} A_{t-1}, \tag{29}$$

where $u_{m,i,t}$ (resp. $s_{m,i,t}$) is the amount of unskilled (resp. skilled) labor used in imitation in sector i at time t, $u_{n,i,t}$ (resp. $s_{n,i,t}$) is the amount of unskilled (resp. skilled) units of labor used by sector i in innovation at time t, σ (resp. ϕ) is the elasticity of unskilled labor in imitation (resp. innovation), and $\gamma > 0$ measures the relative efficiency of innovation compared to imitation in generating productivity growth.

We shall assume:

(A1) *The elasticity of skilled labor is higher in innovation than in imitation, and conversely for the elasticity of unskilled labor, that is:* $\phi < \sigma$.

Let S (resp. $U = 1 - S$) denote the fraction of the labor force with higher (resp. primary or secondary) education. Let $w_{u,t}\bar{A}_{t-1}$ (resp. $w_{s,t}\bar{A}_{t-1}$) denote the current price of unskilled (resp. skilled) labor.

The total labor cost of productivity improvement by intermediate firm i at time t, is equal to:

$$W_{i,t} = [w_{u,t}(u_{m,i,t} + u_{n,i,t}) + w_{s,t}(s_{m,i,t} + s_{n,i,t})]\overline{A}_{t-1}.$$

Letting $a_t = A_t/\bar{A}_t$ measure the country's distance to the technological frontier, and letting the frontier technology $\bar{A}_t$ grow at constant rate g, the intermediate producer will solve:

$$\max_{u_{m,i,t}, s_{m,i,t}, u_{n,i,t}, s_{n,i,t}} \{\delta[u_{m,i,t}^{\sigma} s_{m,i,t}^{1-\sigma}(1 - a_{t-1}) + \gamma u_{n,i,t}^{\phi} s_{n,i,t}^{1-\phi} a_{t-1}]\bar{A}_{t-1} - W_{i,t}\}. \tag{30}$$

Using the fact that all intermediate firms face the same maximization problem, and that there is a unit mass of intermediate firms, we necessarily have:

$$u_{j,i,t} \equiv u_{j,t}; s_{j,i,t} \equiv s_{j,t} \text{ for all } i \text{ and for } j = m, n; \tag{31}$$

and

$$S = s_{m,t} + s_{n,t}; U = 1 - S = u_{m,t} + u_{n,t}. \tag{32}$$

Taking first order conditions for the maximization problem (30), then making use of (31) and (32), and then computing the equilibrium rate of productivity growth

$$g_t = \int_0^1 \frac{A_t(i) - A_{t-1}}{A_{t-1}} di,$$

one can establish (see VAM (2003)):

Lemma 1 *Let* $\psi = \frac{\sigma(1-\phi)}{(1-\sigma)\phi}$. *If parameter values are such that the solution to (30) is interior, then we have:*

$$\frac{\partial g_t}{\partial a} = \phi(1-\phi)h'(a)h(a)^{1-\phi}[h(a)U - S],$$

where

$$h(a) = (\frac{(1-\sigma)\psi^{\sigma}(1-a)}{(1-\phi)\gamma a})^{\frac{1}{\sigma-\phi}} \geq \frac{S}{U}.$$

This, together with the fact that $h(a)$ is obviously decreasing in a given our assumption (A1), immediately implies:

Proposition 2 *A marginal increase in the fraction of labor with higher education, enhances productivity growth all the more the closer the country is from the world technology frontier, that is:*

$$\frac{\partial^2 g_t}{\partial a \partial S} > 0.$$

The intuition follows directly from the Rybczynski theorem in international trade. Stated in the context of a two sector-two input economy, this theorem says that an increase in the supply of input in the sector that uses that input more intensively, should increase "output" in that sector more than proportionally. To transpose this result to the context of our model, consider the effect of an increase in the supply of skilled labor, keeping the supply of unskilled labor fixed and for given a. Given that skilled workers contribute relatively more to productivity growth and profits if employed in innovation rather than in imitation (our Assumption (A1)), the demand for additional skilled labor will tend to be higher in innovation. But then the marginal productivity of unskilled labor should also increase more in innovation than in imitation, hence a net flow of unskilled workers should also move from imitation into innovation. This in turn will enhance further the marginal productivity of skilled labor in innovation, thereby inducing an ever greater fraction of skilled labor to move to innovation. Now the closer the country is to the technology frontier (i.e the higher a), the stronger this Rybszynski effect as a higher a increases the efficiency of both, skilled and unskilled labor, in innovation relative to imitation. A second, reinforcing, reason is that an increase in the fraction of skilled labor reduces the amount of unskilled labor available in the economy, hence reducing the marginal productivity of skilled labor in imitation, all the more the closer the country is from the frontier.

We can now confront this prediction with cross-country evidence on higher education, distance to frontier, and productivity growth.

6.3.2 Empirical evidence

The prediction that higher education has stronger growth-enhancing effects close to the technological frontier can be tested using cross-regional or cross-country data. Thus VAM consider a panel dataset of 19 OECD countries over the period 1960-2000. Output and investment data are drawn from Penn World Tables 6.1 (2002) and human capital data from Barro-Lee (2000). The Barro-Lee data indicate the fraction of a country's population that has reached a certain level of schooling at intervals of five years, so VAM use the fraction that has received some higher education together with their measure of TFP (itself constructed assuming a constant labor share of .7 across countries) to perform the following regression:

$$g_{j,t} = \alpha_{0,j} + \alpha_1 dist_{j,t-1} + \alpha_2 \Lambda_{j,t-1} + \alpha_3 (dist_{j,t-1} * \Lambda_{j,t-1}) + u_{j,t},$$

where $g_{j,t}$ is country j's growth rate over a five year period, $dist_{j,t-1}$ is country j's closeness to the technological frontier at $t-1$ (i.e. 5 years before), $\Lambda_{j,t-1}$ is the fraction of the working age population with some higher education in the previous period and $\alpha_{0,j}$ is a country dummy controlling for country fixed effects. The closeness variable is instrumented with its lagged value at $t-2$, and the fraction variable is instrumented using expenditure on tertiary education per capita lagged by two periods, and the interaction term is instrumented using the interaction between the two instruments for closeness and for the fraction variables. Finally, the standard errors we report allow for serial correlation and heteroskedasticity.

The results from this regression are shown in Table 1 below. In particular, we find a positive and significant interaction between our education measure and closeness to the frontier, as predicted by the theory in the previous subsection. This result demonstrates that it is more important to expand years of higher education close to the technological frontier.

7 Conclusion

In this chapter we argued that the endogenous growth model with quality-improving innovations provides a framework for analyzing the determinants of long-run growth and convergence that is versatile, simple and empirically useful. Versatile, as the same framework can be used to analyze how growth interacts with development and cross-country convergence and divergence, how it interacts with industrial organization and in particular market structure, and how it interacts with organizations and institutional change. Simple, since all these aspects can be analyzed using the same elementary model. Empirically useful, as the framework generates a whole range of new microeconomic and macroeconomic predictions while it addresses empirical criticisms raised by other endogenous growth models in the literature.

Far from closing the field, the chapter suggests many avenues for future research. For example, on growth and convergence, more research remains to be done to identify the main determinants of cross-country convergence and divergence.[33] Also important, is to analyze the role of international intellectual property right protections and foreign direct investment in preventing or favoring convergence. On growth and industrial organization, we have restricted

[33] In Aghion, Howitt and Mayer-Foulkes (2004) we emphasize the role of credit constraints in R&D as a distinguishing factor between the countries that converge in growth rates and in levels towards the frontier, those that converge only in growth rates, and those that follow a divergent path towards a lower rate of long-run growth. Whether credit constraints, or other factors such as health, education, and property rights protection, are key to this three-fold classification, remains an open question

attention to product market competition among existing firms. But what can we say about entry and its impact on incumbents' innovation activities?[34] On institutions, we have just touched upon the question of how technical change interacts with organizational change. Do countries or firms/sectors actually get stuck in institutional traps of the kind described in Section 6? What enables such traps to disappear over time? How do political economy considerations interact with this process? There is also the whole issue of wage inequality and its interplay with technical change, on which the Schumpeterian approach developed in this chapter can also shed light.[35]

If we just had to select three aspects or questions, so far largely open, and which could also be explored using our approach, we would suggest the following. First, on the role of basic science in generating (very) long-term growth. Do fundamental innovations (or the so called "general purpose technologies") require the same incentive system and the same rewards as industrial innovations? How can one design incentive systems in universities so that university research would best complement private research? A second aspect is the interplay between growth and volatility. Is R&D and innovation procyclical or countercyclical, and is macroeconomic volatility always detrimental to innovation and growth? Answering this question in turn opens up a whole new research topic on the macropolicy of growth[36] A third aspect is the extent to which our growth paradigm can be applied to less developed economies. In particular, can we use the new growth approach developed in this chapter to revisit the important issue of poverty reduction?[37] On all these questions, we believe that over time compelling answers will emerge from a fruitful dialogue between applied theorists, in particular those working on endogenous growth models of the kind developed in this chapter, and microeconometricians who use firm-level panel data to analyze the interplay between competition and innovation or between productivity growth and organizations.

Finally, in this chapter we have argued that modelling growth as resulting from quality-improving innovations, provides a natural framework to address a whole array of issues from competition to development, each time with theoretical predictions that can be empirically tested and also lead to more precise policy prescriptions. However, one might think of more direct ways of testing the quality-ladder model against the variety model analyzed in the other chapters. For example, in current work with Pol Antras and Susanne Prantl, we are using a panel data set of UK firms over the past fifteen years, to assess whether variety had any impact on innovation and growth. Using input-output tables, our preliminary results suggest that exit of input firms has but a positive effect on the productivity growth of final producers.

[34] See Aghion et al (2003a, 2003b) for preliminary work on entry and growth.

[35] E.g, see Aghion (2003) and the chapter by Krusell and Violante in this Handbook volume.

[36] See Aghion-Angeletos-Banerjee-Manova (2004).

[37] See Aghion and Armendariz de Aghion (2004) for some preliminary thoughts on this aspect.

References

Acemoglu, D, Aghion, P, Griffith, R, and F. Zilibotti (2003): “Technology, Hold-Up, and Vertical Integration: What Do We Learn From Micro Data?”, mimeo IFS, London.

Acemoglu, D, Aghion, P, and F. Zilibotti (2002): “Distance to Frontier, Selection, and Economic Growth”, NBER Working Paper 9066

Aghion, P, Angeletos, M, Banerjee, A, and K. Manova (2004), ” Volatility and Growth: Financial Development and the Cyclical Composition of Investment”, Harvard Working Paper.

Aghion, P, and B. Armendariz de Aghion (2004): ”A New Growth Approach to Poverty Reduction”, mimeo Harvard.

Aghion, P, A. V. Banerjee, and T. Piketty (1999): “Dualism and Macroeconomic Volatility”, *Quarterly Journal of Economics,* 114 pp. 1359-97.

Aghion, P, Bloom, B, Blundell, R, Griffith, R, and P. Howitt (2002): “Competition and Innovation: An Inverted-U Relationship”, NBER Working Paper 9269.

Aghion, P, and P. Bolton (1997): “A Model of Trickle-Down Growth and Development”, *Review of Economic Studies.*

Aghion, P, Harris, C, Howitt, P, and J. Vickers (2001): “Competition, Imitation, and Growth with Step-by-Step Innovation”, *Review of Economic Studies,* 68, 467-492.

Aghion, P, Harris, C, and J. Vickers (1997): “Competition and Growth with Step-by-Step Innovation: An Example”, *European Economic Review Papers and Proceedings,* pp. 771-782

Aghion, P, and P. Howitt (1992): “A Model of Growth through Creative Destruction”, *Econometrica,* 60, 323-351.

Aghion, P, and P. Howitt (1998): *Endogenous Growth Theory,* MIT Press, Cambridge, MA.

Aghion, P, Howitt, P, and D. Mayer-Foulkes (2004): “The Effect of Financial Development on Convergence: Theory and Evidence”, unpublished, Brown University.

Aghion, P, P. Howitt, and G. L. Violante (2002): “General Purpose Technology and Wage Inequality”, *Journal of Economic Growth,* 7, pp. 315-45.

Aghion, P, Meghir, C, and J. Vandenbussche (2003): “Productivity Growth and the Composition of Education Spending”, unpublished.

Aghion, P, and J. Tirole (1997): “Formal and Real Authority in Organizations”, *Journal of Political Economy,* 105, 1-29.

Arrow, K. J. (1969): “Classificatory Notes on the Production and Transmission of Technological Knowledge”, *American Economic Review Papers and Proceedings,* 59, pp. 29-35.

Banerjee, A, and A. Newman (1993): “Occupational Choice and the Process of Development”, *Journal of Political Economy,* 101, 274-298.

Barro, R. J., and X. Sala-i-Martin (1992): “Convergence”, *Journal of Political Economy,* 100, pp. 223-51.

Barro, R. J., and X. Sala-i-Martin (1997): "Technological Diffusion, Convergence, and Growth", *Journal of Economic Growth,* 2, pp. 1-26.

Baumol, W. J. (1986): "Productivity Growth, Convergence, and Welfare", *American Economic Review,* 76, pp. 1072-85.

Benhabib, J, and M. Spiegel (2002): "Human Capital and Technology Diffusion", Unpublished, NYU.

Bernanke, B., and M. Gertler (1989): "Agency Costs, Net Worth, and Business Fluctuations", *American Economic Review,* 79, pp. 14-31.

Blundell, R, Griffith, R, and J. Van Reenen (1999): "Market Share, Market Value and Innovation in a Panel of British Manufacturing Firms", *Review of Economic Studies,* 66, 529-554.

Boone, J (2000): "Measuring Product Market Competition", CEPR Discussion Paper 2636.

Coe, D. T., and E. Helpman (1995): "International R&D Spillovers", *European Economic Review,* 39, pp. 859-87.

Coe, D. T., E. Helpman, and A. W. Hoffmaister (1996): "North-South R& D Spillovers", *Economic Journal,* 107, pp. 134-49.

Cohen, W, R. Levin (1989): "Empirical Studies of Innovation and Market Structure", Chapter 18 of R. Schalensee and R. Willig, *Handbook of Industrial Organization,* Elsevier.

Cohen, W. M., and D.A. Levinthal (1989): "Innovation and Learning: The Two Faces of R&D", *Economic Journal,* 99, pp. 569-96.

Corriveau, L (1991): "Entrepreneurs, Growth and Cycles," PhD Dissertation, University of Western Ontario.

Dinopoulos, E, and P. Thompson (1998): "Schumpeterian Growth without Scale Effects", *Journal of Economic Growth,* 3, pp. 313-35.

Djankov, S, La Porta, R, Lopez-de-Silanes, F, and A Shleifer (2002): "The Regulation of Entry," *Quarterly Journal of Economics*, CXVII.

Durlauf, S, and P. Johnson (1995): "Multiple Regimes and Cross-Country Growth Behavior", *Journal of Applied Econometrics,* 10, pp. 365-84.

Eaton, J, and S. Kortum (1996): "Trade in Ideas: Patenting and Productivity in the OECD", *Journal of International Economics,* 40, pp. 251-78.

Eaton, J, and S. Kortum (2001): "Technology, Trade, and Growth: A Unified Framework", *European Economic Review,* 45, pp. 742-55.

Evans, P (1996): "Using Cross-Country Variances to Evaluate Growth Theories", *Journal of Economic Dynamics and Control,* 20, pp. 1027-49.

Evenson, R. E., and L. E. Westphal (1995): "Technological Change and Technology Strategy", In *Handbook of Development Economics,vol 3A*, edited by T. N. Srinivasan and Jere Behrman, 2209-99. Amsterdam: Elsevier.

Frankel, J, and D. Romer (1999): "Does Trade Cause Growth?", *American Economic Review,* 89, 379-399.

Galor, O, and J. Zeira (1993): "Income Distribution and Macroeconomics", *Review of Economic Studies,* 60, 35-52.

Geroski, P (1995): *Market Structure, Corporate Performance and Innovative Activity*, Oxford University Press.

Gerschenkron, A (1952): "Economic Backwardness in Historical Perspective", In *The Progress of Underdeveloped Areas*, edited by Bert F. Hoselitz. Chicago: University of Chicago Press.

Griffith, R, S. Redding, and J. Van Reenen (2001): "Mapping the Two Faces of R&D: Productivity Growth in a Panel of OECD Industries", unpublished.

Grossman, G, and E. Helpman (1991): *Innovation and Growth in the Global Economy,* MIT Press.

Grossman, S, and O. Hart (1986): "The Costs and Benefits of Ownership: A Theory of Lateral and Vertical Integration", *Journal of Political Economy, 94, 691-719.*

Ha, J, and P. Howitt (2004): "Accounting for Trends in Productivity and R&D: A Schumpeterian Critique of Semi-Endogenous Growth Theory", unpublished..

Howitt, P (1999): "Steady Endogenous Growth with Population and R&D Inputs Growing", *Journal of Political Economy,* 107, pp. 715-30.

Howitt, P (2000): "Endogenous Growth and Cross-Country Income Differences", *American Economic Review,* 90, 829-46.

Howitt, P, and D. Mayer-Foulkes (2002): "R&D, Implementation and Stagnation: A Schumpeterian Theory of Convergence Clubs", NBER Working Paper 9104.

Jones, C (1995): "R&D-Based Models of Economic Growth", *Journal of Political Economy,* 103, 759-84.

Jones, C (1999): "Growth: With or Without Scale Effects?" *American Economic Review, Papers and Proceedings,* 89, 139-44..

Keller, W (2002): "Technology Diffusion and the World Distribution of Income: The Role of Geography, Language, and Trade", Unpublished, University of Texas.

van de Klundert, T, and S. Smulders (1997): "Growth, Competition, and Welfare", *Scandinavian Journal of Economics,* 99, pp. 99-118.

La Porta, R, F. Lopez-de-Silanes, A. Shleifer, and R. W. Vishny (1998): "Law and Finance", *Journal of Political Economy,* 106, pp. 1113-55.

Levine, R, N. Loayza, and T. Beck (2000): "Financial Intermediation and Growth: Causality and Causes", *Journal of Monetary Economics,* 46, pp. 31-77.

Lucas, R (1988): "On the Mechanics of Economic Development", *Journal of Monetary Economics, 22, 3-42.*

Maddison, A (2001):*The World Economy: A Millennial Perspective.* Development Centre Studies. Paris: OECD.

Mankiw, G, Romer, D and D. Weil (1992): "A Contribution to the Empirics of Economic Growth", *Quarterly Journal of Economics,* 107, pp. 407-37.

Mayer-Foulkes, D (2002): "Global Divergence", Documento de Trabajo del CIDE, SDTE 250, División de Economía.

Mayer-Foulkes, D (2003): "Convergence Clubs in Cross-Country Life Expectancy Dynamics", In *Perspectives on Growth and Poverty*, edited by Rolph van der Hoeven and Anthony F. Shorrocks, 144-71. Tokyo: United Nations University Press.

Nelson, R, and E. Phelps (1966): "Investment in Humans, Technological Diffusion, and Economic Growth", *American Economic Review, 61, 69-75.*

Nickell, S (1996): "Competition and Corporate Performance", *Journal of Political Economy,* 104, 724-746

Peretto, P. F. (1998): "Technological Change, Market Rivalry, and the Evolution of the Capitalist Engine of Growth", *Journal of Economic Growth,* 3, pp. 53-80.

Piketty, T, Postel-Vinay, G, and J-L Rosenthal (2003): " Wealth Concentration in a Developing Economy: Paris and France, 1807-1994", mimeo EHESS (Paris).

Pritchett, L (1997): "Divergence, Big-Time", *Journal of Economic Perspectives,* 11, pp. 3-17.

Quah, D (1993): "Empirical Cross-Section Dynamics in Economic Growth", *European Economic Review,* 37, pp. 426-34.

Quah, D (1996): "Convergence Empirics Across Economies with (Some) Capital Mobility", *Journal of Economic Growth,* 1,: 95-124.

Quah, D (1997): "Empirics for Growth and Distribution: Stratification, Polarization, and Convergence Clubs", *Journal of Economic Growth,* 2, pp. 27-59.

Romer, P (1990): "Endogenous Technical Change", *Journal of Political Economy,*

Savvides, A, and M. Zachariadis (2004): "International Technology Diffusion and the Growth of TFP in the Manufacturing Sector of Developing Economies", *Review of Development Economics*, forthcoming.

Scherer, F (1967): "Market Structure and the Employment of Scientists and Engineers", *American Economic Review,* 57, 524-531.

Segerstrom, P, Anant, T, and E. Dinopoulos (1990): "A Schumpeterian Model of the Product Life Cycle", *American Economic Review, 80, 1077-1092*

Tirole, J (1988): *The Theory of Industrial Organization.* Cambridge, MA: MIT Press.

Young, A (1998): "Growth without Scale Effects", *Journal of Political Economy*, 106, 41-63.

Zachariadis, M (2003): "R&D, Innovation, and Technological Progress: A Test of the Schumpeterian Framework without Scale Effects", *Canadian Journal of Economics,* 36, pp. 566-86.

Table 1: Growth, Financial Development, and Initial GDP Gap

Estimation of equation: $g - g_1 = \beta_0 + \beta_f F + \beta_y (y - y_1) + \beta_{fy} F (y-y_1) + \beta_x X$

Financial development *(F)*	Private Credit			Liquid Liabilities			Bank Assets		
Conditioning set (*X*)	Empty	Policy[a]	Full[b]	Empty	Policy[a]	Full[b]	Empty	Policy[a]	Full[b]
Coefficient estimates									
β_f	-0.015	-0.013	-0.016	-0.029	-0.030	-0.027	-0.019	-0.020	-0.022
	(-0.93)	(-0.68)	(-0.78)	(-1.04)	(-0.99)	(-0.90)	(-1.07)	(-1.03)	(-1.12)
β_y	1.507***	1.193*	1.131	2.648***	2.388**	2.384**	1.891***	1.335*	1.365
	(3.14)	(1.86)	(1.49)	(3.12)	(2.39)	(2.11)	(3.57)	(1.93)	(1.66)
β_{fy}	-0.061***	-0.063***	-0.063***	-0.076***	-0.077***	-0.073***	-0.081***	-0.081***	-0.081***
	(-5.35)	(-5.10)	(-4.62)	(-3.68)	(-3.81)	(-3.55)	(-5.07)	(-4.85)	(-4.46)
sample size	71	63	63	71	63	63	71	63	63

Notes: The dependent variable g-g_1 is the average growth rate of per-capita real GDP relative to the US, 1960-95. F is average Financial Development 1960-95 using 3 alternative measures: Private Credit is the value of credits by financial intermediaries to the private sector, divided by GDP, Liquid Liabilities is currency plus demand and interest-bearing liabilities of banks and non-bank financial intermediaries, divided by GDP, and Bank Assets is the ratio of all credits by banks to GDP. $y - y_1$ is the log of per-capita GDP in 1960 relative to the United States. [a]The Policy conditioning set includes average years of schooling in 1960, government size, inflation, the black market premium and openness to trade. [b]The Full conditioning set includes the policy set plus indicators of revolutions and coups, political assassinations and ethnic diversity. Estimation is by IV using L (legal origins) and $L (y$-$y_1)$ as instruments for F and $F (y$-$y_1)$. The numbers in parentheses are t-statistics. Significance at the 1%, 5% and 10% levels is denoted by ***, ** and * respectively.

Figure 1: Innovation and Product Market Competition