Institutions and Long-Term Development Policy

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Mexico

September 16th, 2005

Abstract

Market failures in human capital investment and innovation explain the main features of human development and economic growth. This is shown in a Schumpeterian multi-country model with technology transfer and trade. Thus, only institutions expanding investments in nutrition, education, health, skills, know-how and research in LDC's, beyond what markets can supply, will succeed in promoting long-term development. It is in the interest of leading countries to supplement home investments with concerted transfers, since the long-term world growth rate increases with world-wide knowledge levels and living standards. Underdevelopment consists of a series of policy-dependent lower steady states, with parallel or divergent growth rates, and with or without a human development trap. Free commerce raises the growth rate of countries able to support production at the global scale. Smaller or more backward countries grow slower and require aid to emerge. Skilled and unskilled workers in LDC's have a conflict of interest between supporting innovation or human capital investment. If innovation is favored, the human capital trap can persist, provoking opposition to globalization. If human capital investment is prioritized, a switch to innovation will eventually be necessary, requiring institutional change.

Give a man a fish and you feed him for a day.
Teach a man to fish and you feed him for a lifetime.
Chinese proverb

1. Introduction

This paper describes the long-term relation between human development and economic growth, in the light of a Schumpeterian theory of economic growth in an open, global economy with technology transfer, trade and human development. The theory implies that the political economy of countries with a human development deficit is characterized by a conflict of interests between its two classes of skilled and unskilled workers. Skilled workers favor promoting technological innovation (including technological adoption), while unskilled workers support human capital accumulation (also resulting in poverty alleviation). The institutional and organizational requirements of these two different development policies coincide in that both benefit from promoting the autonomous functioning of the markets and the efficiency of government expenditure (through public goods such as the rule of law, transparency and accountability). However, they differ in that they address different market failures requiring different financial and institutional solutions. When technological innovation is pursued, the human capital trap can persist and limit its success. When human capital investment is pursued, a change of tack to technological innovation will eventually be required.

Different policy choices (including autarchy versus openness) and different levels of market and government efficiency give rise to a series of different steady states in technological change, representing different forms of underdevelopment. The unskilled workers' optimal policy results in a two-stage trajectory that first eliminates the low human capital trap and then embarks on technological change, reminiscent of the history of ex-socialist countries. The skilled workers' optimal policy instead can result in the persistence of the human capital trap. Under each of these policy regimes, market and government efficiency are important determinant of whether divergence or convergence with the leading countries will result. Free commerce (although not necessarily FDI)[1] eliminates some of the worst regimes that exist in autarchy, when incentives for innovation are too low yet human capital investment is not pursued. Nevertheless, when incentives for in-

[1]Free commerce refers to the free trade of domestically produced goods, excluding foreign direct investment (FDI). "Free Trade" policies usually includes the later, which generates innovation incentives that must be accounted for (see Mayer-Foulkes, 2005).

novation are higher but research has diminishing returns, countries lagging behind too far, whose resources are unable to support innovative production at the global scale, may have a lower growth rate under free commerce than under autarchy, due to the loss of innovative sectors to foreign competition. Finally, from a global point of view, development is not a zero sum game. Leading countries' welfare essentially depends on the world growth rate, which is maximized when the world is fully developed. This can only be achieved if every country is endowed with its share of leading technological sectors. Concerted technological transfer is in the interest of the leading countries and can be a basis for peace and prosperity.

As will become clear below, the model of development presented here describes the interplay and trade-offs between technological change and the dynamics of human capital accumulation that make poverty persistent. In a simple way, it explains the basic forces shaping the political economy of development, in particular those having to do with the relation between economic growth and poverty. Hence, it provides the stage for a discussion of the role of institutions in development. As Douglass North (1993) points out in *The New Institutional Economics and Development,* "successful development policy entails an understanding of the dynamics of economic change if the policies pursued are to have the desired consequences. And a dynamic model of economic change entails as an integral part of that model analysis of the polity since it is the polity that specifies and enforces the formal rules." The model meets these requirements in general terms, and provides a basis for evaluating institutional policies for development. Before this, I summarize the model's assumptions, mechanisms and results.

1.1. Schumpeterian theory of economic growth

Econometric studies at the cross-country level have concluded that productivity differences are amongst the main sources of income differences.[2] Another underlying factor is human capital[3] These two factors, technological progress and human capital accumulation, are important determinants of capital accumulation. Thus recent growth models often concentrate on just these two elements. An additional

[2]Studies attributing cross-country differences in per-capita GDP to differences in productivity, include Knight, Loayza and Villanueva (1993), Dollar and Wolff (1994), Islam (1995), Caselli, Esquivel and Lefort (1996), Klenow and Rodriguez Clare (1997), Prescott (1998), Hall and Jones (1999), Feyrer (2000), Parente and Prescott (2000), Easterly and Levine (2001), Martin and Mitra (2001).

[3]Arrow (1962), Uzawa (1965), Frankel (1962), Romer (1986), Lucas (1988), Romer (1990), Mankiw, Romer and Weyl (1992).

challenge has been to simultaneously explain the combination of the Great Divergence of incomes occurring from the late 19th Century to the present day[4], and the rapid convergence in Europe[5] and miracle convergence episodes in other areas, such as East Asia, in the second half of the 20th Century. This unequal pattern of economic growth can be accounted for in terms of club-convergence,[6] modelling the concepts of development and underdevelopment as qualitatively different steady states.

The Schumpeterian analysis of endogenous technological change first concentrated on R&D in developed countries as the source of economic growth (Aghion and Howitt, 1988, 1992). A more general concept of innovation including technological transfer and adoption in a multi-country model can induce convergence (Howitt, 2000) and can be used to address problems of development including divergence. For example, the existence of a human capital threshold distinguishing R&D from implementation can give rise to convergence clubs and explain long-term divergence (Howitt and Mayer-Foulkes, 2005). Institutional differences reflected in financial development can determine technological absorption rates and also explain convergence clubs and long-term divergence (Aghion, Howitt and Mayer-Foulkes, 2005). Foreign direct investment in the open global economy giving access to cheap labor can give rise to asymmetric innovation incentives favoring leading countries, as well as crowd out local innovation: these mechanisms can explain persistent inequality and divergence between economies differing only in their relative status, without any assumption of increasing returns (Mayer-Foulkes, 2005). The present paper explains the relation between human development and economic growth in the setting of a global economy with technological transfer and trade, and serves to generate the basic long-term policy alternatives for development, as well as their institutional requirements.

The first step in our Schumpeterian model puts together the arguments for convergence into a basic two-country model incorporating free commerce. The basic mechanism works as follows. Free commerce makes home wages proportional

[4]Pritchett (1997) estimates that the proportional gap in per-capita GDP between the richest and poorest countries worsened by a factor of five between 1870 and 1990. Similarly, according to Maddison (2001) this gap grew from 3 in 1820 to 19 in 1998. The proportional per-capita income gap between Mayer-Foulkes' (2002) richest and poorest convergence groups grew by a factor of 2.6 between 1960 and 1995, and between Maddison's (2001) richest and poorest groups by a factor of 1.75 between 1950 and 1998.

[5]Barro and Sala-i-Martin (1992), Mankiw, Romer and Weil (1992) and Evans (1996).

[6]Baumol (1986), Durlauf and Johnson (1995), Quah (1993, 1997), Mayer-Foulkes (2002, 2003, 2005).

to technological levels. Innovation in both lagging and leading countries, broadly understood to include technological adoption, is costly[7] and responds to the incentives for world profits. Innovation investment aimed at achieving proportional productivity jumps, which in principle are proportionally costly,[8] obtains higher than proportional returns in lagging countries, because of their access to the advanced contemporary knowledge of the leading countries (technology transfer). This is Gerschenkron's (1952) *advantage of backwardness* in technological change, which constitutes a force for convergence. However, country-specific differences in size, human capital, policies and institutions can lead to persistent inequality and divergence, if these affect the incentives for innovation strongly enough. Lower incentives for innovation will result in a reduced rate of technological change. If these disadvantages are not too strong, at some point the advantage of backwardness will kick in and a stationary state with a fixed technological lag will result. Stronger disadvantages, however, will not be fully compensated, and will result in a permanently lower rate of technological change than the leading countries', giving rise to divergent steady states. Thus marginal changes in parameters will have level effects at higher and growth effects at lower income levels.

To model innovation under free commerce, an assumption about innovation races must be made. The model makes a simple assumption, that winning sectors are allocated in equal proportions by nature. This is a conservative assumption in that lower human capital levels and the implied higher relative human capital wages could adversely affect innovation races and resulting in lower steady states.

A discussion of innovation is not complete without a discussion of the presence of market failures and the role of government. First, the very incentives for innovation are monopoly profits on an invention. This gives rise to huge players in the international scene whose only counterpart in underdeveloped countries may be the government. Competing with them and accessing the advantage of backwardness through production for the world market may require solving considerable problems of coordination and scale, negotiating technological transfer, ensuring a coherent policy of self-interest, subsidizing infant industries, identifying potential areas of success (by private or public agents), and so on. More basically, implementing technological change often requires concrete public inputs, such as

[7]In his survey on international technology diffusion Keller (2004) finds international diffusion is neither inevitable nor automatic, requiring domestic investments. 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.

[8]This is the *fishing out* effect.

roads, railroad tracks, airports, the electricity distribution network, the "internet superhighway", new regulations, and so on. Moreover, a widespread fact about innovation in the present day is that the social incentives for it are greater than the private incentives. Consequently, policies promoting innovation have been routinely applied in most if not all developed and recently developed countries. In the model, we simply assume that innovative production has a public input. Government promotes innovation by announcing some level of public inputs for use in the production of successful innovations, determining their expected profit level. Such public inputs may include the maintenance of appropriate institutions such as property rights if these are costly. Institutional arrangements promoting innovation whose cost is negligible will be subsumed in a general fixed productivity effect.

The next step is to incorporate human development.

1.2. Human development

The concept of "Human Development", understood as an index of human well-being including education, health and income, drew wide attention with the 1990 UNDP Human Development Report, which "addresses, as its main issue, the question of how economic growth translates — or fails to translate — into human development.". This is one of the questions that the multiple steady states in the present model will address. However, a more dynamic, long-term conception of *human development*, and of its mutual interaction with economic growth, is our point of departure.

Historical and macroeconomic studies have shown that health accounts for at least one third of long-term economic growth,[9] with continuing importance to this day.[10] These studies have uncovered momentous secular rises in stature, weight and life expectancy that form an integral part of long-term human development.[11]

[9]Such studies include Nobel Prize winning historical studies by Fogel (1991, 1992, 1994[a], 1994[b]) for England over the last 200 years; Arora (2001) (for seven advanced countries using 100- to 125- year time series of diverse health indicators); Mayer (2001a), Mayer (2001b), Weil, D. (2001).

[10]E.g. Barro (1991), Barro and Lee (1994), Barro and Sala-i-Martin (1995), Barro (1996), Knowles and Owen (1995, 1997), Bhargava, Jamison, Lau, and Murray (2000), Easterly and Levine (1997), Gallup and Sachs (2000), Sachs and Warner (1995), Sachs and Warner (1997).

[11]Average stature rose from 164 to 181 cm in Holland between 1860 and 2002 and from 161 to 173 cm in France and Norway between 1705 and 1975. Average weight rose from 46 to 73 kg in Norway and France, 1705 to 1975. Life expectancy rose from 41 to 78 years in England between 1841 and 1998; and from 29 to 60 years in India between 1930 and 1990. (Fogel, 2002;

This line of research has concluded that the synergism between technological and physiological improvements has produced a rapid, culturally transmitted form of human evolution that is biological but not genetic, called by Fogel (2002) *techno-physio evolution.* However, microeconomic studies, using a unified conception of human capital including nutrition, health and education and measuring the impact of adult health on productivity, have been unable to explain the historical magnitude of this impact.[12] The appropriate explanation seems to emerge from a related field of study, the 'gradient' of adult health along income, which places childhood health at the origin of the gradient.[13] Thus, the *intergenerational* transmission of human development plays a fundamental role. Underlying this transmission of well-being are a series of market failures limiting human capital investment on children and inducing vicious cycles or poverty traps, whose nature changes as development proceeds. An example occurring at low levels of development is the productivity trap due to low nutrition addressed by the efficiency theory of wages,[14] whose study has documented substantial effects of nutrition on labor productivity.[15] At later stages, when education becomes important, low human capital traps can occur through increasing returns or indivisible investments in education.[16] Other mechanisms that could lead to poverty traps in human capital accumulation include: unequal inheritance of assets such as social capital, knowledge, or early child development,[17] child labor traps, and so on (Emerson and Souza, 2003).

Human development can therefore be understood as an intergenerational process

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Cervellati, Matteo and Uwe Sunde, 2003.)

[12]E.g. Schultz (1992, 1997, 1999), Thomas, Schoeni and Strauss (1997), Strauss and Thomas (1998), Savedoff and Schultz (2000).

[13]The large magnitude of the impact of early childhood health on schooling and therefore on adult income is confirmed by Case, Fertig and Paxson, 2003 in a study based on the 1958 National Child Development Study, which has followed all children born in Great Britain in the week of March 3, 1958 from birth to age 42. These authors find that "controlling for parents' incomes, educations and social status, that children who experience poor health have significantly lower educational attainment, and significantly poorer health and lower earnings on average as adults".

[14]E.g. Leibenstein (1957), Mazumdar (1959), Mirlees (1975), Stiglitz (1976), Bliss and Stern (1978), Dasgupta and Ray (1984, 1986), Dasgupta (1991).

[15]For surveys see Barlow (1979), Martorell and Arrayave (1984), Strauss (1985), Srinivasan (1992), Behrman and Deolalikar (1988).

[16]Galor and Zeira (1993), Galor and Tsiddon (1997), Azariadis and Drazen (1990), Durlauf (1996), Benabou (1996).

[17]See Levinger (1992), World Bank (1993) and Van der Gaag (2002) for the importance of early child development.

of human capital accumulation, slowed by the presence of market failures limiting the necessary investment, in which early child development plays a critical role. The presence of the constituent elements for such a human development trap, including the division of the population into two classes of families, is shown for Mexico in Mayer-Foulkes (2004).

We model these failures simply, through the requirement for an indivisible, or threshold, level of investment.[18] We assume that in this process, both the threshold investment and the resulting human capital levels are proportional to the current technological levels. At lower levels of development, human capital may be thought to be more intensive in nutrition and health, while at higher levels education may become a more important component. In the model, when human capital is scarce, unskilled labor wages are low. Under the assumption that children are not creditworthy, only skilled parents, motivated by a degree of altruism, can invest in their children's human capital. Thus, children of unskilled parents will be unskilled in the next generation. For simplicity, human capital is the only inheritance, so in each generation the adult population will consist of two classes of identical individuals, skilled or unskilled, so long as the trap holds. All of the conditions are proportional to the technological level: what is constructed is a *relative* poverty trap in which incomes can grow if there is technological change, but inequality can nevertheless persist.[19] This is consistent with the extraordinary persistence of within-country inequality, at widely different income levels and growth rates.[20] In the model, the government can supplement parental income so as to make human capital investment possible. Once human capital accumulation reaches a certain level, the unskilled labor wage rises enough for every child to acquire human capital and the poverty trap disappears. Note that now human capital is oversupplied. Given adults' choice of skilled and unskilled work, skilled and unskilled wages will equalize. The model is put in this way by assuming that non-marketable benefits of nutrition, health and education will motivate parental investment in human capital even when skilled and unskilled wages are equal. This assumption, which is realistic enough, is made for simplicity: it eliminates an intertemporal cost-benefit analysis for human capital.

[18] This is analogous to the threshold requirement in nutrition and health for education studied in by Galor and Mayer-Foulkes (2002).

[19] Concurrent treatment of the demographic transition is beyond the scope of this paper. Its theoretical link with subsistence levels requires an absolute rather than a relative treatment of human development, planned for another paper.

[20] As Kanbur (2005) states: "There is no statistical correlation between changes in per capita income and changes in inequality, taking countries as the unit of observation."

In the multi-country Schumpeterian growth model, the presence of a human development trap decreases per-capita income through two mechanisms. The first is a lower market size reducing the incentives for innovation and therefore resulting in a lower steady state. This

implies, as explained above, that inequality reduction will have growth effects at lower and level effects at higher income levels. The second mechanism is the reduction in per-capita income due directly to suboptimal levels of human capital. Skilled wages will be relatively high while unskilled wages will be relatively low. In the open economy case, the market size effect is much reduced.[21]

1.3. Governance and policies

In the model, the state of governance is described by two parameters and by the allocation of expenditure on two policy instruments. The first parameter is a measure of fixed productivity effects including not only natural endowments but also 1) institutional arrangements affecting the general efficiency of production and innovation such as the rule of law and other institutions promoting the autonomous functioning of the markets, and 2) inefficiencies due to taxation. The second parameter is a measure of government efficiency in expenditure, including corruption. These tow parameters define the *efficiency of governance*. Achieving optimality in them is assumed to have negligible cost. This assumption, which may seem unreasonable, is made for the following reasons. First, one of the arguments favoring policies for market efficiency is that their cost is negligible compared to direct government intervention in the economy. The model will qualify what these policies can achieve in the face of market failures for human capital investment and innovation. Second, the issues addressed here are the trade-offs between supporting human capital investment or innovation, rather than an analysis of governance steady states. Nevertheless, in some of the steady states of the model incentives for corruption will arise, which will be pointed out. Also, the presence of a human development trap will induce social conflict, which can be understood (albeit exogenously) to be counterproductive for governance.

The two costly policy instruments that complete the definition of the role of government in the model are the support for human capital investment and innovation that have been described. These are carried out subject to the governments budget, which in turn depends on its expenditure efficiency.

[21] However, if research were more human capital intensive than production, an effect eliminated here for simplicity, an innovation disadvantage would remain.

1.4. Political economy of growth and poverty

Modelling a human development deficit through the presence of a poverty trap naturally gives rise to a discussion of political economy, because of the implied presence of two classes of people, skilled and unskilled. Two government objective functions are defined and their optimal policies compared. These are maximizing the expected future wages for children of skilled and unskilled parents.[22]

For children of skilled parents, the objective function is next generation's wage. This depends positively on innovation and negatively on the aggregate supply of skills. Indirectly, however, the supply of skills may have positive effects through its impact on innovation incentives. Children of unskilled parents will mainly benefit from a government lottery assigning human capital investment. However, their future wage also has a positive impact from innovation. The unskilled will prefer policies with a higher mix of human capital investment, unless the expected benefits from innovation are truly high.

Another way of putting this is the following. The unskilled will benefit more form accessing currently available knowledge through increased skills than by remaining unskilled and using new, higher technology.

Our analysis does not incorporate an endogenous policy choice. Instead it assumes that one of the policies is dominant and examines the resulting steady state.

1.5. The resulting steady states

Under autarchy, if the unskilled workers' optimal policy is followed, the following trajectory and steady state results.

Human capital accumulation, followed by divergent or convergent technological transition. The lagging country will experience a transition to a steady state with optimal human capital investment. At first, this investment may be supported exclusively. However, once the human development trap is overcome, government support will shift completely to innovation. The final steady state growth rate will depend on the efficiency of governance. Divergent and convergent states are both possible.

If instead the skilled workers' optimal policy is followed:

Technological and human capital stagnation. For very low levels of population, governance efficiency, or other fixed productivity parameters such as when a

[22] Theses objective functions avoid the complexities of intertemporal optimization.

country is land locked, the incentives for innovation will be insufficient and there will be no technological change. However, skilled workers will not favor human capital investment since the additional supply will lower their wages. The growth rate is zero. Any government revenue will best be spent on rents...

Relative human capital stagnation. For a sufficiently high combination of population, governance efficiency, and other fixed productivity effects, there will be sufficient incentives for innovation. In this steady state, however, skilled workers do not favor human capital investment. Divergent and convergent states are both possible.

Optimal human capital investment. In this steady state, the development trap no longer exists and government policy only supports innovation. This steady state coincides with the final steady state reached when the unskilled workers' optimal policy is followed. However, it may be reachable following the skilled workers' optimal policy for exceptional situations with sufficiently high population, governance efficiency, fixed productivity effects, as well as initial level of human capital.

Under free commerce, the world growth rate will rise if the leading countries do not loose too many innovative sectors and their lagging partners are viable enough to sustain parallel growth. The worst steady state, technological and human capital stagnation, ceases to exist, because lagging countries access the incentives for innovation available to the leading country, assumed to be positive. All remaining steady states are still possible. The growth rate of countries not lagging too far behind, whose government can support innovative production at the global scale, with sufficiently high governance efficiency and fixed productivity effects to sustain parallel growth, will rise to the new world growth rate. Their relative level to the leader will become closer the higher their static gains in efficiency due to comparative advantage; the smaller their market size; the higher the advantage of backwardness; and the larger the share of innovative races won. However, countries lagging sufficiently far behind will not be able to support innovative production at the global scale and may be pushed to a divergent steady state with a lower growth rate than in autarchy. The mechanism is the following. Under free commerce, innovation races between countries reduce the sectors available for research. When government support is squeezed into less sectors, and under diminishing returns to research, the resulting growth rate (of technology and therefore income) is lower. This result can produce multiple steady states between identical economies, that is, independently of institutional and human capital differences. It is analogous to the innovation crowding out occurring in the presence of FDI (Mayer-Foulkes, 2005)

Summarizing, according to the model the human development trap will remain in countries not systematically supporting human capital investment, independently of the rates of growth achieved. This conclusion is consistent with the facts of growth and inequality.[23] It is based on acknowledging the market failures that exist for human capital investment. On the other hand, human capital investment can only be prioritized until the optimal human capital investment is reached. After this, technological innovation must be supported. The change in priorities may be difficult if governing interests have become entrenched.

The political economy implicit in the human development trap throws light on why economic growth translates — or fails to translate — into human development.

1.6. Institutions for economic growth and development

Institutions, understood as the "rules of the game of a society" (North, 1993),[24] form the matrix in which its economy functions. "They are formed to reduce uncertainty in human exchange. Together with the technology employed they determine the costs of transacting (and producing)." (*ibid*) Institutions supporting developed market economies include property rights, the rule of law and the protection of civil and political freedoms. Of course, developed societies include a whole series of institutions, now understood to include organizations, covering functions that the markets do not. Moreover, governance is sufficiently developed to regulate and impose constraints on the market when necessary, and to generate resource flows that may be required.

The magic of markets, as was recognized by Adam Smith, is that they generate an autonomous form of human exchange possessing certain optimal properties. However, markets do not always function, and institutions to make them function cannot always be found.[25] Thus the following principles for optimal institutional

[23] Anand and Kanbur (1993), Deininger and Squire (1996), Squire and Zou (1998), Kanbur (2005).

[24] Citing this work, institutions "more formally are the humanly-devised constraints that structure human interaction. They are composed of formal rules (statute law, common law, regulations), informal constraints (conventions, norms of behavior, and self imposed codes of conduct), and the enforcement characteristics of both."

[25] Curiously, the assumption of perfect markets in theoretical economic models tends to shift the explanation of cross-country income differences towards the institutional context of the models — and away from economic causes.

arrangement would seem elementary:

1) Generate market institutions where markets apply. When organizations are performing the role of markets, apply a pro-market reform. Solve suboptimalities with as little intervention as possible.

2) Where markets fail to generate necessary investments or expenditures, the necessary flows must be generated in the least costly way, including the possibility of public expenditure and government organization.

The criteria for these decisions are objective: Do markets apply effectively? Are there market failures? Are there missing investment flows? What are the institutional alternatives and their costs? These are, in principle, not questions of conviction but of fact.

Do such simple considerations have a bearing on the institutional debate? Unfortunately they do. Consider the Washington Consensus, "... development strategies focusing around privatization, liberalization, and macrostability (meaning mostly price stability); a set of policies predicated upon a strong faith, stronger than warranted, in unfettered markets and aimed at reducing, or even minimizing, the role of government." (Stiglitz, 2004) According to our model, this is a policy for technological and human capital stagnation, addressing the efficiency of governance only vaguely, and promoting openness without an innovation policy! Its meager results in both human development and innovation, for example in Latin America since the late 1980s, or, worse, in the transition economies from the former Soviet block, were almost warranted!

Even though the present model gives only a partial explanation of the persistence of inequality and divergence in the open economy it nevertheless also helps to understand the successful strategies pursued in East Asia, where the development state took an active role. There, although human development was not ignored, inequality was a minor problem, liberating resources for pursuing strategies for innovation. These included dealing with problems of coordination, scale, infant industry, and ensuring the achievement of technological independence (see Wan, 2005), counteracting innovation crowding out by FDI (Mayer-Foulkes, 2005).

The model also throws light on the poor economic performance of Africa. Situated at very low human capital levels, incentives for innovation are very low, as are country resources to support production at the global scale, implying that openness can reduce the growth rate in the face of international innovation competition.

Underdevelopment may mostly be the consequence of market failures rather than poor institutions. The main candidates are failures in human development and in technological transfer. Both are clearly insufficiently funded. The consequences in human well-being are staggering. Development policy must *somehow* induce these flows of nutrition, education, health, skills and know-how for production and research, that markets are not inducing. These flows need not necessarily pass through governments, but could be subcontracted through NGO's or other local or international competitive providers, or could take place through a series of organizations designed for the purpose.

The model shows that overcoming the human development trap is the essential component of pro-poor growth. In this sense, the Millennium Development Goals form an integral part of growth policy, whose effects must be conceptualized in terms of the appropriate thresholds, and may be intergenerational. So are conditional cash transfer programs such as Oportunidades in Mexico, which promote human capital investment for the young.[26] Empowerment of the poor falls in the same category. Human development policy is an essential component to develop the groundwork for equality and freedom. In its absence, globalization policies face the opposition of the unskilled, as the model shows.

The model draws a sharp distinction between human capital and technology, that may not be so sharp in practice, particularly in relation to adult workers. An example of what this means is the following: micro skill transfer programs, analogous to micro credit, for adults.

The model's conception of innovation is of course abstract. Supporting innovation in practice requires an industrial policy, an agricultural policy, and so on. Some experience is already available for conducting such policies effectively. Further study is needed, however, on how to promote technological transfer and local know how as countries integrate with the world economy.

The model shows that the world growth rate is maximal when all countries are developed. To achieve this, it is in the interest of the developed world that underdeveloped countries achieve leadership in a good number of technological sectors. This will need a helping hand. Leading edge research in local production can be supported world-wide.

The Schumpeterian equivalent of Keynesian spending is the transfer of known skills, production know-how, research, and even infrastructure, within and between countries.

[26] Perhaps parental employment could also be used as an instrument for ameliorating the condition of children and breaking the human development trap, focussed for example in the production of non-tradeables such as housing, urbanization and sanitation that increase country competitiveness.

The remainder of the article presents the model, and then a concluding discussion.

2. The basic framework

The Schumpeterian growth model is cast in a simple discrete-time framework following Acemoglu, Aghion and Zilibotti (2002), Howitt and Mayer-Foulkes (2005), Aghion, Howitt and Mayer-Foulkes (2005) and Mayer-Foulkes (2005). The model will cover the impact of human development on economic growth under autarchy and free commerce. In the autarchic case there are m countries which make use of each others' technological ideas; once commerce is included, $m = 2$ for simplicity.

There is a continuum of tradeable general goods indexed by $i \in [0, 1]$, produced with labor and human capital and used for consumption and innovation. Each country has a population consisting of a continuum of individuals living for two periods and endowed with one unit of skilled or unskilled labor services in the second period. Generation t is born in period $t-1$ and numbers N_{jt}, $j = 1, ..., m$. We shall consider the population fixed unless otherwise stated, so each adult has one child

2.1. Human capital

In any given country at any given time t there is knowledge of production, of level A_t, that is generally available. Children not receiving an investment in human capital at time $t-1$ will supply one unit of unskilled labor as adults. Children receiving an indivisible investment in human capital costing ρA_{t-1} will obtain, due to the externalities of research and production taking place at that time, A_t units of human capital. As adults, they will be able to choose between supplying skilled or unskilled labor, and will also enjoy some non-tradeable benefits of being healthy and educated. Each parent in generation $t-1$ would like to educate her child, but due to other pressing needs can only dedicate a maximum proportion η_e of her income for paying the necessary investment. Children have no resources of their own and are not creditworthy. If their parents do not invest in them, they will not receive adequate health and education unless the government completes from taxes the available parental funding (a proportion η_e of their income). Write N_t^L for the number of adults who did not receive an investment in human capital and N_t^H for the number who did ('L' for labor (unskilled) and 'H' for human capital), where $N_t^L + N_t^H = N_t$. The aggregate supply of human capital at time

t is $N_t^H A_t$.

Assume the wages per unit of labor and human capital at time $t-1$ are w_{t-1}^L and w_{t-1}^H. For any individual, let δ^H be 1 if she acquired human capital and 0 otherwise, and let $\delta^L = 1 - \delta^H$ be the complementary indicator function. For any given adult, earnings at time $t-1$ are:

$$z_{t-1} = \delta_{t-1}^L w_{t-1}^L + \delta_{t-1}^H w_{t-1}^H A_{t-1}.$$

Let $c_{kt}(i)$ is the amount of good i consumed in period $k = 1$ or 2 and time t, and define

$$c_{kt} = \exp[\int_0^1 \log(c_{kt}(i))\, di. \tag{2.1}$$

Optimization of expenditure implies $c_{kt}(i) = c_{kt}$. Thus the budget constraint for parents is:

$$\beta^{-1} c_{1t-1} + c_{2t} + \delta_{t+1}^H e_t = z_t,$$

where δ_{t+1}^H represents their decision on their child. Assume the human capital investment function uses general goods as follows:

$$\exp[\int_0^1 \log(e_t(i))\, di] = \rho A_t.$$

Expenditure optimization again implies $e_t(i) = e_t = \rho A_t$. Parents will allocate

$$e_t = \begin{cases} 0 & \rho A_t > \eta_e z_t \\ \rho A_t & \rho A_t \leq \eta_e z_t \end{cases}$$

We assume that parents will educate their children whenever possible, because of the non-marketable benefits of health and education. However, when they are adults, they will only work in a skilled job if this pays as well as an unskilled one, so $w_{t+1}^H A_{t+1} \geq w_{t+1}^L$. If the supply of skilled workers is too high some of them will work as unskilled workers and the equilibrium $w_{t+1}^H A_{t+1} = w_{t+1}^L$ will hold.[27]

Our assumptions on parental preferences are summarized by the utility function

$$U_t(c_{1t-1}, c_{2t}, e_t) = \max\left[\beta^{-1} c_{1t-1} + c_{2t}, \frac{I(e_t - \rho A_t)}{1 - \eta_e}\left(\beta^{-1} c_{1t-1} + c_{2t}\right)\right],$$

[27] The assumption tha everyone seeks health and education beyond its economic benefits is not only realistic but also simplifies the model because parents need not perform an intertemporal cost-benefit analysis adding a further dimension to the dynamics.

where I is the indicator function

$$I(x) = \begin{cases} 1 & x \geq 0, \\ 0 & x < 0. \end{cases}$$

Observe that $e_t \gtrless \eta_e z_t \Leftrightarrow \frac{1}{1-\eta_e}(z_t - e_t) \lessgtr \frac{1}{1-\eta_e} z_t (1-\eta_e) = z_t$,so parents decide on education as stated.

The subutility function for consumption is intertemporally linear, so the real interest rate is given by $1+r = \beta^{-1}$.[28] There is indifference between consumption in the first and second periods so long as the discount rate occurs according to the interest rate. Hence the amounts actually consumed in each period are determined by what borrowing is demanded for human capital investment and innovation.

2.2. General goods, productivity and innovation

The economy has infinitely many small producers who can produce any good i by using human capital according to the production function:

$$Y_t(i) = \varphi A_t^{1-\alpha} L_t^{1-\alpha}(i) H_t^{\alpha}(i), \tag{2.2}$$

where $L_t(i)$, $H_t(i)$ are the amounts of labor and human capital used to produce good i, and φ is a fixed productivity effect that may include institutional, geographic and other factors.

Technological change is costly. At time $t-1$, the i^{th} innovator may attempt a technological jump of magnitude $\Gamma > 1$, so as to produce good i with labor productivity ΓA_t. To implement these innovations a public good promoting the adoption of the innovating will be necessary. The level of provision of this public good will determine the innovation jump Γ that will be feasible. In the autarchic case, innovators will decide to innovate according to their expected profit. In the open case, this decision will be embedded in an innovation competition game defining who wins the race, she or her competing i^{th} analogue in the other country. When she succeeds (innovates), she will form a large national or world monopoly which will be the i^{th} incumbent firm at time t. Let $\mu_t(i)$ be the probability that if she attempts to innovate she succeeds. Then:

$$A_t(i) = \left\{ \begin{array}{cc} \Gamma A_t & \text{with probability } \mu_t(i), \\ A_t & \text{with probability } 1-\mu_t(i). \end{array} \right\}$$

[28] Linear utility implies people are indifferent between investing in any country. Thus, by assuming δ is the same across countries, perfect indirect (financial) investment can be allowed with no change in the analysis.

Goods i for which an innovation has just occurred are produced according to the Leontief production function:

$$Y_t(i) = \varphi(\Gamma A_t)^{1-\alpha} \min\left[L_t^{1-\alpha}(i) H_t^{\alpha}(i), \frac{P_t(i)}{\Gamma^{1-\alpha}-1}\right], \tag{2.3}$$

where $P_t(i)$ is a public good necessary to produce the recently innovated i^{th} good. The larger the jump Γ that is being implemented by the innovator, the higher the proportion of the public good $P_t(i)$ that is needed for production. The need for the public input in production function (2.3) is introduced to represent the role of government in innovation policy. However, it also serves to simplify the model by making aggregate labor demand neutral to the innovation rate. For this reason, the ratio of public to private labor is set at $\Gamma^{1-\alpha} - 1$. Public goods are produced according to the production function

$$P_t(i) = L_t^{P\ 1-\alpha}(i) H_t^{P\ \alpha}(i) \tag{2.4}$$

using labor $L_t^P(i)$ and human capital $H_t^P(i)$. Suppose that the public sector uses labor and human capital in the same (optimal) proportion as the private sector, and that the public good is allocated in the optimal amount $P_t^*(i)$, so

$$\begin{aligned} L_t^P(i) &= \left(\Gamma^{1-\alpha} - 1\right) L_t(i) \\ H_t^P(i) &= \left(\Gamma^{1-\alpha} - 1\right) H_t(i). \end{aligned}$$

Then the privately perceived production function for innovated goods is analogous to the one for competitive goods,

$$Y_t(i) = \varphi(\Gamma A_t)^{1-\alpha} L_t^{1-\alpha}(i) H_t^{\alpha}(i), \tag{2.5}$$

except that its technological level ΓA_t is higher and society as a whole pays (through lump sum taxation) for the labor and human capital inputs for the public good.

The incumbent's specific knowledge disappears at her death,[29] but general knowledge diffuses during production within each country, so next period's shared technological level is:

$$A_{t+1} = (1 + \mu_t(\Gamma - 1)) A_t. \tag{2.6}$$

[29] Alternatively, it could be assumed that by the next period her specific knowledge is outdated, or that the set of general goods $i \in [0, 1]$ is irrelevant to consumption and innovation, having been replaced through technological progress with a new set of general goods.

2.3. Consumer and producer optimization

The Cobb-Douglass subutility function (2.1) for consumption in each period implies that consumers dedicate an equal expenditure to each good i. Since the production function for all competitively produced goods i is identical and has homogenous returns of degree 1 with decreasing returns in each factor, labor and human capital allocation is identical across goods, so $L_t(i) = L_t^C$, $H_t(i) = H_t^C$. Competitively produced goods are sold at their unit cost

$$p_t = \frac{w_t^{H\ \alpha} w_t^{L\ 1-\alpha}}{\varphi A_t^{1-\alpha} \varepsilon_\alpha}, \text{ where } \varepsilon_\alpha = \alpha^\alpha (1-\alpha)^{1-\alpha}.$$

Innovative producers face competition at this price, and a constant consumer expenditure. Therefore they minimize costs by reducing production to the minimum level compatible with price p_t, and produce the same amount of each good as the competitive sector, so

$$\varphi \Gamma^{1-\alpha} A_t^{1-\alpha} L_t^{I\ 1-\alpha} H_t^{I\ \alpha} = \varphi A_t^{1-\alpha} L_t^{C\ 1-\alpha} H_t^{C\alpha}.$$

Because of their higher technology, innovators save on labor and human capital inputs and make a profit. Since their optimal ratio of unskilled to skilled is unchanged,

$$L_t^I = \frac{L_t^C}{\Gamma^{1-\alpha}}, H_t^I = \frac{H_t^C}{\Gamma^{1-\alpha}}, \tag{2.7}$$

and the profit rate per unit product is:

$$\pi = 1 - \Gamma^{-(1-\alpha)} > 0$$

Labor and human capital inputs demanded for the public good are:

$$L_t^P(i) = L_t^P = \frac{\Gamma^{1-\alpha} - 1}{\Gamma^{1-\alpha}} L_t^C, \quad \text{so} \quad L_t^P + L_t^I = L_t^C,$$

and similarly for $H_t^P + H_t^I = H_t^C$. As stated above, for simplicity the model is set up so that the need for a public good supporting innovation makes the aggregate demand of labor and human capital of innovative sectors equal that of competitive sectors.

Goods will also be demanded for research, in the same proportional structure as for consumption, as will be shown below. Hence, all goods are produced at the same price and in the same quantity $Y_t(i) = Y_t = B_t/p_t$, where B_t is the aggregate expenditure on consumption and research. Real aggregate demand B_t/p_t depends on whether the economy is closed or open. Observe that real wages per unit human capital are indexed by:

$$\frac{w_t^{H\alpha} w_t^{L1-\alpha}}{p_t \varepsilon_\alpha} = \varphi A_t^{1-\alpha}. \tag{2.8}$$

Let L_t, H_t be the aggregate levels of labor and human capital at time t. Since the level of production of innovative and competitive goods is equal across sectors, and since aggregate labor and human capital demand is equal across sectors, aggregate production is:

$$\frac{B_t}{p_t} = Y_t = \varphi_j A_t^{1-\alpha} L_t^{1-\alpha} H_t^{\alpha}. \tag{2.9}$$

In each country relative wages between skilled and unskilled labor are determined by the Cobb-Douglass production functions (2.2), (2.3), (2.4) according to

$$\frac{H_t}{L_t} = \frac{\alpha w_t^L}{(1-\alpha) w_t^H}.$$

Because skilled workers with skill level A_t will not work for a lesser salary than unskilled workers, $w_t^H A_t \geq w_t^L$ so $H_t/L_t \leq \alpha/(1-\alpha)$. Hence given N_t^H skilled adults out of a population of N_t,

$$H_t = \min\left[N_t^H, \alpha N_t\right] A_t, L_t = N_t - H_t. \tag{2.10}$$

In effect, the economy is identical for all values N_t^H higher than αN_t, and

$$\frac{L_t}{H_t} \geq \frac{1-\alpha}{\alpha}. \tag{2.11}$$

Define the efficiency of human capital allocation $0 < \kappa \leq 1$ by

$$L_t^{1-\alpha} H_t^{\alpha} = \kappa \varepsilon_\alpha N_t.$$

κ rises from low values of H_t/L_t until the allocation reaches optimality $\kappa = 1$ at $H_t/L_t = \alpha/(1-\alpha)$.

2.4. The human development trap

Skilled parents will investment in their children's human capital if their salary can cover the costs, so $\eta_e w_t^H A_t > \rho A_t$, or $\eta_e \alpha \left(L_{jt}/H_{jt}\right)^{1-\alpha} \varphi > \rho$. We assume that this is always the case, so based on (2.11) assume

$$\eta_e \varepsilon_\alpha \varphi > \rho.$$

On the other hand, unskilled parents will not be able to carry out the investment if $\eta_e w_t^L \leq \rho A_t$, that is, if N_{jt}^H/N_{jt} is below the level n_{Trap}^H given by:

$$\left(\left(\frac{N_{jt}^H/N_{jt}}{1-N_{jt}^H/N_{jt}}\right)/\frac{\alpha}{1-\alpha}\right)^\alpha = \frac{\rho}{\varphi \eta_e \varepsilon_\alpha} \leq 1 \tag{2.12}$$

Above this level the following generation will be fully endowed with human capital and skilled and unskilled workers will earn the same. Below this level there will be a human development trap and two classes of workers, unskilled earning less than skilled.

2.5. Research

At the end of period $t-1$, production will be allocated between consumption and investment in research. Introduce an index j for countries. Innovative firms will have access to a knowledge level A_{jt}, resulting from the previous knowledge level A_{jt-1} and from the diffusion of the new knowledge level ΓA_{jt-1} at a rate μ_{jt-1} during production. Let the R&D investment needed to obtain a technological jump Γ at rate μ_{jt} in any sector i be given by:

$$\mu_{jt} = \Psi(\frac{\psi(a_{jt})R_{jt-1}}{A_{jt}}), \tag{2.13}$$

where research intensity R_{jt-1} is given by the Cobb-Douglass production function:

$$R_{jt-1} = \exp[\int_0^1 \log(R_{jit-1})di].$$

Here $R_{jt-1}(i)$ is the quantity of good i used for research. It follows from the common Cobb-Douglass kernel that consumption and research demand for goods i are proportional. Investment in innovation uses each good in the same amount

$R_{jit-1} = R_{jt-1}$ and simply transfers some constant proportion from consumption to innovation. In the research production function (2.13), the division by A_{jt} recognizes the "fishing-out" effect: the resources needed to obtain a technological jump Γ are proportional to the knowledge level. Suppose there is a single technological leader, country 1, and let $a_{jt} = A_{jt}/A_{1t} < 1$ be the relative technological level of country j with respect to the leader. Lagging countries face an innovation function identical to the one faced by the leader at previous levels of development, except for the convergence term $\psi(a_{jt})$. Through technological diffusion, the presence of the leading country's more advanced technological level A_{1t} reduces the resources that country j needs to invest in order to achieve the same jump Γ. This is Gerschenkron's (1952) "advantage of backwardness", represented by a decreasing function:

$$\psi(a_{jt}) = \psi_0 - (\psi_0 - \psi_1)\, a_{jt}. \tag{2.14}$$

For the function Ψ yielding the final probability of innovation (2.13) set

$$\Psi\,(n) = 1 - (1+n)^{-1}\,. \tag{2.15}$$

This satisfies $\Psi(0) = 0, \Psi < 1, \Psi' > 0, \Psi'' < 0,\ \Psi'\,(n) = (1+n)^{-2} = (1 - \Psi\,(n))^2$. The fact that Ψ is bounded will allow examining the effects of country size.

Innovators in each sector choose $\mu_{jt} \geq 0$ to maximize the expected real payoff:

$$\frac{\mu_{jt}\pi_{jt}}{(1+r)\,p_{jt}} - R_{jt-1} = \Psi\left(\frac{\psi(a_{jt})R_{jt-1}}{A_{jt}}\right)\frac{\pi_{jt}}{p_{jt}} - R_{jt-1}. \tag{2.16}$$

The interior first order maximization condition can be written:

$$\left(1 - \mu_{jt}\right)^2 \psi(a_{jt})\frac{\beta\pi_{jt}}{p_{jt}A_{jt}} = 1. \tag{2.17}$$

3. Government policy

The effectiveness of government and the general nature of its policies are characterized in this model by several parameters. Two parameters cover aspects designated here as having negligible cost whose level will not be optimized within the government budget. The first is a measure of fixed productivity effects φ including not only natural endowments but also institutional arrangements affecting the general efficiency of production such as the rule of law and other institutions promoting the autonomous functioning of the markets. The second is a measure of government efficiency in expenditure. Government expenditures will be based on a lump sum tax of a fixed proportion τ of income up to a maximum $\tau^{\max} > 0$. However, government will only deliver services with efficiency $0 < \zeta \leq 1$, reflecting problems such as corruption. Inefficiencies arising from taxation will be subsumed in φ.

Besides these parameters we analyze two costly policy instruments. The first is the support of innovation. The government will guarantee the provision of a proportion υ_t of the public goods necessary for the full supply of innovated goods. Government expenditure on innovative production will amount to $G_t^I = \mu_t \upsilon_t P_t^*$, where P_t^* is the optimal level of public expenditure in each sector. Innovator profits will be reduced by a factor υ_t and the shortfall in production will be covered by the competitive sector.

The second is an investment in human capital for children whose families do not have sufficient resources for the purpose. An expenditure E_t^P will ensure that $E_t^P / \left(\rho A_t - \eta_e w_t^L\right)$ more children acquire adequate levels of health and education. We assume this investment is assigned by a lottery implying all needy families have some expectation of receiving the investment. Thus if a human development trap is in place, so $N_t^H / N_t < n_{\text{Trap}}^H$,

$$N_{t+1}^H = N_t^H + \frac{E_t^P}{\rho A_t - \eta_e w_t^L}. \tag{3.1}$$

Given an aggregate income Y_t, the government budget constraint is:

$$G_t^I + E_t^P = \tau \zeta Y_t \leq \tau^{\max} \zeta Y_t. \tag{3.2}$$

The promotion of innovation will raise expected wages in the next period, benefitting both skilled and unskilled workers. When a human development trap is present, human capital investment will be applicable and will benefit the expected wage of children from unskilled families, and raise the incentives for innovation through raising the efficiency of production κ and therefore effective market size. However, it will lower skilled wages by raising the supply of skilled workers. If the government budget is high enough, there will be no conflict and both policies will be possible. Otherwise each class will support different policy objectives, evaluated below for the cases of autarchy and free commerce. If the government is more corrupt, conflict will be starker.

4. Autarchy

Consider country j with no trade. As noted before, aggregate income in country j is given by (2.9). Hence the first order interior conditions for innovation are given by:

$$\left(1-\mu_{jt}\right)^2 \Omega(a_{jt})\upsilon_{jt} = 1, \tag{4.1}$$

where the *effective innovation incentives* (corrected for the fishing out effect and convergence) are:

$$\Omega(a_{jt}) = \psi(a_{jt})\beta\pi\varphi_j\kappa_j\varepsilon_\alpha N_{jt},$$

a decreasing function of a_{jt}. Define:

$$f(\Omega) = \max\left[1-\frac{1}{\sqrt{\Omega}}, 0\right].$$

The function f solves (4.1), is zero for $\Omega \leq 1$ and is strictly increasing thereafter. The innovation rate μ_{jt} (which must be nonnegative) is given by:

$$\mu_{jt}(a_{jt}, \upsilon_{jt}) = f\left(\Omega_{jt}(a_{jt})\upsilon_{jt}\right). \tag{4.2}$$

4.1. Leading country

For simplicity I assume that leading country 1 is fully supplied with human capital and has a sufficiently efficient government to fully support innovation. That is, $\upsilon_1 = \zeta_1 = 1$; $\mu_{1t}P^*_{1t} \leq \tau^{\max}Y_{1t} \Leftrightarrow \tau^{\max} \geq \mu_{1t}\pi$ (since under our special labor demand invariant construction $\pi = P^*_{1t}/Y_{1t}$). I further assume $\varphi_1 = 1$. In the case of the leading country, $a_{1t} = 1$, so the innovation rate is the constant:

$$\mu_{1t} = f(\Omega_1) \text{ where } \Omega_1 = \psi_1\beta\pi\varepsilon_\alpha N_1.$$

The population N_1 is assumed to be large enough to imply $\Omega_1 \geq 1$ and therefore to have $\mu_{1t} > 0$. Country 1's growth rate, also the autarchic growth rate, is given by:

$$g_1^{\mathrm{A}} = \frac{A_{1t+1}}{A_{1t}} - 1 = \mu_1(\Gamma - 1).$$

('A' for autarchy). g_1^{A} is increasing but bounded in the population level N_1.

Income per capita in Country 1 is

$$\frac{Y_{1t}}{N_{1t}} = \varepsilon_\alpha A_{10}\left(1+g_1^{\mathrm{A}}\right)^t.$$

4.2. Lagging countries, no human capital investment

In the case of a lagging country, assume for the present that its government does not invest in human capital, so that its relative human capital level N_{jt}^H/N_{jt} is either (1) trapped at a level below n_{Trap}^H, (2) lies on the interval $(n_{\text{Trap}}^H, \alpha)$ and will next period become 1, or (3) is already 1. (Recall that, by (2.10), $N_{jt}^H/N_{jt} = 1 \Rightarrow H_{jt}/N_{jt} = \alpha$.) On the other hand, assume that the government supports innovation with its full budget $\tau^{\max}\zeta_j Y_{jt}$. Define the function

$$V(\Omega, \upsilon) = f(\Omega\upsilon)\upsilon.$$

Given $\Omega > 0$, this is an increasing function of both its variables satisfying $V(\Omega, \upsilon) = 0$ for $\upsilon \leq \Omega^{-1}$. Expenditures in innovation support are $G^I = \pi V(\Omega_{jt}(a_{jt}), \upsilon_{jt})Y_{jt}$ (recall $P_{jt}^* = \pi Y_{jt}$). For each Ω there is an inverse function $\upsilon(\Omega, E)$ with values above Ω^{-1} satisfying $V(\Omega, \upsilon(\Omega, E)) = E$. The function $\upsilon(\Omega, E)$ is decreasing in the first and increasing in the second variable. The maximum possible support for innovation a government can offer is:

$$\upsilon_{jt}(a_{jt}) = \min\left[\upsilon(\Omega_{jt}(a_{jt}), \frac{\tau^{\max}\zeta_j}{\pi}), 1\right]. \tag{4.3}$$

Set

$$\mu_{jt}(a_{jt}) = f(\Omega(a_{jt})\upsilon(a_{jt})).$$

It is shown in Appendix B that for fixed government expenditures although $\upsilon_\Omega \leq 0$, μ_{jt} is increasing in $\Omega(a_{jt})$. Also, when $\zeta_j \to 0$, $\mu_{jt} \to 0$. $\mu_{jt}(a_{jt})$ is zero if $\Omega(a_{jt}) \leq 1$.

Country j's relative technological level a_{jt} will follow the dynamics:

$$a_{jt+1} = \frac{A_{jt+1}}{A_{1t+1}} = \frac{\left[1 + \mu_{jt}(a_{jt})\,(\Gamma - 1)\right] A_{jt}}{\left[1 + \mu_1\,(\Gamma - 1)\right] A_{jt}} = \frac{1 + \mu_{jt}(a_{jt})\,(\Gamma - 1)}{1 + \mu_1\,(\Gamma - 1)} a_{jt}.$$

It is convenient to study these dynamics in the relative growth form[30]

$$\frac{a_{jt+1}}{a_{jt}} = H_j^{\mathrm{A}}(a_{jt}) \equiv \frac{1 + \mu_{jt}(a_{jt})\,(\Gamma - 1)}{1 + \mu_1\,(\Gamma - 1)}.$$

[30] The phase diagram can be viewed in the $(a_{jt}, a_{jt+1}/a_{jt})$ plane. Trajectories are mapped following the function $H_j^{\mathrm{A}}(a_{jt})$ and then rectangular hyperbolas to the $a_{jt+1}/a_{jt} = 1$ line.

Income per capita in Country j is:

$$\frac{Y_{jt}}{N_{jt}} = \varepsilon_\alpha \kappa_j a_{jt} A_{10} \left(1 + g_1^{\mathrm{A}}\right)^t .$$

Country j converges in growth rates to country 1 if it tends to a steady state $H_j^{\mathrm{A}}(a_j^*) = 1$ at which its innovation rate $\mu_{jt}(a_j^*) = \mu_1$ equals the leader's (with $a_j^* \geq 0$). A divergent steady state $a_j^* = 0$ occurs if $H_j^{\mathrm{A}}(0) < 1$, yielding a negative relative growth rate for country j. If instead $H_j^{\mathrm{A}}(1) > 1$, country j will overtake country 1 once it approaches it.

Observe that the functions $\Omega(a_{jt})$ and $\psi(a_{jt})$ are strictly decreasing and continuous, so $\mu_{jt}(a_{jt})$ is strictly decreasing when it is not zero (that is, when $\Omega(a_{jt}) > 1$). If $\Omega(a_{jt}) \leq 1$ then $H_j^{\mathrm{A}}(a_{jt}) < 1$. Finally, $H_j^{\mathrm{A}}(a_{jt})$ is continuous by construction.

Hence the solutions to $H_j^{\mathrm{A}}(a_j^*) = 1$ are unique if they are positive and otherwise the steady state is $a_j^* = 0$. The relative technological levels a_{jt} converge to steady states a_j^* as $t \to \infty$.

Proposition 1. Under autarchy, countries fall into four groups.

(1) $H_j^{\mathrm{A}}(1) > 1$. Country j will overtake country 1.

(2) $H_j^{\mathrm{A}}(1) \leq 1$ and $H_j^{\mathrm{A}}(0) \geq 1$. Country j converges in growth rates to country 1. A unique steady state $0 \leq a_j^* \leq 1$ exists given by $H_j^{\mathrm{A}}(a_j^*) = 1$. At this steady state $\omega_j \mu_j^* = f\left(\psi(a_j^*)\varphi_j N_j\right)$.

(3) $H_j^{\mathrm{A}}(0) < 1$. In this case the steady state is $a_j^* = 0$. Country j diverges in growth rates from country 1. The growth rate is $\omega_j \mu_j^* (\Gamma - 1) < g_1^{\mathrm{A}}$, with $\omega_j \mu_j^* = f\left(\psi_0 \varphi_j L_j\right)$.

Marginal rises in productivity effects φ_j, population size N_j, or human capital levels N_{jt}^H / N_{jt}, if they are suboptimal, will result in marginal positive level effects in case (2) and growth effects in case (3). Similarly with the efficiency of public spending ζ_j, when the government budget restricts its ability to support innovation. (All proofs are in Appendix A)■

The dependence of steady states on human capital and innovation suppoty is shown in Figure 1.

In the autarchic case, identical economies have the same steady states independently of their initial conditions, Galor's (1996) definition of convergence, which now includes "converging" to a divergent steady state. To study identical economies, set $\varphi_j = N_j = \zeta_j = 1$.

Corollary 2. Under autarchy,

(1) Countries identical in parameters and human capital distribution have the same steady states.

(2) If a country has a higher steady state, it must have better institutional arrangements and productivity fixed effects φ_j, higher government efficiency ζ_j, a higher level of human capital N_j^H/N_j, or a larger population N_j. The presence of a human capital trap has a double effect: it lowers the steady state a_j^* and the efficiency of production κ_j. The per capita income level converges to

$$\frac{Y_{jt}/N_{jt}}{Y_{1t}/N_{1t}} = a_j^* \kappa_j. \blacksquare$$

Corollary 3. There are four kinds of steady states, according to whether they diverge or converge in growth rates ($H_j^{\mathrm{A}}(a^*) < 1$ or $H_j^{\mathrm{A}}(a^*) = 1$) and according to whether they exhibit optimal human capital accumulation or a human development trap ($N^H/N < n_{\mathrm{Trap}}^H$ or $N^H/N \geq \alpha$; the intermediate stage disappears in one generation).$\blacksquare$

4.3. Lagging countries, optimal policies

By assumption, the leading country is not subject to a human capital poverty trap. All of the population will be educated in their youth, although in their adult period some will be employed in skilled and others in unskilled labor. Also, enough public resources are available through taxation to support innovation optimally. However, this situation need not hold in lagging countries. We discuss two policy objectives corresponding to the two classes that are present when there is a human development trap, skilled and unskilled workers. The strategies consist in maximizing the expected wages for children of parents who this period are 1) skilled workers and 2) unskilled workers (in which case the expectation is over the government lottery for human capital investment). In the absence of a poverty trap only the first policy will be present. Both policy objectives are subject to the dynamic equations (3.1), (2.6) and to the government budget constraint (3.2).

Omit the index for country j for the remainder of this section. The objective function for skilled workers is:

$$\max O_{t+1}^H \equiv w_{t+1}^H = \alpha \frac{Y_{t+1}}{N_{t+1}^H}.$$

The objective function for unskilled workers is maximizing the expected wage under a probability $E_t^P / \left(\rho A_t - \eta_e w_t^L\right)$ of becoming skilled as the result of the government investment E_t^P on human capital:

$$\max O_{t+1}^L = (1-\alpha)\frac{Y_{t+1}}{N_{t+1}^L} + \frac{E_t^P}{\rho A_t - \eta_e w_t^L}\left(\frac{\alpha}{N_{t+1}^H} - \frac{1-\alpha}{N_{t+1}^L}\right)Y_{t+1}.$$

Note that the difference between these two objective functions is:

$$\max\left(O_{t+1}^L - O_{t+1}^H\right) = \left(1 - \frac{E_t^P}{\rho A_t - \eta_e w_t^L}\right)\left(\frac{1-\alpha}{N_{t+1}^L} - \frac{\alpha}{N_{t+1}^H}\right)Y_{t+1}.$$

The budget constraint is:

$$\upsilon_{t+1}\mu_{t+1}\pi Y_{t+1} + E_t^P = \tau\zeta Y_t \tag{4.4}$$

and can be written

$$\upsilon_{t+1}\mu_{t+1}\left(N_{t+1}^H, \upsilon_{t+1}\right)\pi Y_{t+1}\left(\upsilon_{t+1}, N_{t+1}^H\right) + \left(N_{t+1}^H - N_t^H\right)\left(\rho A_t - \eta_e w_t^L\right) = \tau\zeta Y_t. \tag{4.5}$$

Thus the problem can be analyzed in terms of the variables $\upsilon_{t+1}, N_{t+1}^H$.Note that expenditures are increasing in both, so the budget constraint curves have a negative gradient.

Let us understand first the local behavior of the innovation and income functions μ_{t+1} and Y_{t+1}. This occurs in two regions In Region 1, μ_{t+1} will be zero, due to insufficient effective incentives for innovation. The watershed level of human capital beyond which $\Omega_t(a_t) > 1$ and these incentives are positive is given by:

$$N_{\mu\, t+1}^{H\ \alpha} = \frac{1}{\psi(a_t)\beta\pi\varphi N_{t+1}^{L\ 1-\alpha}}.$$

In Region 2, μ_{t+1} will be positive and increasing in N_{t+1}^H, since when human capital increases so does the efficiency of production κ and therefore the effective market size. Consequently, Y_{t+1} will be constant in Region 1, while it will have positive derivatives in both its variables in Region 2.

When Y_{t+1} is constant, skilled workers' wages are decreasing in their supply N_{t+1}^H, so they will not favor marginal human capital investments by the government on the poor. Also, any promise for innovation support ω_{t+1} will be vain, since there are no incentives for innovation. At levels of N_{t+1}^H for which there are incentives for innovation, skilled workers will clearly support them, since they will raise Y_{t+1}. Here, since rises in N^H_{t+1} will also raise the incentives for innovation, it could be that the incentives for increasing the size of the pie Y_{t+1} would be higher than the disincentives arising from the wage reduction that an increase in the relative supply of human capital would bring.

The arrows in Figure 2.1 thus establish the derivatives of skilled workers' objective function. Given the assumption that N^H_{t+1}/N_{t+1} does not worsen, an improvement in next period's skilled wages can only occur in Region 2. If the initial conditions are situated in Region 1, with $\upsilon_{t+1} = 0$, $N^H_{t+1} \leq N^H_{\mu\,t+1}$, the optimal marginal policy for skilled workers is conserving the status quo with no spending at all, since human capital investment will reduce their wages, while innovation support is not feasible.[31] Marginal policies increasing wages can only be found in Region 2, with $\upsilon_{t+1} > 0$, $N^H_{t+1} > N^H_{\mu\,t+1}$. Here N^H_{t+1} rises with innovation support and exceptionally, for high values of υ_{t+1} and Γ, with human capital investment. Turning to finite rather than marginal policies, given a sufficient budget in some instances optimal policies may exist involving a jump from Region 1 to Region 2, that may secure a rise in skilled wages through innovation even in spite of a rise in the supply of skilled workers. If the initial conditions are situated in Region 2, however, skilled workers will always support innovation although they may not have any further incentives to alleviate poverty by increasing human capital.

How do the policy preferences of the unskilled compare with those of the skilled? (Figure 2.2) First, they will always invest in human capital. Second, they will almost always exchange some of the support for innovation preferred by skilled workers for human capital investment, unless of course the budget is enough to cover both needs completely. Skilled and unskilled workers would share an optimal policy whenever it reaches optimal human capital investment, but there are exceptional situations where it would be shared. These exceptional conditions arise if corner solutions involving both the boundary constraint and the constraint $\upsilon_{t+1} \leq 1$ exist. It is shown in the proof of Lemma 4, however, that these can only exist for unrealistically large Γ, that is, technological improvements averaging more than 6% per year in the leading country for 25 years (one generation), when $\alpha = 1/2$. Γ would have to be larger still for $\alpha < 1/2$, for example 9% for $\alpha = 1/3$. These statements are proved in the following lemma.

[31] This 'status quo' state clearly provides an incentive for corruption as an optimal use of tax resources.

Lemma 4. If Γ is not unrealistically large, for any optimal policy for skilled workers that does not reach optimal human capital investment, unskilled workers would prefer a policy allocating more human capital investment. The conclusion also holds for any Γ in situations where the government budget cannot sustain a full support for innovation $\upsilon_{t+1} = 1$.

We now examine the steady states and trajectories that can result from following the optimal policies for skilled or unskilled workers. Note that these policies coincide once human capital accumulation has reached its optimal level.

Proposition 5. A lagging country with a positive government budget can be in the following steady states.

1. If the unskilled workers' optimal policy is followed:

(1.1) *Human capital accumulation, followed by a divergent or convergent technological transition.* The lagging country will experience a transition to a steady state with optimal human capital investment. During the transition, human capital investment may be supported exclusively or may include some support for innovation. The steady state growth rate depends on the other institutional arrangements and productivity fixed effects φ and on the government efficiency ζ. The growth rate may be lower or higher than Country 1's with $a^* = 0$ or $a^* > 0$. If the lagging country's parameters are the same as Country 1's, it will reach the same steady state.

2. If the skilled workers' optimal policy is followed:

(2.1) *Optimal human capital investment.* In these steady states the development trap no longer exists and government policy need only support innovation.

(2.2) *Relative human capital stagnation.* This steady state correspond to states in Region 2 when skilled workers have incentives for innovation but not human capital accumulation.

(2.3) *Technological and human capital stagnation.* This Region 1 steady states correspond to the status quo states considered above, with zero technological change and zero human capital accumulation. They occur when there is a human capital trap; human capital is too low for innovation, and the government budget and/or efficiency is too low to reach Region 2, so there is no technological change; $a^* = 0$.

Steady states 2.1 and 2.2 may be convergent or divergent, depending on the other institutional arrangements and productivity fixed effects φ and on its government efficiency ζ as in case (1.1).

5. Free commerce

Consider two countries 1 and 2 trading domestically produced general goods, with labor and investment immobile. Write a_t for a_{2t}, and let $\varphi_1 = 1$, so that φ_2 is the relative efficiency of country 2. Assume also that country 1 has an optimal human capital supply, so that its effective labor supply is:

$$L_{1t}^{1-\alpha} H_{1t}^{\alpha} = \varepsilon_\alpha N_{1t}.$$

Country 2's effective labor supply is

$$L_{2t}^{1-\alpha} H_{2t}^{\alpha} = \kappa_2 \left(\frac{H_{2t}}{L_{2t}} \right) \varepsilon_\alpha N_{2t}.$$

where this equation defines $0 < \kappa_2 \left(H_{2t}/L_{2t} \right) \leq 1$, the efficiency of labor in country 2 as a function of its human capital allocation H_{2t}/L_{2t}, relative to an optimal allocation.

Goods will trade at the same international price which can be set at $p_1 = p_2 = 1$, one per unit of good. Real wages in Country 1 and Country 2 remain unchanged

5.1. Innovation

In the autarchic case a single innovator is assigned to the i^{th} good in each country. In effect this abstracts from the problem of domestic innovation races. In the multi-country case the problem of innovation competition must be addressed. Since the concern is not with the particular nature of innovation races, but with their long-term effects on economic growth, I simply assume that nature assigns a subset of sectors with measure ω_j to innovators from country j, with $\omega_1 + \omega_2 = 1$. Several scenarios can be examined with this assumption. First, identical countries can be assigned $\omega_1 = \omega_2$. Alternatively, endogenous assignments $\omega_j(a_t)$ can be considered. Also, it may be thought that the human capital level N_t^H/N_t has positive externalities on the number of sectors for which research can be performed, for example if the measure of innovators is reduced in the presence of a human development trap, so that $\omega_j = \omega_j(N_t^H/N_t)$. We assume that if both countries fully support innovation, then each sets $\omega_1 = \omega_2 = \frac{1}{2}$, dividing sectors equally between countries. In particular, if lagging Country 2 sets $\omega_2 < \frac{1}{2}$, then we assume Country 1 has the resources to set $\omega_1 = 1 - \omega_2 > \frac{1}{2}$. As soon as the government in Country 2 announces support for a set of sectors with $\omega_2 = \frac{1}{2}$, these are recuperated for Country 2.

5.2. Production, consumption and commerce

As before, goods are consumed in equal aggregate quantities Y_t and at the same price p_t. Note now that Y_{jt} is given by (2.9) (incorporating index j), while aggregate world production (or real expenditure) is the sum:

$$\frac{B_t}{p_t} = Y_t = \sum_j \varphi_j A_{jt} L_{jt}^{1-\alpha} H_{jt}^{\alpha}. \tag{5.1}$$

The assumption of trade balance is implicit in the model. Each country consumes each good in proportion to its income. Recall real profits in each innovative sector are $\pi_{jt}/p_t = \pi \upsilon_{jt} Y_t$, where υ_{jt} is the proportion of optimal production that can be produced given government support for its production in country j.

Suppose that as a result of the innovation process each country j has innovated on a measure $\omega_j \mu_j \geq 0$ of sectors. In each of these sectors there is government support for producing a proportion υ_{jt} of world demand, and the remainder must be produced competitively. Since the government will not support more innovative production than can be produced in its own country,

$$\omega_j \mu_{jt} \upsilon_{jt} Y_t \leq Y_{jt}. \tag{5.2}$$

If any capacity remains (expressed as a remaining supply of labor and human capital human), it must be used for competitive production, producing an income $\xi_j Y_t$ so that

$$\left(\upsilon_{jt} \omega_j \mu_{jt} + \xi_j\right) Y_t = Y_{jt}$$

and

$$\sum_{j=1}^{2} \left(\upsilon_{jt} \omega_j \mu_{jt} + \xi_{jt}\right) = 1 \tag{5.3}$$

Using (5.1) to solve for ξ_{jt}, competitive sectors have measures:

$$\begin{aligned} \xi_{1t} &= \frac{1}{1+\varphi_2 a_t \kappa_2 \frac{N_{2t}}{N_{1t}}} - \upsilon_{1t} \omega_1 \mu_{1t} \geq 0, \\ \xi_{2t} &= \frac{1}{1+\varphi_2^{-1} a_t^{-1} \kappa_2^{-1} \frac{N_{1t}}{N_{2t}}} - \upsilon_{2t} \omega_2 \mu_{2t} \geq 0. \end{aligned} \tag{5.4}$$

Observe that ξ_{jt} cannot both be zero simultaneously because $\upsilon_{1t}\omega_1\mu_{1t} + \upsilon_{2t}\omega_2\mu_{2t} < \omega_1 + \omega_2 = 1$. When $\xi_{jt} = 0$ we say country j is specialized in producing innovated goods.

5.3. The two-country dynamics

The effective innovation incentives in (4.1) are:

$$\Omega_{1t}(a_t) = \psi_1 \beta \pi \varepsilon_\alpha (N_{1t} + \varphi_2 a_t \kappa_2 N_{2t}), \tag{5.5}$$
$$\Omega_{2t}(a_t) = \psi(a_t) \beta \pi \varepsilon_\alpha \left(a_t^{-1} N_{1t} + \varphi_2 \kappa_2 N_{2t}\right). \tag{5.6}$$

Hence the innovation rates are $\mu_{jt}(a_t, \upsilon_{jt}) = f(\Omega_{jt}(a_t)\upsilon_{jt})$. While $f(\cdot)$ and $\Omega_{1t}(\cdot)$ are increasing functions, $\Omega_{2t}(\cdot)$ is decreasing. Thus μ_{1t} is an increasing and $\mu_{2t}(\cdot)$ a decreasing function of a_t. υ_{jt} must meet two criteria: the implied support is within the government budget

$$\mu_{jt}\upsilon_{jt}\pi Y_t + E_{jt}^P = \tau_j \zeta_j Y_{jt}, \tag{5.7}$$

and the implied production is feasible, as expressed in (5.2). Given these conditions, the two-country dynamics are given by:

$$\frac{a_{t+1}}{a_t} = H^{\mathrm{F}}(a_t) = \frac{1 + \omega_2 \mu_{2t}^{\mathrm{F}}(a_t, \upsilon_{2t})(\Gamma - 1)}{1 + \omega_1 \mu_{1t}^{\mathrm{F}}(a_t, \upsilon_{1t})(\Gamma - 1)}. \tag{5.8}$$

As in the case of autarchy, assume first that the government does not invest in human capital. On the other hand, assume that the government supports innovation to the fullest in view of its budget $\tau^{\max}\zeta_2 Y_{2t}$. Then υ_{jt} is the maximum value satisfying the three inequalities:

$$\mu_{jt}\upsilon_{jt} \le \frac{\tau_j \zeta_j Y_{jt}}{\pi Y_t}, \mu_{jt}\upsilon_{jt} \le \frac{Y_{jt}}{\omega_j Y_t}, \upsilon_{jt} \le 1. \tag{5.9}$$

Recall $\mu_{jt}\upsilon_{jt} = f(\Omega(a_t)\upsilon_{jt})\upsilon_{jt} = V(\Omega(a_t), \upsilon_{jt})$ and $V(\Omega, \upsilon(\Omega, E)) = E$. Hence

$$\upsilon_{2t}(a_t) = \min\left[\upsilon\left(\Omega(a_t), \frac{z_2}{1 + N_{1t}/(\varphi_2 a_t \kappa_2 N_{2t})}\right), 1\right],$$

where

$$z_j = \min\left[\frac{\tau_j \zeta_j}{\pi}, \frac{1}{\omega_j}\right]$$

gives the combination of parameters that is the stronger constraint: government resources or economy size.[32]

[32] If we take the realistic values $\tau_j \le 0.3$, $\pi = 0.3$ (implying $\alpha = .42222$ for $\Gamma = 1.025$), then since $\zeta_j \omega_j < 1$ it will be government support rather than economy size that is the binding constraint.

For Country 1, $\upsilon_{1t} = 1$ if $f(\psi_1 \beta \pi \varepsilon_\alpha N_{1t}) \leq \min\left[\tau_j \zeta_j / \pi, 1/\omega_j\right]$, which we assume. We also assume that it always has incentives for innovation, independently of the size of Country 2, so $\psi_1 \beta \pi \varepsilon_\alpha N_{1t} > 1$.

For Country 2, though, for small enough a_t, government support υ_{2t} will become bounded by government resources or economy size, independently of Country 2's relative size, efficiency (in institutions, fixed effects or spending), and human capital levels, because as $a_t \to 0$ $z_2/(1+N_{1t}/(\varphi_2 a_t \kappa_2 N_{2t})) \to 0$ so $\upsilon_{2t}(a_t) \to 0$. Country 2's small-sized economy will be unable to support innovative production at the global scale. Let a_{Min} be the minimum level of a_t at which $\upsilon_{2t}(a_t) = 1$ and Country 2 becomes constrained.

Country 2's relative technological dynamics are now completely determined, by substituting $\upsilon_{1t} = 1$ and $\upsilon_{2t} = \upsilon_{2t}(a_t)$ in (5.8).

By construction, functions $\mu_{1t}^{\text{F}}(a_t)$, $\mu_{2t}^{\text{F}}(a_t)$ are continuous. When they are non-zero, either $\mu_{1t}^{\text{F}}(a_t)$ is strictly increasing or $\mu_{2t}^{\text{F}}(a_t)$ is strictly decreasing, or both. So long as $a_t \geq a_{\text{Min}}$, so $\upsilon_{2t} = 1$, since both innovation rates cannot be zero, $H^{\text{F}}(a_t)$ is strictly decreasing and there is a unique solution for $H^{\text{F}}(a^*) = 1$, given by the solution to $\omega_2 \mu_{2t}^{\text{F}}(a_t) = \omega_1 \mu_{1t}^{\text{F}}(a_t)$.

If $a_t < a_{\text{Min}}$, so $\upsilon_{2t} < 1$, then $\upsilon_{2t}(a_t)$ is an increasing function so the possibility of multiple steady states arises. For small values of a_t, government expenditures will be small so

$$\upsilon_{2t} \approx \Omega_{2t}(0)^{-1} + \frac{\omega^{-1} z_2}{1 + N_{1t}/(\varphi_2 a_t \kappa_2 N_{2t})}$$

(see Appendix B), hence

$$\begin{aligned}
\lim_{a_t \to 0} \upsilon_{2t}(a_t)\Omega_{2t}(a_t) &\approx 1 + \lim_{a_t \to 0} \frac{\omega^{-1} z_2 a_t \Omega_{2t}(a_t)}{a_t + N_{1t}/(\varphi_2 \kappa_2 N_{2t})} \\
&= 1 + \omega^{-1} z_2 \psi_0 \beta \pi \varepsilon_\alpha \varphi_2 \kappa_2 N_{2t},
\end{aligned}$$

because $\lim_{a_t \to 0} a_t \Omega_{2t}(0) = \psi_0 \beta \pi \varepsilon_\alpha N_{1t}$. Thus

$$\mu_{2t}^{\text{F}}(0) = \lim_{a_t \to 0} \mu_{2t}^{\text{F}}(a_t) = 1 - \frac{1}{\sqrt{1 + \omega^{-1} z_2 \psi_0 \beta \pi \varepsilon_\alpha \varphi_2 \kappa_2 N_{2t}}}$$

On the other hand

$$\mu_{1t}^{\text{F}}(0) = 1 - \frac{1}{\sqrt{\psi_1 \beta \pi \varepsilon_\alpha N_{1t}}}.$$

Hence $H^{\mathrm{F}}(0) = \frac{1+\frac{1}{2}\mu^{\mathrm{F}}_{2t}(0)(\Gamma-1)}{1+\frac{1}{2}\mu^{\mathrm{F}}_{1t}(0)(\Gamma-1)}$. There is a steady state $a^* = 0$ if

$$\psi_1 \beta\pi\varepsilon_\alpha N_{1t} > 1 + 2z_2\psi_0\beta\pi\varepsilon_\alpha\varphi_2\kappa_2 N_{2t}, \tag{5.10}$$

which holds for small enough z_2, φ_2, κ_2 or N_{2t}.

Summarizing our results, Proposition 1 carries over for the case of free commerce as follows.

Proposition 6. Suppose that Country 1 has incentives for innovation independently of the size of Country 2; that Country 2 does not invest in human capital, dedicating all of its public resources to supporting innovation. Under free commerce, Country 2's relative technological level a_t converges to three types of situations.

(1) $H^{\mathrm{F}}(1) > 1$. If its initial conditions are sufficiently high (for example if $a_0 \geq a_{\mathrm{Min}}$) Country 2 will overtake Country 1, which falls into one of the steady states described below, after the country roles are reversed.

(2) Country 2 converges to a steady state $a^* > 0$ (for which $H^{\mathrm{F}}(a^*) = 1$), sharing Country 1's growth rate. This solution is unique in the interval $[a_{\mathrm{Min}}, 1]$.

(3) Country 2 converges to a steady state $a^* = 0$ with a lower growth rate than Country 1. A necessary condition is (5.10). When for Country 2 $z_2 = \tau_j\zeta_j/\pi < 1/\omega_2$, its resulting innovation rate $\mu^{\mathrm{F}}_{2t}(0)$ is the same as in the autarchic case. However now $\omega_2 = 1/2$ rather than 1, so the growth rate of its knowledge level A_t, and therefore its growth rate, is less.■

Countries with identical parameters need not have the same steady state, if z is small enough, since then a low enough initial condition implies converging to case (3) above.

On the interval $[a_{\mathrm{Min}}, 1]$, if a country has a higher steady state, one of the following must be higher: institutional arrangements and productivity fixed effects φ_j, government efficiency ζ_j, or human capital level N^H_j/N_j. As before, the presence of a human capital trap has a double effect: it lowers the steady state a^*_j and the efficiency of production κ_j. When both countries can afford full support for innovation, population levels N_j affect the global growth rate but not the steady state level a^*, since the steady state is given by:

$$\mu^{\mathrm{F}}_{1t}(a^*) = \mu^{\mathrm{F}}_{2t}(a^*) \Leftrightarrow \Omega_{1t}(a^*) = \Omega_{2t}(a^*) \Leftrightarrow \psi_1 a_t = \psi(a_t).$$

Finally, observe that divergent countries at $a^* = 0$ will probably loose innovation races, since they have a lower innovation rate μ^{F}_{2t}, and therefore will tend to find their ω_2 further diminished, lowering their growth rate.

The result here shows, more generally, that when innovative production at the global scale can only be supported with resources proportional to country income, divergence may follow. In this type of situation, countries sufficiently small an far behind cannot catch up on their own. One form of aid could be infrastructure.

5.4. Optimal policy

We maintain the same objective functions as before. Government policy decisions are very similar to those described for autarchy, with the following differences. Region 1 disappears, because since Country 1 has incentives to innovate so does Country 2, even when its budget for innovation support is small. Raising the human capital ratio continues to raise the incentives for innovation. This effect could be smaller, since it happens through increasing the size only of the home market, or larger, since it may occur at lower research levels and therefore at higher returns to research. Nevertheless, Lemma 4 continues to hold, allowing even larger Γ (see the proof of Lemma 4 in Appendix A).

We can now examine the steady states and trajectories that result from following the optimal policies for skilled or unskilled workers under free commerce. Note again that these policies coincide once human capital accumulation has reached its optimal level. The free commerce version of Proposition 5 is the following

Proposition 7. A lagging country with a positive government budget can be in the following steady states.

1. If the unskilled workers' optimal policy is followed:

(1.1) *Human capital accumulation, followed by divergent or convergent technological transition.* The description of this trajectory is analogous to the autarchic case except that Region 1 does not exist.

2. If the skilled workers' optimal policy is followed:

(2.1) *Optimal human capital investment.* In these steady states the development trap no longer exists and government policy need only support innovation.

(2.2) *Relative human capital stagnation.* This steady state correspond to states in Region 2 when skilled workers have incentives for innovation but not human capital accumulation.

Steady states 2.1 and 2.2 may be convergent or divergent, depending on the other institutional arrangements and productivity fixed effects φ and on the country resource parameter z_2.

6. Free commerce versus autarchy

When is free commerce better than autarchy? Although the model presented here focuses on the interaction between trade and innovation, trade theory also emphasizes the efficiency gains due to comparative advantage. To include these, suppose that when countries engage in trade the fixed productivity effects increase from φ_j (now φ_j^{A}) to φ_j^{F}.

Suppose country 1 has incentives to innovate independently of whether it trades with country 2. Its effective innovation incentives increase by a factor:

$$\frac{\Omega_{1t}^{\mathrm{F}}}{\Omega_{1t}^{\mathrm{A}}} = \frac{\varphi_1^{\mathrm{F}} + \varphi_2^{\mathrm{F}} a_t \frac{L_2}{L_1}}{\varphi_1^{\mathrm{A}}} > 1.$$

It benefits from trade if the growth rate rises, which occurs if $\mu_1^{\mathrm{A}} < \omega_1 \mu_1^{\mathrm{F}}$:

$$f\left(\Omega_{1t}^{\mathrm{A}}\right) < \omega_1 f\left(\Omega_{1t}^{\mathrm{F}}\right).$$

Country 1 must not loose too many innovation sectors to country 2.

Country 2's effective innovation incentives will also rise, by a factor:

$$\frac{\Omega_{2t}^{\mathrm{F}}}{\Omega_{2t}^{\mathrm{A}}} = \frac{\varphi_2^{\mathrm{F}} + \varphi_1^{\mathrm{F}} a^{*\mathrm{A}-1} \frac{L_1}{L_2}}{\varphi_2^{\mathrm{A}}} > 1.$$

Suppose that $a^{*\mathrm{F}} > a_{\mathrm{Min}}$, so that Country 2 can fully support innovation.. Since it converges in growth rates, Country 2 will benefit from free commerce if Country 1 does. Turning to its relative level, if $\omega_1 = \omega_2$, the steady state will occur at $a^{*\mathrm{F}}$ instead of $a^{*\mathrm{A}}$ where

$$\Omega_{2t}^{\mathrm{F}}\left(a^{*\mathrm{F}}\right) = \Omega_{1t}^{\mathrm{F}}\left(a^{*\mathrm{F}}\right).$$

Country 2's relative level a_t rises after opening at the autarchic steady state if:

$$\frac{\Omega_{2t}^{\mathrm{F}}\left(a^{*\mathrm{A}}\right)}{\Omega_{1t}^{\mathrm{F}}\left(a^{*\mathrm{A}}\right)} = \frac{\varphi_1^{\mathrm{A}}}{\varphi_2^{\mathrm{A}}} \times \frac{\varphi_2^{\mathrm{F}} + \varphi_1^{\mathrm{F}} a^{*\mathrm{A}-1} \frac{L_1}{L_2}}{\varphi_1^{\mathrm{F}} + \varphi_2^{\mathrm{F}} a^{*\mathrm{A}} \frac{L_2}{L_1}} = \frac{\varphi_1^{\mathrm{A}} L_1}{\varphi_2^{\mathrm{A}} a^{*\mathrm{A}} L_2} > 1. \tag{6.1}$$

Since $\Omega_{2t}^{\mathrm{A}}\left(a^{*\mathrm{A}}\right) = \Omega_{1t}^{\mathrm{A}}$ defines $a^{*\mathrm{A}}$, it can be shown that (6.1) is implied by:

$$\frac{\psi_0}{\psi_1}\left(1 - \frac{\varphi_2^{\mathrm{A}} L_2}{\varphi_1^{\mathrm{A}} L_1}\right) > 0.$$

The benefits of free commerce increase the worse the autarchic relative inefficiency of country 2; the smaller its market size relative to country 1's; the higher the advantage of backwardness; and the larger the innovation share ω_2/ω_1.

However, when Country 2's support for innovation is constrained, and a_t tends to a divergent steady state, the resulting growth rate is less under free commerce than under autarchy due to sectoral competition reducing ω_2 (see Proposition 6, part 3).

6.1. Optimal world growth rate

The highest world growth rate will occur with the largest market incentives, that is for the highest $N_{1t} + \varphi_2 a^* \kappa_2 N_{2t}$. Supposing all countries are equally efficient, this implies $a^* = 1$ and $\kappa_2 = 1$. Country 2 must not be lagging behind and it must have an optimal level of human capital. To reach $a^* = 1$, it of course requires $\omega_2 = \omega_1$. In effect, both countries together will now form a single leading country with a higher growth rate due to a larger market. proportional to a higher population $N_{1t} + N_{2t}$,

$$g_1^{\mathrm{F}*} = f\left(\psi_1 \beta \pi \varepsilon_\alpha \left(N_{1t} + N_{2t}\right)\right)$$

Country 1's long-term welfare is improved when Country 2 fully catches up.

Note to the contrary that when Country 2 diverges and $a^* = 0$, the world growth rate reduces to the autarchic growth rate, given Country 1 wins innovation races in all sectors and $\omega_1 = 1$.

7. Conclusions

Market failures in human capital accumulation and in technological change and innovation are a generally accepted fact. The Schumpeterian growth model presented here shows that these two hypotheses are sufficient to explain the long-term relation between human development and economic growth. The model's diverse steady states are consistent with the broad physiognomy of economic growth: widely varying incomes and growth rates, episodes of miracle growth (understood as transitions between steady states), economic growth without inequality reduction, positive and negative impacts of trade on growth, convergence to parallel growth paths of a large group of countries, long-term divergence and stagnation. An extension of the model would also account for the demographic transition. The inherent political economy of the model includes regimes characterized by corruption and stagnation, persistent inequality with intermediate levels of income, as well as development. The model also describes, in broad terms, the change in regime that the socialist countries required after their great successes in human capital formation. This involved a change of institutions that had become entrenched in the process.[33] The model shows how the combination of variables describing country states, namely governance efficiency and other productivity fixed effects, government expenditure efficiency, human accumulation levels, as well as human capital and innovation policies, together define steady state membership, and within that, growth rates or relative levels. At low levels of income, changes in these parameters lead to growth effects, while at high income levels they lead to level effects. Finally, the model shows that small countries lagging too far behind may not be able to emerge on their own.

Thus, by and large, the impact of these market failures explains the main features of economic growth. Let us agree that market forces are strong and in many situations unstoppable, and that their forces gave rise to modern economic growth and development — to understand that if they fully dominated the global scenario, more equilibrium and convergence would be observed. Institutions and policies for development must be two-pronged: they must promote healthy market functioning and governance — and also address the main market failures. This means that funding flows for early child development, nutrition, education, health, skills, production know-how and research, must be induced.

The assumption, in theoretical economics, that markets are perfect, leads to the conclusion that the problems lie with institutions. This non-sequitur is a not inconsiderable source of the institutional debate. Instead, methodologies must be developed to evaluate both the assumption and the conclusions. Policies, on the other hand, must reach a judicious mix between enhancing, complementing, or substituting market functions. The implicit institutional arrangements range from generating property rights and a state of law, through regulation and taxes, to providing public goods and funding programs. When active policies are necessary, these need not be performed by an inefficient central authority; instead, funding and organizational strategies can be used to develop local initiative, governance, capabilities and rights — as well as human capital and productivity. What are needed are institutions to perform what the market does not. The precise form these take is not so important, and can adapt to other objectives including effi-

[33] The mainstream populations in the developed world probably emerged from the human development trap during the Post War era. The neoclassical revolution and partial dismantlement of the welfare state that followed can be interpreted as a similar change of regime.

ciency, so long as the missing investments flow. Conversely, institutional policies not generating these flows will fail.

Development is not a zero-sum game. Dismantling the human development trap will generate large economic forces for world growth, and will reduce conflict both within and between countries. The incentives for innovation, and therefore the world growth rate, will be maximized when all countries are developed. It is in the economic interest of leading countries to foster productive and innovative capabilities around the world. The transfer of skills, know-how, research and infrastructure, within and between countries, is an instrument for prosperity and peace.

8. Appendix A. Proofs

Proof of Proposition 1. Everything is clear except for the derivation of the growth rate when $a_j^* = 0$: $\lim_{t\to\infty} G_{jt} \equiv \lim_{t\to\infty} A_{jt+1}/A_{jt} - 1 = \left(1 + g_1^{\mathrm{A}}\right) \lim_{t\to\infty} (a_{t+1}/a_t) - 1 = \left(1 + g_1^{\mathrm{A}}\right) H^{\mathrm{A}}(0) - 1 = \omega_j \mu_j^* (\Gamma - 1) < g_1^{\mathrm{A}}$.■

Proof of Corollary 2. (1) Since country j is identical to country 1, $H_j^{\mathrm{A}}(1) = H_1^{\mathrm{A}}(1) = 1$, so the unique steady state is $a_j^* = 1$. (2) This follows from Proposition 1.■

Proof of Corollary 3. This is clear.■

Proof. of Lemma 4. If the optimal policy is conserving the status quo in Region1, unskilled workers will prefer investing in human capital as much as possible (some spending is possible due to the assumption $\zeta\tau^{\max} > 0$), and possibly even support some spending on innovation. If the optimal policy for skilled workers lies in Region 2, the discussion above implies $\upsilon_{t+1} > 0$. Suppose $\upsilon_{t+1} < 1$, so that its level is dictated by a budget constraint, and consider alternative policies using the same budget. The derivative of O_{jt}^H along the budget constraint is zero. Since the constraint curve has a negative gradient, it is possible to increase N_{jt+1}^H while decreasing ω_{t+1}. Note that the derivative of O_{jt}^L along the budget constraint equals that of $O_{jt+1}^L - O_{jt+1}^H$. Write $\approx$ for "is a positive multiple of". Since

$$\begin{aligned}\frac{d}{dN_{jt+1}^H}\left(O_{jt+1}^L - O_{jt+1}^H\right) &\approx \frac{d}{dN_{jt+1}^H}\left(\frac{1-\alpha}{N_{t+1}^L} - \frac{\alpha}{N_{t+1}^H}\right)Y_{t+1} \\ &= \frac{d}{dN_{jt+1}^H}\left(\frac{1-\alpha}{N_{t+1}^L}Y_{t+1}\right) > 0,\end{aligned}$$

$$\frac{d}{d\upsilon_{t+1}}\left(O_{jt+1}^L - O_{jt+1}^H\right) \approx -\frac{dY_{t+1}}{d\upsilon_{t+1}} < 0,$$

$O_{jt+1}^L - O_{jt+1}^H$ and therefore O_{jt+1}^L increases along the budget constraint when N_{jt+1}^H is increased and υ_{t+1} is decreased. Unskilled workers would spend more on poverty alleviation and less on innovation. If instead $\upsilon_{t+1} = 1$ and the budget is not a constraint, that is, for the skilled it would be counterproductive to invest in more human capital, then again the derivative of O_{jt}^H along $\upsilon_{t+1} = 1$ is zero and the same argument will prove that O_{jt}^L has a positive derivative towards more human capital investment. However, if the optimal solution for O_{jt}^H is a corner solution on the intersection of $\upsilon_{t+1} = 1$ and the budget constraint, it is conceivable that this solution is optimal for O_{jt}^L as well. This exceptional situation requires the following conditions:

1) If more resources were available, skilled workers would benefit from a higher investment in human capital through its returns to innovation.

2) If more innovation support were available, both skilled and unskilled workers would benefit from a higher investment in innovation rather than human capital.

We show here that 1) is not possible if Γ is not unreasonably large, since then $dO_t^H/dN_{t+1}^H \leq 0$. In fact, 2) may provide a more stringent condition, at the cost, however, of a more complex calculation. Write $x = N_t^H/N_t$, so

$$\frac{N_t^H}{N_t^L} = \frac{x}{1-x}, N_t^{L\ 1-\alpha} N_t^{H\ \alpha} = (1-x)^{1-\alpha} x^\alpha N_t.$$

Suppose human capital is at or below its optimum level, $0 < x \leq \alpha$. Note

$$\begin{aligned} \frac{d}{dx}\left((1-x)^{1-\alpha} x^\alpha\right) &= (\alpha(1-x) - (1-\alpha)x)(1-x)^{-\alpha} x^{\alpha-1} \\ &= (\alpha - x)(1-x)^{-\alpha} x^{\alpha-1} \geq 0, \\ \frac{d}{dx}\frac{x}{1-x} &= (1-x)^{-2} \end{aligned}$$

Recall that in our present notation $\Omega(a_t) = \psi(a_t)\beta\pi\varphi_j N_{t+1}(1-x)^{1-\alpha} x^\alpha$ and

$$O_t^H \approx (1 + \omega f(\Omega(a_t)\upsilon_{t+1})(\Gamma - 1))\left(\frac{N_{t+1}^H}{N_{t+1}^L}\right)^{-(1-\alpha)},$$

with $\omega = 1$ for the autarchic case and $\omega < 1$in the case of free commerce.

$$\begin{aligned} \frac{dO_t^H}{dx} &\approx \omega f'(\Omega(a_t)\upsilon_{t+1})(\Gamma - 1)\psi(a_t)\beta\pi\varphi\upsilon_{t+1}N_{t+1}(\alpha - x)(1-x)^{-\alpha} x^{\alpha-1} \\ &\quad - (1-\alpha)(1 + \omega f(\Omega(a_t)\upsilon_{t+1})(\Gamma - 1))\left(\frac{x}{1-x}\right)^{-2+\alpha}(1-x)^{-2} \end{aligned}$$

For any value of x for which $\Omega(a_t) \geq 1$, at $\upsilon_{t+1} = \Omega(a_t)^{-1}$,

$$\begin{aligned} \frac{dO_t^H}{dx} &\leq \omega(\Gamma - 1)\frac{(\alpha - x)(1-x)^{-\alpha} x^{\alpha-1}}{(1-x)^{1-\alpha} x^\alpha} - (1-\alpha)\left(\frac{x}{1-x}\right)^{-2+\alpha}(1-x)^{-2} \\ &\approx \omega(\Gamma - 1)\frac{(\alpha - x)}{(1-x)x} - \frac{(1-\alpha)}{(1-x)^\alpha x^{2-\alpha}} \end{aligned}$$

This is negative for small Γ, namely,

$$\Gamma \leq 1 + \frac{1-\alpha}{\omega} \min_{0 \leq x \leq \alpha} \frac{(1-x)^{1-\alpha}}{(\alpha - x)\, x^{1-\alpha}}, \tag{8.1}$$

For higher values of υ_{t+1}, f' is smaller while the term containing f is negative. Hence $\frac{dO_t^H}{dx} \leq 0$ for all values of x and υ_{t+1} for which $\Omega(a_t) \geq 1$. If instead $\Omega(a_t) < 1$, then $f = 0$ and clearly $\frac{dO_t^H}{dx} \leq 0$. The inequality is stricter in the autarchic case.

For the comment preceding the Lemma, set $\omega = 1$. Applying calculus to obtain the upper bounds (8.1), at $\alpha = 1/2$, the maximum is at $x = 0.19098$ and the bound is $\Gamma \leq 4.3302$. Visual examination of the plot of Γ's bound shows this is decreasing in α, so this estimate holds for $\alpha \leq 1/2$. If one generation is equivalent to a period of 25 years, the first bound is reasonable if one believes possible technological improvements average less than 6% per year. For smaller ω, as in free commerce, the bound is less stringent. For example if $\omega = 1/2$, Γ need only average less than 8.5% per year.■

Proof of Proposition 5. At the steady states, human capital accumulation is invariant.

1. Since the unskilled workers' optimal policy always includes some human capital investment, its optimal level will eventually be reached. This may be a convergent or divergent steady state, according to parameters φ, ζ (see Corollary 3).

2. Since the skilled workers' optimal policy may leave human capital levels stagnant, the four types of steady states in Corollary 3 are possible. Human capital may be trapped in Region 1, with zero technological growth, steady state 2.3; or it may be trapped in Region 2, with a convergent or divergent growth rate, steady state 2.2; or it may be reach optimal levels, steady state 2.1, also with a convergent or divergent growth rate.■

Proof of Proposition 6. Everything is clear except for the last sentence of (3). The growth rate in the autarchic and free commerce cases are given by $\omega - \frac{\sqrt{\omega}}{\sqrt{\omega+Z}}$, where $Z = z_2 \psi_0 \beta \pi \varepsilon_\alpha \varphi_2 \kappa_2 N_{2t}$, with $\omega = 1$ at autarchy and $\omega = 1/2$ in free commerce. Note

$$\frac{d}{d\omega}\left(\omega - \frac{\sqrt{\omega}}{\sqrt{\omega + Z}}\right) = 1 - \frac{1}{2}\frac{Z}{(\omega + Z)^{3/2}\,\omega^{1/2}} > 1 - \frac{1}{2}\frac{Z}{(\omega + Z)\,\omega} > 0$$

for $\omega \geq \frac{1}{2}$ since then $\frac{Z}{(\omega+Z)\omega} < \frac{1}{\omega} \leq 2$. Hence the free commerce growth rate is less than the autarchic growth rate. This is because dedicating research to less sectors involves decreasing returns to research.■

Proof of Proposition 7. At the steady states, human capital accumulation is invariant.

1. Since the unskilled workers' optimal policy always includes some human capital investment, its optimal level will eventually be reached. This may be a convergent or divergent steady state, according to Country j's parameters.

2. Since the skilled workers' optimal policy may leave human capital levels stagnant, the four types of steady states described in Corollary 3 are possible. Human capital may be trapped in Region 2, with a convergent or divergent growth rate, steady state 2.2; or it may be reach optimal levels, steady state 2.1, also with a convergent or divergent growth rate.■

9. Appendix B

For fixed government expenditures $\omega f(\Omega\upsilon)\upsilon = E$, ($\omega = 1$ in the autarchic case)

$$0 = f'(\Omega\upsilon)\left(\upsilon + \Omega\upsilon_\Omega\right)\upsilon + f(\Omega\upsilon)\upsilon_\Omega$$

$$\Rightarrow 0 = \frac{1}{2}(\Omega\upsilon)^{-3/2}\left(\upsilon + \Omega\upsilon_\Omega\right)\upsilon + \left(1 - (\Omega\upsilon)^{-1/2}\right)\upsilon_\Omega$$

$$\Rightarrow \upsilon_\Omega = -\frac{\frac{1}{2}\Omega^{-3/2}\upsilon^{1/2}}{1 - \frac{1}{2}(\Omega\upsilon)^{-1/2}} < 0$$

$$\Rightarrow \mu_\Omega = -f(\Omega\upsilon)\upsilon_\Omega > 0$$

On the other hand, the derivative of υ with E is given by:

$$\omega f'(\Omega\upsilon)\Omega\upsilon_E\upsilon + \omega f(\Omega\upsilon)\upsilon_E = 1,$$

$$\Rightarrow \upsilon_E = \left(\omega f'(\Omega\upsilon)\Omega\upsilon + \omega f(\Omega\upsilon)\right)^{-1}$$

At $\upsilon = \Omega^{-1}$, $E = 0$ and $\upsilon_E = \omega^{-1}$. Hence to a first order approximation, for small E is:

$$\upsilon(\Omega, E) \approx \Omega^{-1} + \omega^{-1}E.$$

Also an increase in government support υ implies $\mu_\upsilon = \omega f'(\Omega\upsilon)\Omega > 0$.

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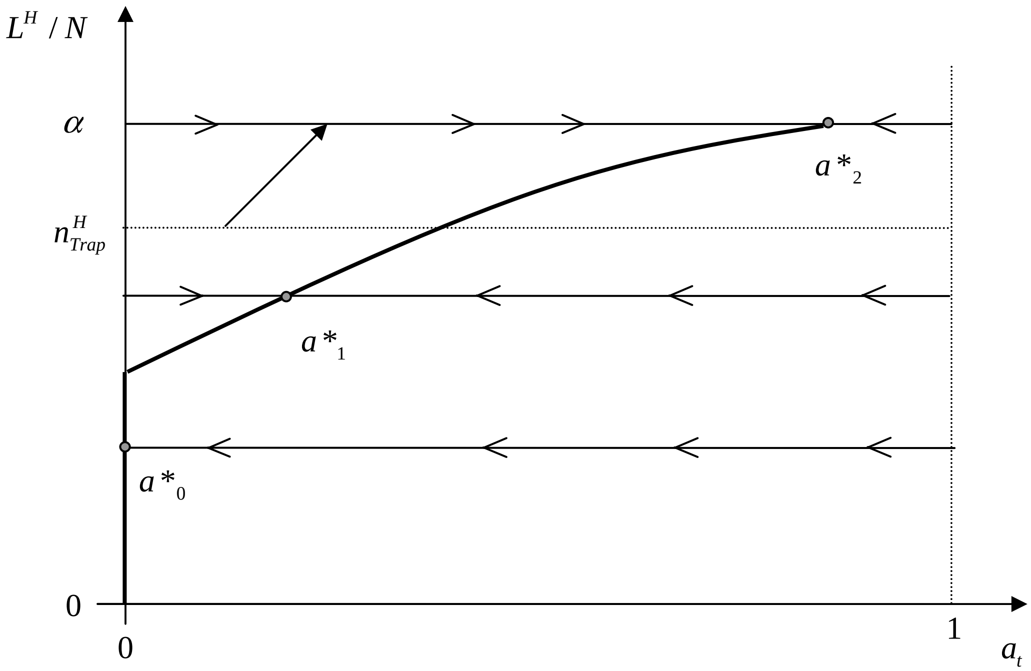

Figure 1. Examples of steady states for the relative technological level The thick curve represents equilibria $a*(L^H/N, \nu)$ for fixed human capital levels L^H/N and innovation support levels ν. A human capital trap exists for human capital levels below $n^H{}_{\text{Trap}}$, At this level the next generation jumps to optimal human capital level α. Increases in human capital levels shift the horizontal lines up, while increases in innovation support shift the equilibria $a*$ to the right. $a*_0$ is a divergent and $a*_1$ a convergent steady state with a human development trap. $a*_2$ is a convergent steady state with optimal human capital.

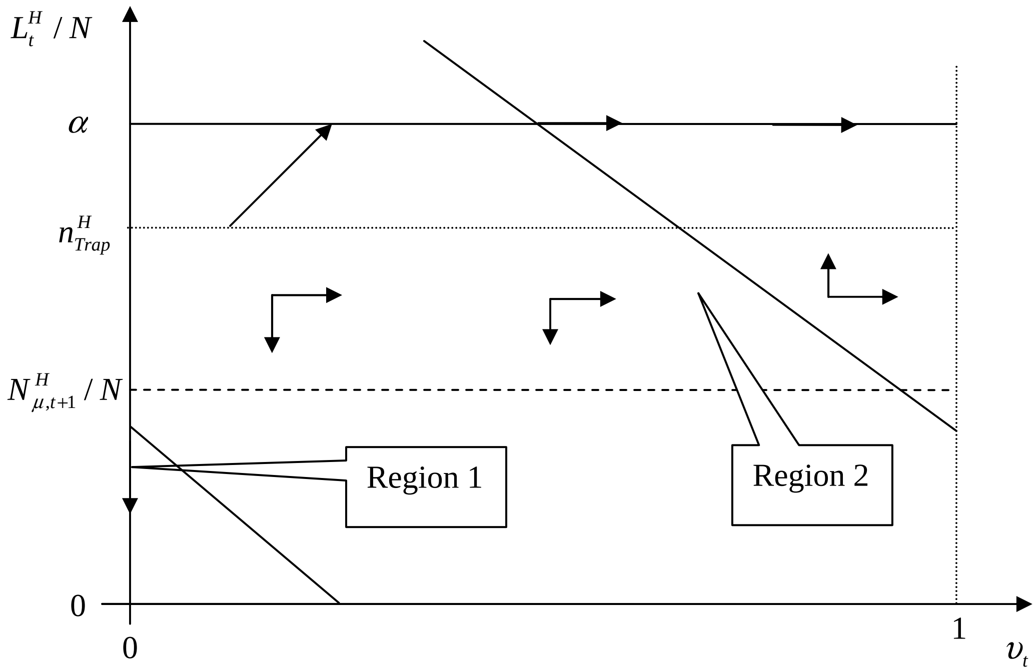

Figure 2.1. Examples of gradient arrows for skilled wages w_t^H. When human capital level is below $N_{\mu,t+1}^H / N$ (Region 1, a segment) there are no incentives for innovation, and skilled workers do not favor human capital investment for the unskilled. Above this level (Region 2, a rectangle), for a sufficient level υ_t of innovation support, human capital investment for the unskilled could be supported. The diagonal lines are budget constraints. The human capital level L_t^H / N lies somewhere on the vertical axis and can only rise. Skilled workers will invest mainly in innovation, or possibly not at all, if initial L_t^H / N lies in Region 1 and the budget is small.

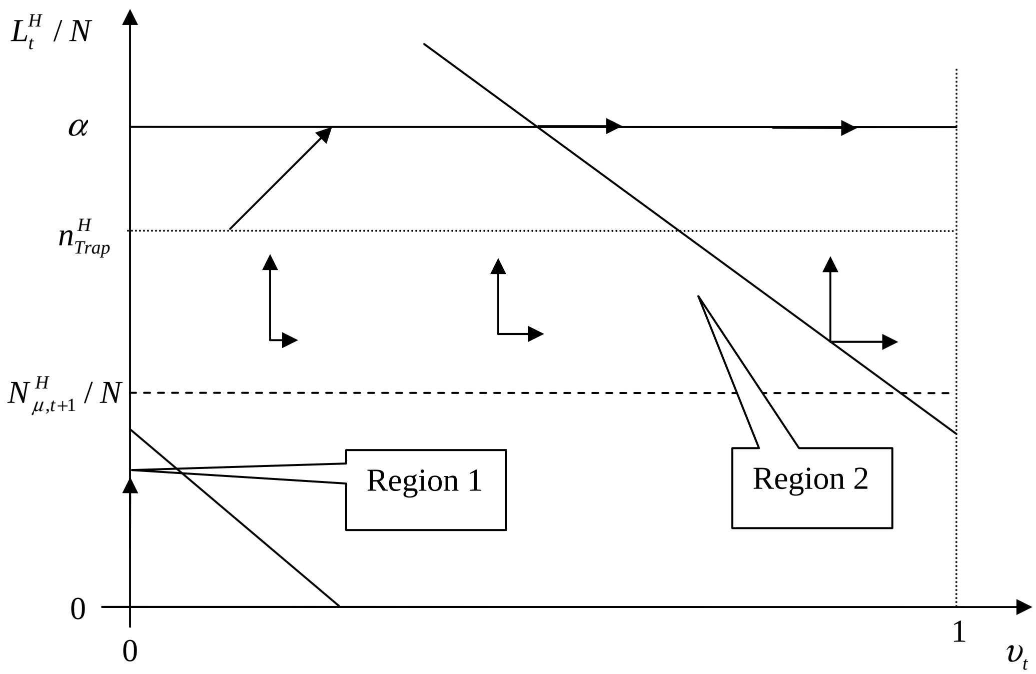

Figure 2.2. Examples of gradient arrows for unskilled wages w_t^L. Regions 1 and 2, and budget constraints, as in Figure 2.1. The human capital level L_t^H / N lies somewhere on the vertical axis and can only rise. Unskilled workers will always have an incentive to invest in human capital, until the human development trap is overcome. After this, everybody is skilled and will invest in innovation.