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SKILL SPECIFIC RATHER THAN GENERAL EDUCATION: A REASON FOR US-EUROPE GROWTH DIFFERENCES?

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ABSTRACT

In this paper, we develop a model of technology adoption and economic growth in which households optimally obtain either a concept-based, "general" education or a skill-specific, "vocational" education. General education is more costly to obtain, but enables workers to operate new technologies incorporated into production. Firms weigh the cost of adopting and operating new technologies against increased revenues and optimally choose the level of adoption. We show that an economy whose policies favor vocational education will grow slower in equilibrium than one that favors general education. Moreover, the gap between their growth rates will increase with the growth rate of available technology. By characterizing the optimal Ramsey education subsidy policy we demonstrate that the optimal subsidy for general education increases with the growth rate of available technology.

Our theory suggests that European education policies that favored specialized, vocational education might have worked well, both in terms of growth rates and welfare, during the 60s and 70s when available technologies changed slowly. In the information age of the 80s and 90s when new technologies emerged at a more rapid pace, however, it may have suboptimally contributed to slow growth and may have increased the growth gap relative to the US.

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1 Introduction

European economic growth has been weak relative to that of the US since the 80s. For instance, both Germany and Italy grew faster than the US in per capita terms during the period between 1970 and 1980, while the situation reversed in the subsequent two decades. During the last two decades Europe has also, with a few notable exceptions, suffered from a "technology deficit" relative to the US. As measured by manufacturing productivity, the share of information technology equipment, or by its contribution to output growth, European technology has lagged behind. Furthermore, Europe has had a tradition of fostering specialized, skill-specific, "vocational" education at the upper-secondary and higher levels.

In this paper, motivated by the above-mentioned empirical facts, we formalize the hypothesis that public policies favoring vocational education over a concept-based, "general" education may contribute to slower technology adoption and economic growth, especially during times of rapid technological change. We posit that only workers with general education can operate new, risky (in terms of task-specific productivity) technologies, whereas vocationally trained workers are more efficient in operating old, established technologies.

The notion that education helps in coping with technical change dates back at least to Nelson and Phelps (1966), who use reduced form specifications to postulate a higher return to education in an economy with more rapid technological change, and to Welch (1970), who provides supportive evidence for the dynamic advantage of education using wages of college graduates.[1] The theoretical contribution of our paper is to embed this idea in an equilibrium growth model that jointly models the adoption decision of firms and the decision of individuals to acquire a particular type of education, and analytically characterize the effect of education policy on growth. On the empirical front, we provide an explanation consistent with the "Eurosclerosis" view that holds rigid government policies responsible for inhibiting economic adjustment, thereby causing low employment and slow growth.[2] Our focus is on continental Europe's education policies.[3]

[1] While Welch (1970) uses R&D intensity as a proxy for technical change, Bartel and Lichtenberg (1987, 1991) use age of equipment as a proxy for *lack* of change and find that the labor cost share and the wage rate decrease with equipment age. Gill (1988) finds that higher TFP industries employ a larger proportion of educated workers and that the wage profile for highly educated workers shifts out with increasing TFP growth and is also steeper. Benhabib and Spiegel (1994) find that the human capital stock affects the speed of technology adoption in a cross-country context, lending support to a specification in Nelson and Phelps (1966). Thus, the advantage of education in adapting to technical change has both theoretical precedence and empirical support in the literature.

[2] The economist Herbert Giersch is generally credited with coining the term "Eurosclerosis."

[3] We formally elaborate on a theme voiced by Lawrence and Schultze (1987); p. 4,5 "The European economies...now experienced problems in graduating from a catch-up economy to one on the frontier of technology... Workers must have general training to adapt to new tasks, and European education, which has encouraged apprenticeships that provide specific skills, must adapt."

In our model, newly born individuals optimally and irreversibly choose between one of the two streams of education mentioned above, based on their intrinsic ability to absorb conceptual education, anticipated market conditions, and government subsidies for the two types of education. They weigh the higher wages associated with operating newer technologies against the higher cost of acquiring general education.

Firms have the choice of producing a single non-storable good either through technologies (production methods) *used* in the previous period – which have become well-understood and readily usable in the present period at no cost – or by adopting, at a cost, new technologies up to the available frontier. This technology frontier evolves exogenously. The non-adopting firms, also referred to as the "low-tech" firms, can use the old technology without any adoption cost. The adopting firms, also referred to as the "high-tech" firms, have to pay a cost of adoption that depends on the distance between the new and the previously used level of technology in a convex fashion, as well as potentially higher wages to attract workers who face the risk of low task-specific productivity caused by their move to an unfamiliar and more complex technology.

We completely characterize the education choices of individuals and the adoption decision of firms, and show that the equilibrium growth rate is lower in an economy that allocates more of a given amount of resources toward vocational education. The equilibrium growth rate is equal under two different education policies if and only if the economy, under both policies, adopts new technologies at the same rate at which they become available.

The positive relationship between the fraction of the work force with general education and growth may intuitively follow from our assumption that only generally educated workers can operate new technologies, although demonstrating this requires a fully specified model such as the one we have developed. However, what is not immediately obvious is the effect of an *increase* in the rate of available technology; the true value of the model lies in showing that in such an event, countries with different education systems that had comparable growth initially could diverge. More specifically, the difference in the growth rate between an economy that focuses on vocational education and one that focuses on general education is shown to increase with the exogenous rate of technology availability; the economy with better general education can more readily exploit the new technologies and might, in fact, be constrained only by their availability. By characterizing the optimal government education subsidy policy we demonstrate that the optimal subsidy for general education increases with the growth rate of available technology.

Our model suggests that while European education policies that favored specialized, vocational education may have worked well during the 60s and 70s when technologies were more stable, they may have contributed to slow growth and increased the European growth gap relative to the US during the information age of the 80s and 90s when new technologies emerged at a more rapid pace.[4] The following observations made in the *European Competitiveness Report 2001* directly speak to this suggestion (p. 10, 11): "The growing consensus that the strong growth and productivity performance in the US is related to increased investment and diffusion of ICT goods and services has raised concerns that the weaker economic performance of EU Member States is caused by sluggishness in the adoption of these new technologies... in recent years skill shortages in important technology areas have been reported in several European countries... It appears that, unlike in previous years, when the long-term trend increase in the demand for skills was met by the supply of technology professionals from the educational system, the surge in demand for ICT-related skills in the 1990s found no corresponding supply forthcoming." (ICT: Information and Communication Technologies)

We do not claim that the emphasis on skill-specific education alone is responsible for Europe's technology deficit or recent slow growth. Clearly, several other explanations such as generous unemployment insurance and inflexible labor laws would be required to complete the quantitative picture. Rather, our aim is to build a framework grounded in reasonable assumptions that focuses on the educational aspect, delivers key observed stylized facts, and lays a theoretical foundation for future empirical and quantitative work.[5] We view the development of a tractable growth model, featuring heterogeneity in the type of education and endogenous technology adoption decisions by firms as a goal in its own right.

In addition to the above-mentioned early precursors in the literature, our paper is related to a few other, more recent, studies. Ljungqvist and Sargent (1998) model unemployment as an event that causes a loss in human capital in order to study the effect of European unemployment insurance schemes on the level of unemployment. Our focus is very different, but in a similar spirit we model stochastic productivity losses arising from a change in production technologies. Violante (2002) posits a skill transferability function across jobs that depends on the technological distance between machine vintages in order to study the relationship between the rate of technological change and wage dispersion. The potential skill loss we model is akin to his transferability function. Neither of these papers is concerned with endogenizing the education decision and studying the effect of education policy on growth. Gould, Moav and Weinberg (2001) also focus on inequality caused by a depreciation of technology-specific skills, but this occurs randomly across sectors in their model; such depreciation is induced by a choice to work in the high-tech sector in our framework. Education is a choice variable for them, but there is no intentional adoption of new technology by firms.

[4] See, for instance, Greenwood and Yorukoglu (1997), who argue that there was an increase in the rate of technological change during the 70s. Hornstein and Krusell (1996), Krusell, Ohanian, Rios-Rull, Violante (2000) and Cummings and Violante (2002) arrive at a similar conclusion.

[5] A first attempt to quantify the relative importance of the education system in explaining US-Europe growth differences is carried out in Krueger and Kumar (2002).

Acemoglu (1998) develops a model in which an increase in skilled labor induces faster upgrading of skill-complementary technologies by firms; in our setup, an increase in the measure of workers with general education would have a similar effect. However, he does not distinguish between vocational and general education among skilled workers and therefore also does not discuss *optimal* policies, while we do. The same is true for the complementary work of Galor and Tsiddon (1997), who argue that during times of rapid technological progress the return to ability increases and that to specific human capital decreases, increasing mobility and the concentration of high-ability individuals in high-tech sectors, thereby fueling future growth. In this view, impediments to mobility in Europe could cause it to trail the US in economic performance, while our primary focus is on educational policy differences between the US and Europe. This paper is also complementary to Galor and Moav (2000), who develop a model in which education does play a dynamic role, but focus on the effect of technological change on wage inequality. Unskilled labor is assumed to count for less in a composite labor input when growth is higher, and ability enables individuals to cope with technological progress. As in these two papers, we also assume an exogenous ability distribution, but given our focus on education policies, we endogenously model the acquisition of general education based on this ability. Furthermore we characterize the response of equilibrium growth rates and education allocation to a change in the growth rate of technological progress, in order to explain the evolution of US-Europe growth differentials, whereas the aforementioned papers focus on other questions. Thus, when Prescott (1998) calls for theories of total factor productivity differences, we provide an education-based theory of such differences.

The rest of the paper is structured as follows. We summarize the stylized facts that motivate our study in Section 2. In Section 3 we present the economic environment and define a competitive equilibrium and a balanced growth path (BGP). The BGP is analyzed in Section 4. Section 5 contains our central theoretical results: an increase in subsidy for vocational education at the expense of general education will decrease growth, and the growth gap relative to an economy that focuses on general education will increase with the rate of arrival of new technologies. In Section 6 we characterize the optimal education subsidy policy, and Section 7 concludes the paper. Formal proofs and derivations are presented in the appendix, unless otherwise noted.

2 Stylized Facts

In this section we present the stylized facts that provide empirical motivation for our study – slow European per capita growth and manufacturing productivity growth since the 80s, Europe's "technology deficit", and its bias toward vocational education.

Consider annualized per capita GDP growth for the US and two countries we will use throughout as representatives of Western Europe – Germany and Italy. In the 70s Germany (2.6%) and Italy (3.1%) grew faster than the US (2.1%). In the 80s, the US grew at the faster rate of 2.3%, compared to 2.0% and 2.2% for Germany and Italy. The US lead solidified in the 90s; it grew at 2.0%, while Germany and Italy managed only 1.0% and 1.2%. The difference in growth rates is even more pronounced during the 1995-98 period; the US grew at 3% while the two European countries managed only 1.3% each.[6]

Since our theoretical framework focuses on technology adoption, productivity growth, technology usage, and technology production might be more relevant indicators of economic performance. Gust and Marquez (2000) study aggregate data and find that labor productivity in the major European countries did not accelerate in the latter half of the 1990s as it did in the US; TFP growth was also lower relative to that of the US. Our model is most likely to apply to the manufacturing sector; there, US labor productivity has outpaced that of Germany from as early as the mid-80s. The 1986-1990 and 1991-2000 figures for the US are 2.3% and 4.3%, and those for Germany are 2.0% and 3.8%. While Italy did better than the US in the initial period (3.8%), during the latter period its labor productivity growth of 2.2% was only half of US productivity growth.[7]

The difference is much starker when one examines technology-driven industries – in the US, these industries recorded an average annual productivity increase of 8.3% in the 1990s, when compared to the 3.5% achieved in the same industries as the European Union.[8]

There is abundant direct evidence that, with the exception of Sweden, Finland, and the Netherlands, Europe lags behind the US in technology usage.[9] Schreyer (2000), presents data on the share of information technology (IT) equipment in total investment. In 1985, this share was 6.3% in the US, and 3.4% each for Germany and Italy. By 1996 the gap had widened, with 13.4% for the US, and 6.1% for Germany and 4.2% for Italy. Schreyer also presents results from growth accounting studies which show the contribution of Information and Communication Technology (ICT) capital to output growth; these are presented in Table 1.[10]

[6] Growth rates are from Scarpetta et. al. (2000).

[7] See Table IV.1 in *European Competitiveness Report 2001*.

[8] See page 66, Graph IV.5, and Table IV.6 in *European Competitiveness Report 2001*. Pharmaceuticals, Office machinery and computers, Motor vehicles, Aircraft and spacecraft, are a few of the industries classified as Technology-driven industries.

[9] It is highly consistent with our theory that these three exceptions have higher figures (relative to the rest of Europe) for one or more of the following statistics: percentage of upper secondary students enrolled in general programs, net enrollment in university-level tertiary education, and percentage of public education expenditure devoted to subsidies for tertiary education. (See tables C3.2, C5.2a, and B3.2 in *Education at a Glance: OECD Indicators, 1997*.)

[10] We present data from Table 4 in Schreyer (2000), which uses a ICT price index harmonized across countries. When these figures are calculated in percentage terms instead of absolute percentage points,

The contribution of ICT capital to output growth has been increasing for all countries, but the gap between the US and European countries has been increasing as well. Since our model is most suited to the technology-driven sectors, delivering a stylized version of this table is an important goal of our theoretical analysis.

Table 1

ICT contribution to output growth (% points)

Economy	**1980-85**	**1985-90**	**1990-96**
US	0.28	0.34	0.42
Germany	0.12	0.17	0.19
Italy	0.13	0.18	0.21

For evidence that increased *usage* of such technology improves productivity, we turn to Stiroh (2002), who conducts econometric tests using industry-level data to show that IT-intensive industries experienced significantly larger labor productivity gains than other industries; he also finds a strong correlation between IT capital accumulation and labor productivity.[11]

There is evidence that ICT *production* is also correlated with TFP growth.[12] In the US, the computer and semiconductor industries contributed more than 50% to nonfarm business TFP growth during 1974-90 despite their small share in output.[13] Europe has lagged behind in ICT production as well (see Chart 3 in Gust and Marquez (2000)).

Though the actual magnitude of the productivity boom in the US during the 90s continues to be debated (see, for instance, Gordon (2000) for a skeptic's view), the facts that Europe has lagged behind the US in the last two decades in technology usage and production, and experienced slower productivity growth, are unlikely to be overturned by recent evidence.

Since our hypothesis is that the diverging trends between the US and Europe can, at least partially, be explained by differences in the educational system, we now present evidence on

similar patterns persist.

[11] A positive correlation between the ICT share and TFP growth also emerges from Graph 6 in the European Commission (2000) report.

The widespread nature of productivity acceleration reported by Stiroh (2002) casts doubts on an alternate explanation for the US productivity advantage, that the US with its more liberal immigration policies attracts highly skilled specialists to the high-tech sectors, and American focus on general education has nothing to do with this advantage. This would not explain why industries as far flung as "Security and Commodity Brokers," not typically populated by immigrants, experienced huge increases in productivity growth. The assumption that only workers with high levels of education immigrate to the US is not tenable, and many immigrants first acquire general education in US universities before they begin work. The immigration explanation also does not explain why there was a *change* in the European economic performance starting in the 80s when there was no corresponding change in European immigration laws.

[12] See Graph 4 in the European Commision's (2000) report.

[13] See Table 4 in Oliner and Sichel (2000).

European focus on vocational education.[14] The classification of education into general and vocational should be viewed as a metaphor for the rigidity and inflexibility of European upper secondary and post-secondary education. Therefore, the issue under consideration includes, but is broader than, that of college versus school education. In Europe, the channeling of students into either stream starts earlier than college; indeed, a portion of the differences in university enrollment between the US and Europe can be attributed to such early pegging of students. For instance, OECD's *Education Policy Analysis* 1997, states that in Germany only about 20% of university entrants are from the vocational stream.[15]

In 1991, 79.3% of upper secondary students in West Germany and 70.6% of Italian students were enrolled in vocational or apprenticeship programs. The EU average was 58%. In contrast, there is no separate stream of vocational education in the US at this level; however, the percentage of students who completed 30% or more of all credits in specific labor market preparation courses was just 6.8% in 1990.[16] Since education at this level is typically fully funded by the government, this data suggests that the European governments spend a greater fraction of their resources on vocational training than the US.[17] Vocational education in the US is typically imparted in two-year community colleges; of those over the age of 18 enrolled in post-secondary education, only 13.8% were working toward a vocational Associate's degree in 1991; this figure fell to 10.5% in 1994.[18]

A related indicator is the net entry rate into universities, where general education is primarily imparted; it is 52% in the US but only 27% in Germany, 33% in France, and 26% in Austria.[19] This lower European enrollment is reflected in attainment; while 25% of adults had completed university-level education and 8% had completed non-university tertiary education (primarily vocational) in the US in 1995, in Germany 13% had completed university education and 10% non-university education. Incidentally, the rate of return for men from such non-university tertiary education is 9% in the US, while it is 17% in Germany, which might point to better employment opportunities for the vocationally educated in that country.[20]

Allocation of educational resources differs between the US and continental Europe as well.

[14] We abstract from the diversity in education systems that exists within continental Europe.

[15] Lazear's (2002) evidence that students who have taken a more general curriculum have a higher chance of becoming entrepreneurs also seems relevant in this context. Entrepreneurship, which is an important channel for adoption of new technologies, is generally thought to lag behind in Europe relative to the US. See for instance, the European Commission's September 2001 policy paper, *Entrepreneurial attitudes in Europe and the US.*

[16] These figures are from Table 3.2 of Medrich et. al. (1994). Also see the European Commission's 1998 report, *Young People's Training.*

[17] The German apprenticeship program involves partial outlays by firms as well.

[18] See Table 87 in Levesque et. al. (2000).

[19] See Table C4.1 in *Education at a Glance: OECD Indicators 1997.*

[20] See Table E5.1 in *Education at a Glance: OECD Indicators 1997.*

The OECD Education Database indicates that the percentage of GDP devoted to primary and secondary education was about the same – 3.8% for the US and Germany in 1997 and 3.4% for Italy. However, the percentage devoted to tertiary education in the US (2.6%) far outstripped the percentages in Germany (1.1%) and Italy (0.8%). The expenditure per student relative to GDP per capita on post-secondary non-tertiary (vocational) education was 49% in Germany for 1997, amounting to 10,839 PPP dollars; little happens on this front in the US. The corresponding figures for tertiary education was 43% in Germany but 59% in the US. In PPP dollars, the tertiary education expenditure per pupil was $9,466 in Germany while in the US was $17,466 (it was $5,972 in Italy).

Therefore, it seems reasonable to conclude that more resources are allocated to vocational education in Europe relative to the US, where the emphasis has been on general education. We use this observation to motivate revenue-neutral policy experiments in which European vocational education subsidies per student are higher than those of the US. The equilibrium enrollment and education attainment implied by the model presented below will then be qualitatively consistent with the data presented above.

3 The Environment

The economy is populated by a continuum of households and two continua of identical firms. Firms in one sector potentially adopt new technologies in every period, and firms in the nonadopting sector do not.[21] There is a single nonstorable consumption good in each time period and households supply labor to the firms. In this section we describe the maximization problems of a typical firm in each sector and of a typical household, and finally define equilibrium and a balanced growth path.

3.1 Firms and Technology Adoption

Each firm in this economy is owned by infinitely lived entrepreneur, who consumes all profits from production in each period, as they, like workers, have no access to an intertemporal storage technology.

A representative firm in the low-tech sector that does not adopt new technologies in the current period faces the production technology:

$$Y_{n,t} = A_t \left(H_{n,t}\right)^{\theta},$$

where $Y_{n,t}$ is output of the nonadopting firm in period t, $H_{n,t}$ is the labor input used by that firm in period t, A_t is the level of technology that is freely available in period t and

[21] We have abstracted from important issues of industrial organization, such as free entry, to keep our model analytically tractable and to focus on the education channel as a source of growth differences between the US and Europe.

$\theta \in (0,1)$ is an intensity parameter. The nonadopting firms take A_t and the real wage rate (per effective unit of labor) $W_{n,t}$ in the nonadopting sector as given.

The firms in the high-tech sector of the economy that (potentially) adopt new technologies face the production technology

$$Y_{a,t} = A'_t \left(H_{a,t}\right)^{\theta},$$

where $Y_{a,t}$ is output of the adopting firm in period t, $H_{a,t}$ is the effective labor input used by that firm and A'_t is the level of technology used in period t, which is a *choice* variable for the adopting firms. We let $W_{a,t}$ denote the real wage rate (per effective unit of labor) in the adopting sector. The technology frontier grows exponentially, i.e.

$$A_{f,t} = \lambda A_{f,t-1}, \tag{1}$$

where $\lambda > 1$ is the constant gross growth rate of the frontier technology. The technology choice of the adopting firm has to satisfy $A'_t \leq A_{f,t}$. We assume that $A_0 = A'_{-1} = A_{f,-1} = 1$; i.e. the economy starts at the technology frontier. The parameter λ is the potential growth rate of the economy. If the economy keeps pace with these periodic inventions by adopting them as fast as they occur, the actual growth rate will be the same as the potential one. An increase in λ is later used to model an increased speed at which new technologies become available.

We further assume that all firms can use the highest technology that was *used* last period, and hence has become common practice; that is, $A_t = A'_{t-1}$ and there is complete spill-over of previously adopted technologies in one period.[22] It is important to note: 1) It is the technology actually *adopted* in the previous period rather than the frontier technology that was *available* last period that spills over costlessly to the next period, and 2) The adopting firms are small and do not take into account the influence that their adoption choice A'_t today has on the next period's common practice A_{t+1}.[23] What we intend to capture with

[22] This can be viewed as a reduced form modeling of learning by doing in which productivity gains spill over across sectors. See, for instance, Young (1993) and the references therein.

We assume that there are no international spillovers of technology. If there are such spillovers, European technology would catch up to the US technology with whatever lag is assumed for the spillover. Data does not seem to support such automatic spillovers. Even with a mature technology such as personal computers, Microsoft data shows that in the US 90% of white-collar workers use them, whereas only 55% in Western Europe do so. The International Data Corporation reports that the US market for PCs grew 15% in 1996, while the Western European market grew only by 7.1%. (See the article, "Europe's Technology Gap is getting Scary," in the March 17, 1997, issue of *Fortune*.)

[23] More formally, let $a'_t(i)$ denote the technology choice of adopting firm $i \in [0,1]$ and $A'_t = \int a'_t(i)di = A_{t+1}$ denote the common practice. Since firms are identical and will have a unique solution to their maximization problem, it follows that a) every firm perceives $A_{t+1} = A'_t$ to be unaffected by its choice of $a'_t(i)$ and b) $a'_t(i) = A'_t = A_{t+1}$. Thus in the main text we do not explicitly distinguish between $a'_t(i)$ and A'_t and let A'_t denote the techology adoption decision of a representative adopting firm.

these assumptions is the notion that most gains from adopting new technologies come in the form of higher short-run profits, before its "bugs" are ironed out and they become available as common technologies to competitors.

Gaining this short-run advantage comes at a cost for the firm, however. To use a level of technology $A'_t \in [A_t,\ A_{f,t}]$, the firm incurs a cost of adopting the new technology, which is increasing and convex in the distance between A_t and A'_t. This cost captures the firm's outlays for training workers in the new technology, fixing the aforementioned "bugs" etc. that will allow the full potential of the new technology to be realized today before it is discovered and ironed out by competing firms. We assume that the cost of adoption takes the following form:

$$C(A_t, A'_t) = \begin{cases} \frac{A_t}{2}\left(\frac{A'_t}{A_t} - 1\right)^2 \text{ if } A'_t > A_t \\ 0 \text{ if } A'_t \leq A_t. \end{cases}$$

Since our analysis will focus on balanced growth paths (BGP) in which the growth rate $x = \frac{A'_t}{A_t} \leq \lambda$ is constant, whenever there is no ambiguity we drop time subscripts from A_t, A'_t and $A_{f,t}$. If A is viewed in units of machines, the cost function implies that along a BGP the cost of retooling each machine with the new technology, $\frac{C}{A} = \frac{1}{2}(x-1)^2$ is constant.[24]

3.2 Households

There is a measure one of two-period lived agents born in each period.

3.2.1 Education Choices

An agent is born with an ability $a \in [0, 1]$ for higher education, which is distributed uniformly across the population; i.e. according to the cumulative distribution function $F(a) = a$. In the first period of her life each agent has to choose between general education g and vocational education v. There is a utility cost for attaining general education, $e(a)$, which is strictly *decreasing* in a. This captures the greater difficulty in learning conceptual material, cost of longer duration of education, lower subsidies relative to vocational training, etc. Once the education choice $i \in \{g, v\}$ has been made, it is irreversible until agents die.

3.2.2 Skill Accumulation

In the second period of an agents' life workers have a skill level for her current occupation of $H \in \mathcal{H} = \{1, h\}$. We assume that workers with vocational education can only work in the nonadopting sector and have job-specific skill level $h > 1$ for working in that sector. Workers

[24] The modeling choice of not making the cost of adoption depend directly on the measure of the labor force with general education appears to be a conservative one. Our results are likely to be strengthened if "skilled" labor is required to adopt technologies.

with general education, in the second period of their life, can only work in the adopting sector and have skill level $H = 1$ with probability $T_l \in (0, 1)$ and $H = h$ with probability $1 - T_l$. Let

$$E_h = h - T_l(h - 1) < h$$

denote the expected skill level of an agent with general education in the second period of its life. We assume a law of large numbers so that T_l is also the deterministic fraction of the population with general education that has skill level $H = 1$.

Our assumption captures the job-readiness that vocational education imparts for the technology *currently* in use, whereas agents with general education face risk of a job-specific productivity loss when operating a new technology. Obviously agents have to be compensated for their lower expected skill level in the second period of their life when choosing general education; this happens through two channels: higher wages in the adopting sector and (possibly) higher direct education subsidies. Restricting agents with vocational education to work in the nonadopting sector and agents with general education in the adopting sector is not crucial for our analysis. In section 8.3 of the appendix we give sufficient conditions that make it *optimal* for v-agents to *choose* the nonadopting sector and for g-agents to choose the adopting sector.[25]

3.2.3 Endowments and Preferences

A newborn household of type a has preferences over stochastic consumption in the second period of her life. The only endowment the household has is one unit of time in each period that is used for education in the first and supplied to the labor market in the second period. An agent that chooses vocational education consumes $c_t = W_{n,t}h$ in the second period, whereas an agent with general education consumes

$$c_t = \begin{cases} W_{a,t} & \text{with probability } T_l \\ W_{a,t}h & \text{with probability } 1 - T_l \end{cases}$$

Households maximize:

$$U(c) = E_t \log(c_{t+1}) - I_g \log(e(a)),$$

by choosing the type of education, where $I_g = 1$ if the household chooses to obtain general education and 0 otherwise. The expectation E_t is taken with respect to the underlying stochastic process governing skill levels for agents with general education.[26]

[25] An earlier version of this paper, available at http://siepr.stanford.edu/papers/pdf/01-35.pdf, demonstrates that the same qualitative results as in the current paper can be shown to hold in a more complicated model where agents face repeated productivity shocks and choose the sector to work in every period.

[26] Note that we abstract from time discounting by the households. Obviously our formulation of preferences, and hence the ensuing analysis is equivalent to having households discount the future and re-scaling the cost of education.

3.3 Recursive Competitive Equilibrium

The aggregate state of this economy is given by the current level of technology A, the technology frontier A_f, and the cross-sectional distribution of workers over their education levels $i \in \{g, v\}$. Let μ_i denote the fraction of the work force with education i in the second period of their life. The aggregate state thus consists of $z = (A, A_f, \mu)$.[27] From our assumptions about the properties of $e(a)$ it is also clear that there exists a cutoff level $a^*(z) \in [0, 1]$ such that all agents with ability $a(z) \geq a^*(z)$ will choose to obtain general education $(I_g = 1)$, whereas all agents with $a(z) < a^*(z)$ will choose to obtain vocational education $(I_g = 0)$.

3.3.1 Workers Utilities

Let by V_i denote an agents' lifetime (second period) utility, after having obtained education $i \in \{v, g\}$. Given wages $W_n(z), W_a(z)$ in the adopting and nonadopting sector these are given by

$$\begin{aligned} V_v(z) &= \log(W_n(z)h) \\ V_g(z) &= T_l \log(W_a(z)) + (1 - T_l) \log(W_a(z)h) \end{aligned} \tag{2}$$

Aggregate effective labor supply in both sectors implied by the aggregate state of the economy is given by

$$\begin{aligned} H_n^s(z) &= \mu_v h \\ H_a^s(z) &= \mu_g E_h. \end{aligned}$$

3.3.2 Equilibrium

We are now in a position to define a recursive competitive equilibrium.

Definition 1 *A **recursive competitive equilibrium** consists of value functions $V_i(z)$ and policy functions $I_g(z)$ for the household, implied aggregate labor supply functions $(H_n^s(z), H_a^s(z))$, a cutoff level $a^*(z)$, labor demand functions for firms $(H_n^d(z), H_a^d(z))$, and a technology adoption function $A'(z)$ for the adopting firms, wage functions $(W_n(z), W_a(z))$ and an aggregate law of motion Φ mapping today's aggregate state z into tomorrow's aggregate state z' such that:*

1. *Given $(W_n(z), W_a(z))$ and Φ, the V_i are defined in (2).*

[27] Note that an agent's ability level a will only affect her education decision in the first period of her life, but not subsequent consumption levels (other than via her education).

2. Given $(W_n(z), W_a(z))$,

$$\begin{aligned} H_n^d(z) &\in \arg\max_{H\geq 0} A\,(H)^\theta - W_n(z)H \\ \left(H_n^d(z), A'(z)\right) &\in \arg\max_{H\geq 0, A'\leq A_f} A'\,(H)^\theta - W_a(z)H - C(A, A'). \end{aligned}$$

3. $H_n^d(z) = H_n^s(z)$; *and* $H_a^d(z) = H_a^s(z)$.

4. The cutoff $a^*(z)$ *satisfies:* $V_g(z) - V_v(z) = \log(e(a^*(z)))$.[28]

5. The aggregate law of motion Φ *is induced by the probability* T_l*, the policy functions* $A'(z)$ *and* $I_{iH}(z)$ *and the cutoff* $a^*(z)$ *(as described below).*

Given a state $z = (A, A^f, \mu)$ today, the state $z' = \Phi(z) = (A', A'_f, \mu')$ tomorrow is determined as follows. The frontier evolves exogenously, $A'_f = \lambda A_f$. Given the endogenously determined technology adoption function $A'(z)$, we have $A' = A'(z)$. This leaves the next period's distribution over types, μ', to be determined. Let $\eta_v(z)$ denote the fraction of newborn agents deciding to get vocational education and $\eta_g(z)$ denote the fraction of newborn agents deciding to obtain general education; given the threshold ability mentioned above, and a uniform ability distribution, these fractions are $\eta_v(z) = a^*(z)$ and $\eta_g(z) = 1 - a^*(z)$ respectively. The distribution over education types tomorrow is therefore given as:

$$\begin{aligned} \mu'_g(z) &= \eta_g(z) \\ \mu'_v(z) &= \eta_v(z). \end{aligned} \tag{3}$$

3.3.3 A Balanced Growth Path

A balanced growth path is defined to be a recursive competitive equilibrium for which all elements of the equilibrium, normalized by the current level of technology in an appropriate fashion, are constant. Since growth in this economy is driven exclusively by the adoption of new technologies, the growth rate along a balanced growth path is given by $x \equiv \frac{A'}{A}$. We normalize wage per skill unit as $w_n = \frac{W_n}{A}$ and $w_a = \frac{W_a}{A}$. The normalized firm maximization problems become:

$$\Pi_n = \max_{H\geq 0} H^\theta - w_n H \tag{4}$$

$$\Pi_a = \max_{H\geq 0, 1\leq x\leq \bar{x}} xH^\theta - w_a H - \frac{1}{2}(x-1)^2, \tag{5}$$

where $\bar{x} = \frac{A_f}{A}$ is the maximal growth rate of technology that the adopting firm can choose. That is, the adopting firm's problem on the BGP now involves a choice of the growth rate

[28] We shall later make assumptions to guarantee an interior $a^* \in (0, 1)$

of technology rather than its level. As for the workers, their lifetime continuation values are given by

$$\begin{aligned} v_v &= \log(w_n h) \\ v_g &= T_l \log(w_a) + (1 - T_l) \log(w_a h) \end{aligned} \tag{6}$$

Continuation functions reduce to two numbers (v_g, v_v) along the BGP. The BGP cutoff level a^* then satisfies the following indifference condition that governs educational choice:

$$v_g - v_v = \log(e(a^*)). \tag{7}$$

Finally, in a BGP the cross-sectional distribution over education and skill level μ is constant over time, i.e. $\mu = \mu' = \bar{\mu}$ with

$$\begin{aligned} \bar{\mu}_g &= \eta_g = 1 - a^* \\ \bar{\mu}_v &= \eta_v = a^* \end{aligned} \tag{8}$$

We therefore have the following definition.

Definition 2 *A* ***balanced growth path*** *consists of values* (v_g, v_v)*, labor supplies* (H_n^s, H_a^s)*, labor demands* (H_n^d, H_a^d) *and a growth rate of technology* x*, wages* (w_n, w_a)*, a cutoff ability level* a^* *and an invariant distribution* $\bar{\mu} = (\bar{\mu}_g, \bar{\mu}_v)$ *such that:*

1. *Given* (w_n, w_a) *the values* (v_g, v_v) *satisfy equation* (6)

2. *Given* (w_n, w_a)*,* H_n^d *solves* (4) *and* (x, H_a^d) *solve* (5).

3. $H_n^d = H_n^s$*; and* $H_a^d = H_a^s$.

4. *The cutoff* a^* *satisfies* (7).

5. *The distribution* $\bar{\mu} = (\bar{\mu}_g, \bar{\mu}_v)$ *satisfies* (8).

We confine ourselves to the analysis of BGP equilibria; in particular we are interested in how different educational policies affect the attainment of general education, and hence the growth rate of the economy along the BGP, as the speed of technological advancement λ increases.

4 Analysis of the BGP

We first outline the steps in our strategy for characterizing the BGP; the applicable subsections and figures are given within parentheses:

- Solve the firms' problems to obtain the relative labor demand function $\frac{H_a^d}{H_n^d}\left(\frac{w_a}{w_n}\right)$ and technology adoption schedule $x\left(\eta_g\right)$ from the problem for adopting firms (Section 4.1).

- Solve for the households' education decision to obtain relative labor supply functions $\frac{H_a^s}{H_n^s}\left(\frac{w_a}{w_n}\right)$. Combine with relative labor demand function $\frac{H_a^d}{H_n^d}\left(\frac{w_a}{w_n}\right)$ to characterize labor market equilibrium and to derive the "education schedule" $x^s\left(\eta_g\right)$ (Section 4.2).

- Combine $x(\eta_g)$ and $x^s(\eta_g)$ to solve for BGP η_g^* and x^* and characterize its properties (Section 4.3, Figure 1)

- Characterize how balanced growth and the education allocation changes with subsidies for general education, s (Section 5.2, Figure 2).

- Perform comparative statics with respect to the speed of technological innovation λ, and show how the results vary with education policy s (Section 5.3, Figure 3).

- Characterize the *optimal* education policy (Section 6).

We now consider each of the above steps in detail.

4.1 Firms, Labor Demand and Technology Adoption

For a given wage in the nonadopting sector w_n the labor demand of firms in that sector is given by, $H_n^d(w_n) = \left(\frac{\theta}{w_n}\right)^{\frac{1}{1-\theta}}$, and profits are obtained as, $\Pi(w_n) = \left(\frac{\theta}{w_n}\right)^{\frac{\theta}{1-\theta}}(1-\theta) > 0$. For the adopting sector we first solve for the conditional labor demand as a function of the wage w_a, and the growth rate, x, as:

$$H_a^d(w_a; x) = \left(\frac{\theta}{w_a}x\right)^{\frac{1}{1-\theta}}, \tag{9}$$

where $x = \frac{A'}{A}$ is the growth rate of technical progress chosen by firms. Using equilibrium in the labor market we have

$$\begin{aligned} \eta_g E_h &= \left(\frac{\theta}{w_a}x\right)^{\frac{1}{1-\theta}} \\ x &= \frac{w_a}{\theta}\left(\eta_g E_h\right)^{1-\theta} \end{aligned} \tag{10}$$

In order to guarantee concavity of the objective function in the critical range and ensure the first order condition is sufficient, we make

Assumption 1: $\theta < \frac{1}{2}$

Using the conditional labor demand function in the objective function we can rewrite the maximization problem of the adopting firm as:[29]

$$\begin{aligned} & \max_{1\leq x\leq \bar{x}} x^{\frac{1}{1-\theta}}\left(\frac{\theta}{w_a}\right)^{\frac{\theta}{1-\theta}}(1-\theta)-\frac{1}{2}(x-1)^2 \\ = & \max_{1\leq x\leq \lambda} x^{\frac{1}{1-\theta}}\left(\frac{\theta}{w_a}\right)^{\frac{\theta}{1-\theta}}(1-\theta)-\frac{1}{2}(x-1)^2 \end{aligned}$$

The first order condition for this problem is (see the appendix for further details; the constraint $1 \leq x$ is never binding and hence neglected)

$$\begin{aligned} \left(\frac{x\theta}{w_a}\right)^{\frac{\theta}{1-\theta}} & \geq \; x-1 \\ & = \; \text{if } x<\bar{x} \end{aligned}$$

Using (10) we can rewrite this as

$$\begin{aligned} \left(\eta_g E_h\right)^{\theta} & \geq \; x-1 \\ & = \; \text{if } x<\lambda \end{aligned}$$

with is an equation in the two endogenous variables (x, η_g). The technology adoption schedule of the adopting firm, as a function of the composition of the labor force η_g, is given as

$$x(\eta_g)=\min\{\lambda, 1+\left(\eta_g E_h\right)^{\theta}\} \tag{11}$$

The technology adoption decision x of the adopting firms is a weakly increasing function of the fraction of the population with general education, since either technology adoption is only constrained by the available technology λ (in which case x is independent of η_g), or an increase in share of agents with general education η_g drives wages in the adopting sector down and thus makes faster technology adoption profitable.

Define $\bar{\eta}_g=\frac{(\lambda-1)^{\frac{1}{\theta}}}{E_h}$ as the minimal fraction of generally educated agents for which maximal growth occurs. We make the assumption that

Assumption 2: $\bar{\eta}_g=\frac{(\lambda-1)^{\frac{1}{\theta}}}{E_h}<1$

Finally, we can compute equilibrium profits of the adopting firm (and hence consumption of its owner), as:

$$\Pi(\eta_g)=\begin{cases} \lambda^{\frac{1}{1-\theta}}\left(\frac{\theta}{w_a}\right)^{\frac{\theta}{1-\theta}}(1-\theta)-\frac{1}{2}(\lambda-1)^2 \text{ if } \eta_g\geq\bar{\eta}_g \\ \left[1+\left(\eta_g E_h\right)^{\theta}\right]^{\frac{1}{1-\theta}}\left(\frac{\theta}{w_a}\right)^{\frac{\theta}{1-\theta}}(1-\theta)-\frac{1}{2}(\eta_g E_h)^{2\theta} \text{ if } \eta_g<\bar{\eta}_g. \end{cases}$$

[29] Given our earlier assumption that the economy starts out at the frontier, on the BGP we have $\bar{x}=\lambda$, or the constraint $x\leq\bar{x}$ is not binding.

As λ increases, $\bar{\eta}_g$ increases, and thus the education interval over which maximal growth occurs, decreases. Intuitively, higher net profits are needed to make it worthwhile for firms to adopt technologies at the new (higher) maximal rate. But this requires lower wages in the adopting sector, which in turn demands a larger share of the population be generally educated and supply their labor services to that sector. As a prelude to our discussion below, note that therefore Europe, having a lower share of the labor force with general education, may fall behind in growth when the speed of available technologies λ increases.

For further reference we note that, as a function of x, the relative labor demand is given by

$$\frac{H_a^d}{H_n^d} = \left(\frac{xw_n}{w_a}\right)^{\frac{1}{1-\theta}}. \tag{12}$$

Again from the labor market equilibrium we thus have

$$\frac{\eta_g E_h}{(1-\eta_g)h} = \left(\frac{xw_n}{w_a}\right)^{\frac{1}{1-\theta}} \tag{13}$$

$$x = \frac{w_a}{w_n}\left(\frac{\eta_g E_h}{(1-\eta_g)h}\right)^{1-\theta} \tag{14}$$

4.2 The Household Education Decision

In this section we discuss how the equilibrium fraction of agents with general education, η_g, is determined. Recall that η_g is related to the threshold ability level a^*, above which all agents obtain general education and below which all agents obtain vocational education, by $a^*\left(\eta_g\right) = 1-\eta_g$. Write (7) as follows in order to obtain the equilibrium threshold ability as a solution to the following equation:[30]

$$v_g\left(\eta_g\right) - v_v\left(\eta_g\right) = \log(e\left(a^*\left(\eta_g\right)\right)) \tag{15}$$

This captures the fixed point problem induced by the education decision – newborn agents anticipate a certain fraction of the work force with general education, η_g, which determines the high-tech wage premium, and thus the value to getting general education; their decision to obtain one or the other type of education has to be consistent with the posited η_g.

We now make the following functional form assumption for the cost of obtaining general education.

Assumption 3: The function $e : [0,1] \to \Re_+$ *is given by:* $e(a) = \frac{1}{a}$.

With this assumption we see that for the ablest agents ($a=1$) the utility cost of obtaining general education, $\log\left(\frac{1}{a}\right)$ equals to 0, whereas for the least able agents this cost becomes

[30]Note that even though the non-normalized value functions V_g and V_v grow over time, their difference is stationary and equal to the difference $v_v - v_g$, due to the assumption of logarithmic utility.

prohibitively high. Then the right hand side of equation (15), as a function of η_g, becomes $\log\left[e\left(a^*\left(\eta_g\right)\right)\right] = \log\left[e\left(1-\eta_g\right)\right] = \log\left(\frac{1}{1-\eta_g}\right) = -\log(1-\eta_g)$. This is a strictly increasing function of η_g, approaching 0 when $\eta_g \to 0$ and approaching $-\infty$ as $\eta_g \to 1$.

Using equation (6), the utility differential is explicitly given as

$$(v_g - v_v)\left(\frac{w_a}{w_n}\right) = \log\left(\frac{w_a}{w_n}\right) - T_l \log(h) \tag{16}$$

Combining costs and utility differentials we have

$$\log\left(\frac{w_a}{w_n}\right) - T_l \log(h) = -\log(1-\eta_g)$$

or

$$\frac{w_a}{w_n} = \left(\frac{1}{1-\eta_g}\right) h^{T_l} \tag{17}$$

Combining this equation with equation (14) yields the education schedule

$$\begin{aligned} x^s(\eta_g) &= \frac{w_a}{w_n}\left(\frac{\eta_g E_h}{(1-\eta_g)h}\right)^{1-\theta} \\ &= h^{T_l}\eta_g^{1-\theta}\left(\frac{1}{1-\eta_g}\right)^{2-\theta}\left(\frac{E_h}{h}\right)^{1-\theta} \end{aligned} \tag{18}$$

The positive relation between growth and the share of agents with general education arises for the following reason. In order to induce a higher fraction η_g of the population to opt for general education, a higher growth rate x is needed; a higher growth rate, x, is associated with higher relative labor demand of the adoption sector and thus a higher wage differential.

4.3 Equilibrium Growth and Education

Using the technology adoption and the education schedule (11) and (18) one can prove the following

Lemma 1 *Suppose the assumptions made above are satisfied. Then there exists a unique BGP equilibrium* $\eta_g^* \in (0,1)$ *.*

Proof. Proof: Both (11) and (18) are continuous functions on $(0,1)$. Furthermore $x^s(0) = 0$, $x^s(1) \to \infty$, $x(0) = 1$ and $x(1) < \infty$, thus by the intermediate value theorem a solution exists. The proof of uniqueness is deferred to the appendix ■

For a graphical representation of this result, see Figure 1.[31]

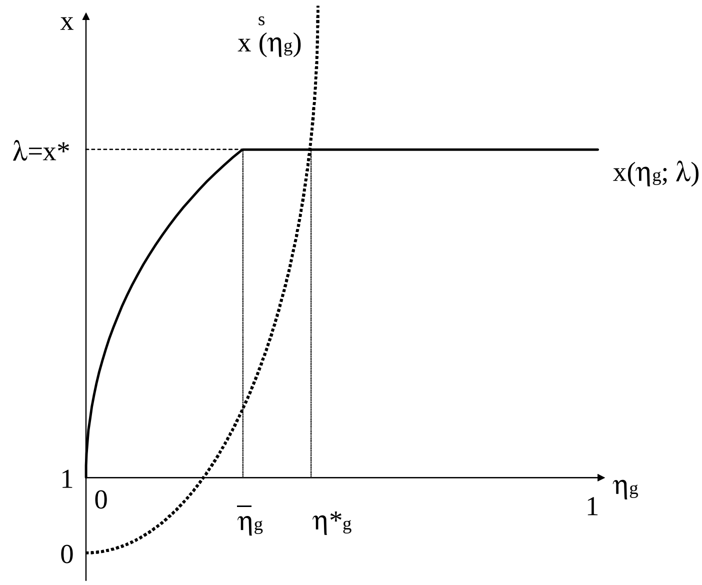

Figure 1: Equilibrium Growth Rate and Education Allocation

The central trade-off between vocational and general education involves on average higher but riskier wages in the adopting sector. It is therefore instructive to analyze how equilibrium growth rates and education allocations change as productivities, and hence wages, in the adopting sector become more risky; the parameter T_l is handy for this analysis. In section 8.4 in the appendix we prove the following

Lemma 2 *A mean-preserving increase in the spread of productivities $h \in \mathcal{H}$, which leaves the expected productivity E_h unchanged, leads to a (weak) decline in the equilibrium growth rate x^* and a (strict) decline in the fraction of the population obtaining general education, η_g^*.*

Intuitively, as general education becomes a riskier proposition, fewer agents find it worthwhile to obtain such education. Adopting firms, faced with a lower supply of appropriately skilled workers, scale back the rate of technology adoption; lower equilibrium growth results.

[31] We note that $x^s(\eta_g)$ may not necessarily be strictly convex as drawn, but that, as shown in the proof, the intersection is unique and the comparative statics presented below remain valid go even if $x^s(\eta_g)$ is not strictly convex on the entire interval $[0, 1]$.

With this characertization of equilibrium we can now, in the appendix, also provide sufficient conditions under which it is optimal for agents with general education to work in the adopting sector and for agents with vocational education to work in the nonadopting sector (rather than to assume that they have to work in a particular sector, as done in the main text for simplicity).

5 Comparing US and European Policies

In section 2, we presented evidence on European educational policies that favor vocational education over general education, while in the US the situation is the reverse. In this section, we study the effects of this policy difference on the growth rates of and the growth gap between the two regions, as implied by our model.

5.1 Policy Differences

We will denote by G the normalized amount of government expenditure available for subsidizing *both* types of education. (In the original problem, since this will be multiplied by A, government subsidies will be growing at the rate of technology.) Let s_v denote the per student subsidy given to a vocational education student and let s_g denote the per student subsidy given to a general education student. Then the government resource constraint, given a uniform ability distribution and an ability threshold a^* is:

$$a^* s_v + (1 - a^*)\, s_g = G, \tag{19}$$

with s_v, $s_g > 0$. We will consider a revenue neutral experiment; that is, assume that G is the same for the US and Europe and that $(s_v)_{Europe} > (s_v)_{US}$ is given. Also define $s = \frac{s_g}{s_v}$ the ratio between the subsidy to general and to vocational education. We now assume that agents have preferences, in the first period of their lives, given by

$$I_g\,(-\log(e(a)) + \log(s_g)) + (1 - I_g)\log(s_v)$$

that is, if they choose general education, they incur disutility $\log(e(a))$ and utility $\log(s_g)$ from the educational subsidy, and if they choose vocational education they obtain utility $\log(s_v)$ from the educational subsidy.[32]

Given this formulation the cost of obtaining general, as opposed to vocational education, is

$$\log\left(\frac{1}{1-\eta_g}\right) - \log(s) = \log\left(\frac{\eta_g}{1-\eta_g} * \frac{\frac{G - s_g\eta_g}{1-\eta_g}}{s_g}\right)$$

and equation (18) now becomes

$$x^s(\eta_g) = h^{T_l}\eta_g^{1-\theta}\left(\frac{1}{1-\eta_g}\right)^{2-\theta}\left(\frac{E_h}{h}\right)^{1-\theta}\left(\frac{\frac{G - s_g\eta_g}{1-\eta_g}}{s_g}\right) \tag{20}$$

[32] What is crucial for our results is not so much the particular functional form of utility from education subsidy, but the separability between utility from subsidies and from consumption.

with policy variable s_g, or alternatively

$$x^s(\eta_g) = \frac{h^{T_l}}{s}\eta_g^{1-\theta}\left(\frac{1}{1-\eta_g}\right)^{2-\theta}\left(\frac{E_h}{h}\right)^{1-\theta} \tag{21}$$

with policy variable $s = \frac{s_g}{s_v}$. Note that, since we treat G as fixed, the level of s_v (or the levels of both s_g, s_v) has to adjust to guarantee government budget balance. We assume that s_g or s are set in such a way as to guarantee $s_v > 0$. Evidently the $x^s(\eta_g)$-schedule tilts to the right around the point $(\eta_g, x) = (0, 0)$ as s increases, since higher differential subsidies towards general education, for a given growth rate x, make more agents choose general education; this gives rise to the results in the next section.

5.2 Growth Rates and Growth Gaps with Different Policies

We model the stronger US focus on general education to mean, in the context of our model, that $s^{US} > s^{EUR}$. This implies that $x^s_{US}(\eta_g) \leq x^s_{EUR}(\eta_g)$, with inequality strict for $\eta_g > 0$. Denote by $\Delta(\lambda)$ the gap between the potential growth rate of the economy and the actual rate, when the frontier evolves exogenously at the rate λ. Formally, the growth gap is $\Delta(\lambda) \equiv \lambda - x^*(\lambda)$, where x^* is the BGP growth rate associated growth rate λ for the frontier technology. We have the following

Proposition 1 *Suppose the assumptions made above are satisfied. Then:*

1. $\eta_g^{US} > \eta_g^{EUR}$
2. *Either* $x^{US} = x^{EUR} = \lambda$ *or* $\lambda \geq x^{US} > x^{EUR}$.
3. *Either* $\Delta^{US}(\lambda) = \Delta^{EUR}(\lambda) = 0$ *or* $\Delta^{EUR}(\lambda) > \Delta^{US}(\lambda) \geq 0$.

Proof. This follows directly from the fact that the $x^s(\eta_g)$-schedule tilts down around the point $(\eta_g, x) = (0, 0)$ as s increases. ■

The first statement asserts that the fraction of workers with general education is higher in the US. The second statement asserts that either the US and Europe both grow at the potential rate λ, or the US grows at a strictly higher rate. If both grow at the maximal rate, the growth gap of both countries with respect to the potential is zero; otherwise the growth gap of Europe is strictly higher. The difference between the US and Europe is illustrated in Figure 2.

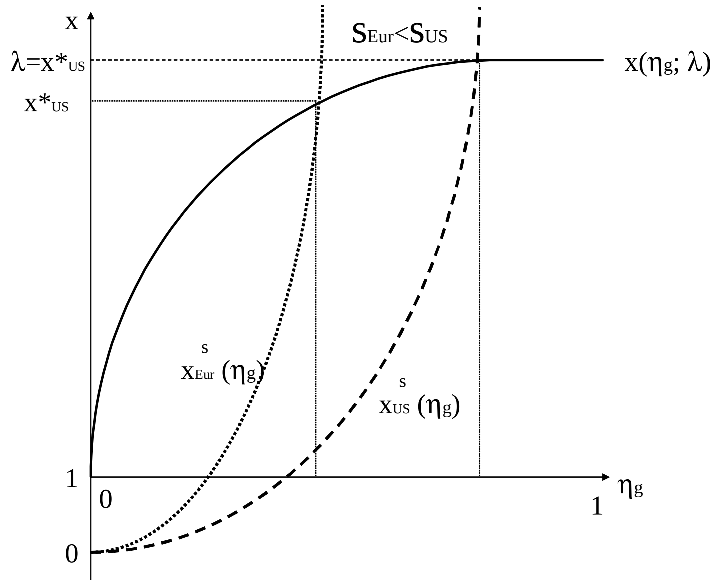

Figure 2: Comparing US and European Education Policies

5.3 Effect of an Increase in Speed of Innovation

We now analyze whether an increase in the rate of technological progress widens the growth gap between the US and Europe. We are thus interested in comparative statics with respect to λ.[33] We have

Proposition 2 *Equilibrium general education attainment* η_g^* *and growth* x^* *increases with* $\lambda : \frac{d\eta_g^*(\lambda)}{d\lambda} \geq 0$ *and* $\frac{dx^*(\lambda)}{d\lambda} \geq 0$. *The increase is strict if and only if* $\eta_g^*(\lambda) \geq \bar{\eta}_g(\lambda)$.

Proof. The proof of this and the following two propositions follows directly from the fact that the $x^s(\eta_g)$ schedule is independent of the potential growth rate λ and the $x(\eta_g, \lambda)$ schedule shifts up one for one with λ only in the region where $\min\{\lambda, 1 + (\eta_g E_h)^\theta\} = \lambda$. ■

The higher λ increases the demand for labor in the adopting sector and thus the high-tech wage premium $\frac{w_a}{w_n}$ in equilibrium; this increases the incentive to acquire general education.

Proposition 3 $\frac{d\Delta(\lambda)}{d\lambda} \geq 0$. *The increase is strict if and only if* $\eta_g^*(\lambda) \geq \bar{\eta}_g(\lambda)$. *Almost surely* $\frac{d\Delta(\lambda)}{d\lambda} \in \{0, 1\}$.[34]

[33] This is reminiscent of Ljungqvist and Sargent's (1998) experiment of increasing economic turbulence to study its effect on European unemployment.

[34] "Almost surely" is intended to mean, for the measure one of parameter combinations for which λ is not equal to the unique threshold $\bar{\lambda}$ corresponding to $\eta_g^*(\bar{\lambda}) = \bar{\eta}_g(\bar{\lambda})$). The number $\bar{\lambda} > 2$ uniquely solves the

That is, the gap in the growth of an economy relative to the potential growth rate λ, is itself (weakly) increasing in λ. This leads us to the central proposition of the paper.

Proposition 4 $\frac{d\Delta^{EUR}(\lambda)}{d\lambda} \geq \frac{d\Delta^{US}(\lambda)}{d\lambda}$ *with strict inequality if* $x^{US} = \lambda > x^{EUR}$.

Though the proposition is phrased in terms of growth gap of each region relative to the (new) potential growth rate, its implication for the gap in growth rates *between* the two regions is obvious. As the rate of change of available technologies, λ, increases, the fraction of agents with general education above which maximal growth occurs, $\bar{\eta}_g$ increases and Europe may fall out of the maximal growth region, whereas the US may continue to be constrained only be the available technology.

As mentioned in the introduction, several economists suggest that the rate at which new technologies came about (as measured, say, by the rate of price decline for equipment) indeed increased in the mid-seventies, reaching its peak in the nineties. Our model suggests that the US, with a much higher fraction of its work force possessing general education was able to adopt these available technologies at a faster rate than Europe could. Even if both regions adopt technology at faster rate, our model predicts that there may be a gap in their rate of adoption, consistent with the data in table 1. This effect is illustrated in Figure 3. The US continues to be constrained only by the availability of technologies, while Europe potentially falls behind.

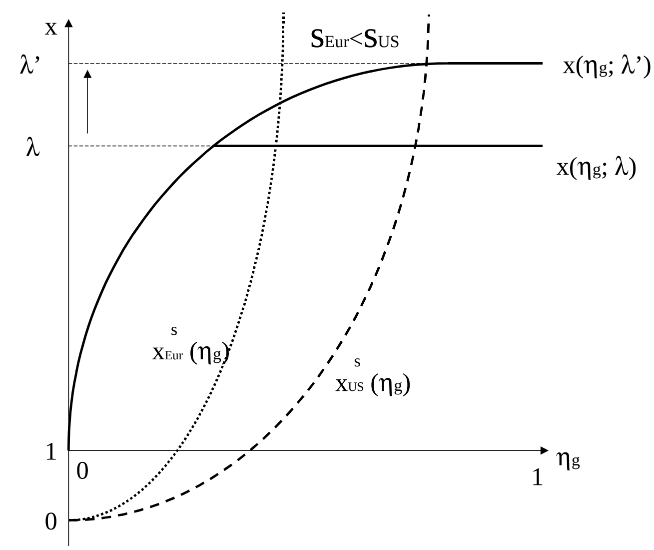

Figure 3: An Increase in λ

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equation

$$\frac{(\lambda-1)^{\frac{2-\theta}{\theta}}}{\lambda} = h^{1-T_t} E_h^{1-\theta} > 1.$$

6 Optimal Policies

The previous section showed that a stronger focus on general education subsidies fosters growth. In this section we want to analyze the socially optimal subsidy level, in order to assess whether in fact Europe's focus on vocational education is suboptimal, or whether the US oversubsidizes the attainment of general education.

6.1 The Government Objective Function

The issue of what the objective of the benevolent government ought to be is not a trivial one, since with two-period lived agents there are many generations to consider, and even within each generation there is a continuum of agents, indexed by ability $a \in [0,1]$, which may potentially receive different Pareto weights in the government objective function. We will assume that within each generation all agents receive equal weight in the social welfare functional and that the benevolent government discounts future generations at social discount factor $\beta \in [0,1)$. We also assume that the government can perfectly commit to future policies and, in order to enable comparison with previous sections, we restrict the government to choose time-constant policies associated with BGP equilibria.

In the appendix we show that the objective function of the government, as a function of its policy choice $s = \frac{s_g}{s_v} \in (0,1)$ can be written as (absent constants that are irrelevant for maximization)

$$W(s) = -(2-\theta)\log(1-\eta_g(s)) - \eta_g(s) - \log\left[\eta_g(s)s + (1-\eta_g(s))\right] + \frac{2\beta\log(x(s))}{1-\beta} \qquad (22)$$

where $\eta_g(s)$ and $x(s)$ solve

$$\begin{aligned} x(s) &= \frac{h^{T_l}}{s}\eta_g(s)^{1-\theta}\left(\frac{1}{1-\eta_g(s)}\right)^{2-\theta}\left(\frac{E_h}{h}\right)^{1-\theta} && (23) \\ x(s) &= \min\{\lambda, 1+\left(\eta_g(s)E_h\right)^{\theta}\} && (24) \end{aligned}$$

The last term in the government objective function captures the effect that future generations obtain higher utility with higher growth rates; if the benevolent government does not value future generations, then $\beta = 0$ and this term disappears. The second to last term summarizes the welfare effects from the differential subsidies directly, whereas the first two terms stem from the utility of consumption, net of the disutility of obtaining general education.

6.2 Characterization of Optimal Policies

From (23) and (24) we note the following properties of equilibrium growth rates and education decisions:

$$\begin{aligned} \lim_{s\to\infty} x(s) &= \lambda, \ \lim_{s\to\infty} \eta_g(s) = 1 \\ \lim_{s\to 0} x(s) &= 1, \ \lim_{s\to 0} \eta_g(s) = 0 \end{aligned}$$

and $\eta_g(s)$ is a strictly increasing function, whereas $x(s)$ is increasing in s, strictly as long as $x(s) < \lambda$. Both functions are continuous in s. Therefore $W(s)$ is a continuous function in s, with $W(s = 0) = \log(\kappa)$ and $W(s = \infty) = \frac{1+\beta}{1-\beta}\log(\lambda) - 1$.

It is useful to define the minimal relative subsidy level for general education $\bar{s}(\lambda)$ that is required to generate maximal growth $x^* = \lambda$ in the BGP equilibrium. It is given implicitly by $\eta_g(\bar{s}(\lambda)) = \bar{\eta}_g(\lambda) \equiv \frac{(\lambda-1)^{\frac{1}{\theta}}}{E_h}$, which can by solved as $\bar{s}(\lambda) = \frac{\kappa}{\lambda\bar{\eta}_g}\left(\frac{\bar{\eta}_g}{1-\bar{\eta}_g}\right)^{2-\theta} \in (0, 1)$, a function that is strictly increasing in λ. Here $\kappa = \frac{E_h^{1-\theta}}{h^{1-\theta-T_l}}$ is a constant.

Exploiting the fact that for all higher subsidy levels $s \geq \bar{s}(\lambda)$, the growth rate remains constant at λ, we can show (by using (23) in (22)) and with the help of arguments spelled out in the appendix

Lemma 3 *1. For all $s \geq \bar{s}(\lambda)$ we have $W'(s|s \geq \bar{s}) > 0$ for $s < 1$, $W'(s = 1|s \geq \bar{s}) = 0$ and $W'(s|s \geq \bar{s}) < 0$ for $s > 1$.*

2. There exists a $\bar{\beta} \in (0, 1)$ such that for all $\beta \geq \bar{\beta}$ we have $W'(s|s < \bar{s}) > 0$ for all $s \in (0, \bar{s}(\lambda))$.

The first result immediately implies that the benevolent government should choose a higher subsidy for general education only to obtain maximal growth, that is $s^*(\lambda) \leq \max\{1, \bar{s}(\lambda)\}$. For the region $s < \bar{s}(\lambda)$, part 2 of the lemma argues that a high enough social discount factor makes growth so desirable that, as long as maximal growth is not reached, a higher subsidy level s is preferred, since it generates higher growth.

Therefore the optimal education subsidy s and its changes with λ depends crucially on whether maximal growth is attainable without higher subsidies for general education or not, that is, whether $s(\lambda) \geq 1$. Note that this inequality is based purely on fundamentals, and is more likely to hold for large λ, all other things being equal. We shall assume that this condition is satisfied and state the following proposition[35]

[35] A second part of this theorem can be stated for the case in which $\bar{s}(\lambda) < 1$. More precisely, let $\lambda < \lambda'$ be such that $\bar{s}(\lambda) < \bar{s}(\lambda') < 1$. Then $s^*(\lambda) = s^*(\lambda')$ and $x(s^*(\lambda)) = x(s^*(\lambda'))$. Either $s^*(\lambda) = s^*(\lambda') = 1$ and growth is maximal or $s^*(\lambda) = s^*(\lambda') < 1$ and $x(s^*(\lambda)) = x(s^*(\lambda')) < \lambda$.

In this case, even without differential subsidies for general education maximal growth can be attained in the competitive equilibrium (that is, the potential growth rate is not too high). The optimal subsidy satisfies $s^* \leq 1$, and is independent of the potential growth rate of the economy.

Proposition 5 *Suppose that $\bar{s}(\lambda) \geq 1$. Then there exists a $\bar{\beta} \in (0,1)$ such that for all $\beta \geq \bar{\beta}$, the optimal solution to the government problem is $s^*(\lambda) = \bar{s}(\lambda) \geq 1$ and for $\lambda' > \lambda$, we have that $s^*(\lambda') > s^*(\lambda)$. Growth is maximal, that is, $x(s^*) = \lambda$.*

Proof. Follows directly from the previous lemma. ■

We interpret this result as follows. Under the assumption $\bar{s}(\lambda) \geq 1$ it is optimal for the benevolent government to provide greater incentives for obtaining general education in order to generate growth. If the government values future generations (and hence economic growth) sufficiently highly, then it is optimal to subsidize general education exactly to the point where maximal growth is assured (but not more).[36] The optimal subsidy is a strictly increasing function of the potential growth rate of the economy λ.

We now relate this proposition on optimal policies to the empirical observations discussed in Section 2 of the paper. In the 70's, when the growth rate of the available technology λ was low it might have been the case that the US oversubsidized general education, whereas European policy was optimal. As λ increased to λ' in the 80's and 90's, and with it the optimal general education subsidy level (i.e. $s^*(\lambda') = \bar{s}(\lambda')$) it is the US policy that becomes optimal and the European policy (i.e. $s < \bar{s}(\lambda')$) is now suboptimal. Therefore, in addition to the growth gap between the US and Europe our model also suggests a welfare gap between the two regions.[37]

This discussion also shows that our model, by no means, implies that subsidizing general education to the maximal extent and pushing the economy to maximal growth at any cost is optimal. [38]

7 Conclusion

We have developed a growth model featuring an occupational advantage of general over vocational education, endogenous technology adoption by firms and educational decisions by households, to argue that two economies that grow at potential when the rate of technological progress is low, could diverge when this rate increases. Our analysis thus provides one

[36] We need the condition on β in order to assure that it is in fact optimal for the Ramsey government to enact policies that assure maximal growth.

[37] In this paper we do not explore the political-economic reasons for why such suboptimal policies may persist, but we view future research in this direction as particularly fruitful and interesting.

[38] Note that a social planner who is constrained to use the amount of resources G for "subsidies" (s_g, s_v) would optimally choose to equate these across agents, i.e. $s^{SP} = 1$. It is also obvious that the planner equates consumption across agents and thus completes the insurance markets assumed to be missing in the competitive equilibrium. Therefore in general the Ramsey government cannot implement fully socially optimal allocations; the second part of the previous proposition shows that under certain conditions at least the Ramsey education subsidy is socially optimal.

possible explanation for the growth gap Europe, which focuses on skill-specific education, has suffered since the eighties relative to the US, which focuses more on conceptual education. It also shows that education policies that were optimal for Europe in the 60's and 70's may have become suboptimal for the information technology age.

It must be emphasized that the use of balanced growth analysis is mostly an analytically convenient way to study the issue of slow European technology adoption. One could instead construct a steady state model and cast European catch-up or falling behind purely as a transitional issue, relying on numerical instead of analytical characterization. If educational reforms are instituted, such as the much discussed reforms to make German universities more competitive, then the growth gaps we have analyzed are going to be necessarily transitional.[39] Indeed, one needs to be cautious about literally mapping variations in general education policy to *permanent* growth rate differences; an analysis using a panel data set with shorter run growth rates and policy variables applicable for those shorter periods might be more appropriate.

While casual evidence suggests that manufacturing productivity growth is strongly correlated with the share of the work force with tertiary education (*European Competitiveness Report 2001*, Table IV.2), rigorous attempts to extend our analysis along quantitative dimensions are warranted. One possibility, which we entertain in Krueger and Kumar (2002), is to calibrate the model presented in this paper to quantify the predicted gap in growth between the US and Europe. Another is to conduct a cross-country, cross-industry, econometric study to assess whether acceleration in adoption rates has been particularly higher in the US relative to Europe in those industries that have seen greater increases in available technologies. The model points to the high-tech premium, $\frac{w_a}{w_n}$, as a crucial equilibrium variable; the mapping of this into empirically reported premia (such as the college premium) deserves further attention. Using years of education as a proxy, cross-country growth studies have found only a weak effect of human capital in explaining growth. Our study points out that the *type* of education obtained, rather than the number of years of education *per se*, could have a crucial bearing on the rate of economic growth.[40] These are topics of ongoing research.

[39] See for instance Hyde Flippo's, "Can the German University be Saved?" an online supplement (http://www.german-way.com), to *The German Way* (Passport Books), which reports a steep increase in the percentage of high school students earning the academic diploma that leads to college study in the city-state of Hamburg, and points to the emergence of private universities such as Universität Witten/Herdecke.

[40] Also see Murphy, Schleifer, and Vishny (1991) in this regard.

8 Appendix

8.1 Further Details on the Firms' Problem

The first order necessary and sufficient condition for the firm is

$$\begin{aligned}(x^*)^{\frac{\theta}{1-\theta}}\left(\frac{\theta}{w_a}\right)^{\frac{\theta}{1-\theta}} &\geq \quad x^*-1 \\ &= \quad \text{if } x^* < \bar{x}\end{aligned}$$

Suppose there exists BGP with $x=\lambda$. Then

$$\bar{x}=\frac{A_f}{A}=\frac{A_f^{-1}}{A}*\frac{A_f}{A_f^{-1}}=1*\lambda=\lambda$$

where $\frac{A_f^{-1}}{A}=1$ because in a BGP with growth rate λ the actual level of technology must equal the potential level at each point of time (remember that we assumed that $A_0=A_{f,-1}$). In order for the firm to optimally choose $x^*=\lambda$ a necessary and sufficient condition is hence

$$\eta_g \geq \bar{\eta}_g = \frac{(\lambda-1)^{\frac{1}{\theta}}}{E_h}$$

Suppose there exists BGP with $x<\lambda$.

First we show that $x^*<\bar{x}=\frac{A_f}{A}$. Suppose not; i.e. suppose $x^*=\bar{x}$. But then

$$x^*=\frac{A_f^{-1}}{A}*\frac{A_f}{A_f^{-1}}\geq\lambda$$

since $A\leq A_f^{-1}$. For a BGP we need $\lambda\leq x^*=x<\lambda$, a contradiction. Hence $x^*<\bar{x}$. But then the optimal choice x^* satisfies

$$(x^*)^{\frac{\theta}{1-\theta}}\left(\frac{\theta}{w_a}\right)^{\frac{\theta}{1-\theta}}=x^*-1 \tag{25}$$

But the unique solution x^* to this equation satisfies $x^*<\lambda$ if and only if

$$(\lambda)^{\frac{\theta}{1-\theta}}\left(\frac{\theta}{w_a}\right)^{\frac{\theta}{1-\theta}}<\lambda-1$$

or $\eta_g<\bar{\eta}_g$.

8.2 Uniqueness of the BGP

We want to argue that the solution η_g^* to the equation

$$\min\left\{\lambda,1+\left(\eta_g E_h\right)^{\theta}\right\}=h^{T_l}\eta_g^{1-\theta}\left(\frac{1}{1-\eta_g}\right)^{2-\theta}\left(\frac{E_h}{h}\right)^{1-\theta} \tag{26}$$

is unique. We established in the main text that any solution η_g^* satisfies $\eta_g^* > 0$. Now multiply both sides of (26) by $\eta_g^{1-\theta}$ to obtain

$$\min\left\{\lambda\eta_g^{1-\theta}, \eta_g^{1-\theta}+\eta_g E_h^{\theta}\right\} = h^{T_l}\eta_g^{2(1-\theta)}\left(\frac{1}{1-\eta_g}\right)^{2-\theta}\left(\frac{E_h}{h}\right)^{1-\theta}$$

Since the left hand side of this equation is concave and the right hand side is strictly convex, there is at most one positive solution $\eta_g^* > 0$ to this equation, which is the unique solution to (26).

8.3 Optimality of Working in the Adoption or Nonadoption Sector

In the main text we have assumed that only agents with general education work in the adopting sector, and characterized a corresponding BGP. We now provide sufficient conditions on the parameters of our model to guarantee that agents with general education would *optimally* choose to work in the adoption sector and agents with vocational education would optimally choose to work in the nonadopting sector. Suppose that g-agents working in the nonadopting sector have productivity h with probability 1 (as v-people have) and that v-agents working in the adopting sector have productivity 1 with probability T_l^v and productivity h with probability $1 - T_l^v$

Thus for g-agents to optimally work in the adopting sector one requires

$$\begin{aligned} T_l \log(w_a) + (1-T_l)\log(w_a h) &\geq \log(w_n h) \text{ or} \\ \frac{w_a}{w_n} &\geq h^{T_l} \end{aligned}$$

which is always satisfied in equilibrium by (17). For the v-agents to optimally work in the nonadopting sector requires

$$\frac{w_a}{w_n} \leq h^{T_l^v} \tag{27}$$

To provide sufficient conditions for (27) to hold, it is convenient to consider the cases $x^* = \lambda$ and $x^* < \lambda$ separately.

Suppose $x^* < \lambda$. Then $\eta_g^* < \bar{\eta}_g = \frac{(\lambda-1)^{\frac{1}{\theta}}}{E_h}$. For (27) to hold a sufficient condition is, using (17)

$$\eta_g^* < \bar{\eta}_g \leq 1 - \frac{1}{h^{T_l^v - T_l}} \tag{28}$$

For $x^* < \lambda$ to obtain in equilibrium a necessary and sufficient condition is $x^s(\bar{\eta}_g) > \lambda$. But since $x^s(\eta_g)$ is strictly increasing in η_g, $x^s(\bar{\eta}_g) > \lambda$ if

$$x^s\left(1 - \frac{1}{h^{T_l^v - T_l}}\right) > \lambda \tag{29}$$

as long as (28) is satisfied. Using the explicit form of $x^s()$ yields, after some algebra, the condition

$$E_h^{1-\theta}\left(h^{T_l^v - T_l} - 1\right)^{1-\theta} h^{T_l^v - 1 + \theta} \geq \lambda \tag{30}$$

For all parameter combinations jointly satisfying (28) and (30) (obviously not an empty set) the equilibrium features growth below potential growth and agents with v-education finding it suboptimal to work in the adopting sector. In particular, the conditions are satisfied if agents with vocational education have a lot to lose by working in the adopting sector (T_l^v high and h high).

A similar argument applies to the case $x^* = \lambda$ and therefore $\eta_g^* \geq \bar{\eta}_g$. Now from (14) is optimal for v-agents to work in the nonadopting sector if

$$\lambda \leq h^{T_l^v} \frac{\bar{\eta}_g E_h}{(1-\bar{\eta}_g)h}$$

and the equilibrium features maximal growth if $x^s(\bar{\eta}_g) \leq \lambda$. But $x^s(\bar{\eta}_g) \leq \lambda \leq h^{T_l^v} \frac{\bar{\eta}_g E_h}{(1-\bar{\eta}_g)h}$ if and only if (after some algebra)

$$\frac{E_h^{1-\theta}}{h^{T_l^v - T_l - \theta}} \leq \left[E_h - (\lambda-1)^{\frac{1}{\theta}}\right](\lambda-1)^{\frac{1}{\theta}}$$

If this condition, again purely on fundamentals, is satisfied, then equilibrium growth is maximal and households with vocational education have no incentive to work in the adopting sector. As before, this condition is satisfied if h and T_l^v are high.

8.4 A Mean Preserving Increase in the Spread of Productivities

Suppose we change the parameter T_l, but in such a way as to keep expected productivity E_h constant. Suppose the low productivity state equals $\kappa < h$ instead of 1, and thus

$$E_h = \kappa T_l + (1-T_l)h$$

Hence

$$\frac{d\kappa}{dT_l} = \frac{h-\kappa}{T_l} > 0 \tag{31}$$

Intuitively, making the low state more likely and keeping expected productivity constant requires a productivity increase in the low state. Thus a reduction in T_l (and therefore a decrease in κ) can be interpreted as a mean-preserving increase in the spread of the productivity process. We want to analyze how equilibrium growth and education allocations change with such an increase.

First, the firm's adoption decision (11) and relative labor demands, and thus equation (14) remain unchanged. Now agents will opt for general education if

$$T_l \log(\kappa w_a) + (1-T_l)\log(w_a h) - \log(w_n h) \geq \log(e(a) = -\log(1-\eta_g)$$

Using this result in (14) yields

$$x^s(\eta_g) = g(T_l)\frac{1}{\eta_g}\left(\frac{\eta_g}{(1-\eta_g)}\right)^{2-\theta}\left(\frac{E_h}{h}\right)^{1-\theta}$$

where $g(T_l) = \left(\frac{h}{\kappa(T_l)}\right)^{T_l}$. This is exactly the equation (18), with $\kappa = 1$. In order to obtain comparative statics results with respect to T_l we simply need to characterize the function $g(T_l)$, or, more easily, the function $f(T_l) = \log(g(T_l)) = T_l [\log(h) - \log(\kappa(T_l))]$. Using (31) we find

$$f'(T_l) = \log\left(\frac{h}{\kappa(T_l)}\right) - T_l \frac{\kappa'(T_l)}{\kappa(T_l)} = \log\left(\frac{h}{\kappa(T_l)}\right) - \left(\frac{h}{\kappa(T_l)} - 1\right) < 0$$

since $h > \kappa(T_l)$. Therefore $g(T_l)$ is a decreasing function of T_l and the $x^s(\eta_g)$ schedule tilts upwards with a decrease in T_l. Therefore, a mean-preserving increase in the spread on productivity (a decrease in T_l) equilibrium growth x^* weakly decreases and equilibrium general education strictly decreases. As the productivity process for working in the adopting sector becomes more risky, the incentives for acquiring general, growth-driving education declines.

8.5 The Social Welfare Function of the Government

Along a balanced growth path wages, education subsidies and total government expenditures grow at rate x. Therefore the lifetime utility of an agent of ability a, born at date t in a balanced growth path with growth rate x equals

$$\begin{aligned} u_t(a) &= I_g \left[T_l \log(W_{at}) + (1 - T_l)\log(W_{at}h) - \log(e(a)) + \log(S_{gt})\right] \\ &\quad + (1 - I_g)\left[\log(W_{nt}h) + \log(S_{vt})\right] \\ &= u(a) + 2\log(A_0) + 2t\log(x) \end{aligned}$$

where

$$\begin{aligned} u(a) &= I_g \left[T_l \log(w_a) + (1 - T_l)\log(w_a h) + \log(s_g) - \log(w_n h) + \log(s_v)\right] \\ &\quad + \log(w_n h) + \log(s_v) - I_g \log(e(a)) \end{aligned} \tag{32}$$

The social welfare function we employ is

$$\hat{W} = \sum_{t=0}^{\infty} \beta^t \int u_t(a)da = \frac{2\log(A_0) + \int u(a)da + \frac{2\beta\log(x)}{1-\beta}}{1-\beta}$$

and thus the benevolent government maximizes

$$\bar{W} = \int u(a)da + \frac{2\beta\log(x)}{1-\beta} \tag{33}$$

by choice of the policy parameters (s_g, s_v), subject to the government budget constraint (19) and the entities (w_a, w_n, x, η_g) forming a BGP equilibrium, given policies (s_g, s_v). Since we are silent about how taxes are collected to finance government expenditure for education G (and its distortions), we take G as a parameter of the government problem and not as a choice of the government.

We can simplify (33) further by noting that in equilibrium the benefit from general education has to equal its cost for the marginal agent,

$$T_l \log\left(w_a\right) + (1 - T_l)\log\left(w_a h\right) + \log\left(s_g\right) - \log\left(w_n h\right) + \log\left(s_v\right) = -\log\left(1 - \eta_g\right)$$

and that from (19) and the first order conditions of the nonadopting firms

$$\begin{aligned} s_v &= \frac{G}{\eta_g s + (1 - \eta_g)} \\ w_n &= \theta\left[(1 - \eta_g)E_h\right]^{\theta - 1} \end{aligned}$$

so that

$$\begin{aligned} \bar{W} &= \int u(a)da + \frac{2\beta\log\left(x\right)}{1 - \beta} \\ &= \psi - (2 - \theta)\log\left(1 - \eta_g\right) - \eta_g - \log\left[\eta_g s + (1 - \eta_g)\right] + \frac{2\beta\log\left(x\right)}{1 - \beta} \end{aligned}$$

where ψ is a constant, so that finally, by the choice of $s \in (0, \infty)$, the government maximizes

$$W(s) = -(2 - \theta)\log\left(1 - \eta_g(s)\right) - \eta_g(s) - \log\left[\eta_g(s)s + (1 - \eta_g(s))\right] + \frac{2\beta\log(x(s))}{1 - \beta}$$

where $\eta_g(s)$ and $x(s)$ solve

$$\begin{aligned} x(s) &= \frac{h^{T_l}}{s}\eta_g(s)^{1-\theta}\left(\frac{1}{1 - \eta_g(s)}\right)^{2-\theta}\left(\frac{E_h}{h}\right)^{1-\theta} \\ x(s) &= \min\{\lambda, 1 + \left(\eta_g(s)E_h\right)^{\theta}\} \end{aligned}$$

as in the main text.

8.6 Derivatives of the Government Objective Function

For all $s \geq \bar{s}(\lambda)$ we have, since growth is maximal,

$$W(s \geq \bar{s}) = W(s = \infty) - \log\left(\frac{\eta_g^{2-\theta} + \frac{\lambda}{\kappa}(1 - \eta_g)^{3-\theta}}{e^{1-\eta_g}}\right)$$

and thus

$$W'(s|s \geq \bar{s}) = \frac{\eta_g^{2-\theta} + \frac{\lambda}{\kappa}(1 - \eta_g)^{3-\theta}}{e^{1-\eta_g}} * \eta_g'(s) * \frac{-e^{1-\eta_g}\left(2 - \theta + \eta_g\right)\eta_g^{1-\theta}}{\left[\eta_g^{2-\theta} + \frac{\lambda}{\kappa}(1 - \eta_g)^{3-\theta}\right]^2} * (s - 1)$$

from which the first part of the proposition follows.

For the case $s < \bar{s}(\lambda)$, from (22) we obtain

$$W'(s|s < \bar{s}) = \frac{\eta_g'(s)}{\eta_g(s)}\left[\left(\frac{1 + \beta}{1 - \beta}\right)\left(\frac{\theta\left(\eta_g(s)E_h\right)^{\theta}}{1 + \left(\eta_g(s)E_h\right)^{\theta}}\right) - (1 - \theta + \eta_g(s)) + \frac{1 - s - \frac{\eta_g(s)}{\eta_g'(s)}}{s + \left(\frac{1}{\eta_g(s)} - 1\right)}\right]$$

We observe that for $\beta \in (0, 1)$ sufficiently big we have that $W'(s|s < \bar{s}) > 0$ for all $s < \bar{s}$.

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