# Ideas, technology and human capital. How education can improve our lives.

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# Introduction

“We've arranged a global civilization in which the most crucial elements profoundly depend on science and technology. We have also arranged things so that almost no one understands science and technology. This is a prescription for disaster. We might get away with it for a while, but sooner or later this combustible mixture of ignorance and power is going to blow up in our faces.” - Carl Sagan

The Soviet Union has been regarded as one of ‘the great experiments of the twentieth century’. (R. C. Allen, 2001). And no wonder. In the 1930’s the Soviet Union experienced tremendous growth, an economic success that lasted until the 1970’s, when growth started to slow down. The main reason for this catch-up growth was given by the rapid and heavy industrialization of the economy, which focused on the extraction of raw materials. In fact, during the 80’s, the Soviet Union produced “80 per cent more steel than the USA, 78 per cent more cement, 42 per cent more oil, 55 per cent more fertiliser, more than twice as much pig-iron and six times as much iron ore. It produces five times as many tractors, and almost twice as many metal-cutting lathes” (Walker, 1986, p.53). And yet, as we know, the Soviet Union could not sustain itself. Who would have thought looking at the previous growth that the USSR’s economy would soon collapse? A state with such control over its resources, which has been experiencing immense economic growth and investing large amounts of capital should, a priori, be able to at least sustain itself. One of the most commonly argued causes for the slowdown of the USSR’s growth and its utter collapse was ‘technological failure’. (R. C. Allen, 2001, p.865). This would partly explain why, even though the investment rate was in fact rising, the country experienced a decline in GDP growth. But what does this ‘technological failure’ mean? For starters it meant that the Soviet model couldn’t offer enough incentives and freedom for technology to develop at the pace of market economies, so the increasing gap with the western competitor became obvious. They became trapped in a sort of *technological conservatism* (R.C. Allen, p.866) that proved that industrial success without technological innovation leads inevitably to economic failure, (arguably due to the diminishing returns of capital that can only be overcome through an increase in productivity). The kinds of barriers imposed to technology can be seen in many accounts on the bureaucratic nightmare that Soviet producers experienced:

“A factory that was producing, for example, farm machinery would require design approvals from at least eight different ministries before it could begin production, and then its contracts with suppliers of raw materials, engine parts, tyres, compressors and so on would each require approval by all the ministries to which the suppliers reported. This bureaucratic nightmare inhibited change and innovation. (...) Better to carry on turning out the old product, even if it might be less efficient.” (Walker, 1986, p.48). [1]

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[1] As it will be shown, this doesn’t mean that the Soviet Union didn’t carry on any research. In fact, productivity increased and better processes were introduced in some industries. (Allen, p.866). The Soviet Union was for a long time a worthy technological competitor of the USA.. It is argued that the reason for

The purpose of this brief example, to which we will come back later, is to showcase the sheer strength of the phenomenon of technological innovation and how determinant it is to the economic development of nations.

The aim of the present paper is to explore the relation between investment policies in education and R&D and the overall economic outcome of nations. It will offer a superficial definition of what technology is, a perspective on the place technology occupies within economic models, and speculate about what policies could potentially procure its development. First, a simple view on the Solow Growth model that explains how technology can be a decisive variable for economic growth, and a brief introduction to the Romer model that rejects the idea of technological innovation as an exogenous value and more as the outcome of knowledge stock and human capital. The intention is to answer these questions:

- What is the evidence of the effect of R&D investment in economies?
- What is the effect of investment in human capital and education?
- How can economies procure constant development of technological innovation?

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the slowdown in growth is due to the fixation on military R&D over civilian goods' R&D and the added inefficient allocation of resources due to a lack of market incentives. (Easterly and Fischer, 1995, p.349)

# Theoretical Framework

The Cambridge Dictionary describes technology as "(the study and knowledge of) the practical, especially industrial, use of scientific discoveries". From which one can infer that the definition of technological innovation should therefore entail the acquisition of new and better practical means of production that are based on scientific evidence. The value of innovation can easily be understood when the differences in production time and costs of agents with different technological means are analysed. For instance, in a production line of a certain piece of furniture, it is easy to imagine the kinds of hardships a worker with a mere screwdriver will go through in comparison to one with access to all sorts of power tools. It is also easy to see how the presence of power tools means a reduction in production time, labour need, and hence overall costs for the firm. Which in turn translates in a reduction of the price for consumers and an increase in social surplus. In other words, technology allows us to get a *'bigger bang for our buck*'. But what technological advancement comes down to is the discovery of new ways of using the same resources. As Schumpeter puts it, "to produce means to combine materials and forces within our reach. (...) Development in our sense is then defined by the carrying out of new combinations" (1949, p.65-6). And these combinations are nothing but the result of human capital put to work and the subsequent birth of new ideas. Predynastic Egyptians used silicon for the production of beads and small vases[2]. Today we use its semiconductor characteristics to produce huge amounts of transistors that power the computation capacities of the world. The differences between predynastic Egyptians and the era of information weren't differences in the presence of raw materials or intellectual capacity, but the use that as a species we could do of it. This can be attributed to the development of new ideas and models capable of explaining empirical manifestations of reality. Another interesting example of the capacities of scientific discoveries is the Haber-Bosch process that 'enabled us to produce enough nitrogen fertiliser to feed the current world population' (G.J.Leigh, 2004, p.33) and question the pessimistic assumptions of the Malthusian cycle. It is then evident that investment in the production of new ideas, discoveries and technologies is crucial for the ever growing population of humans, as well as investment in education so that those technologies can be put to work. In the coming section the growth model proposed by Solow will be explored in order to better understand how technology actually can determine economic outcome.

[2] https://www.britannica.com/science/silicon

## The Solow Growth Model

The Solow Growth model departs from the neoclassical aggregate production function where the output is equal to the function of physical capital input $K$, labour input $L$ and technology (or productivity) $A$. In order to simplify, we will assume that technology and labour remain constant:

$$Y = F(A, K, L) \rightarrow Y = F(K)$$

Another important assumption of the model is diminishing returns of capital. Which entails that an increase in K will yield an increase in Y, but at a diminishing rate. A function that shares these properties could then be:

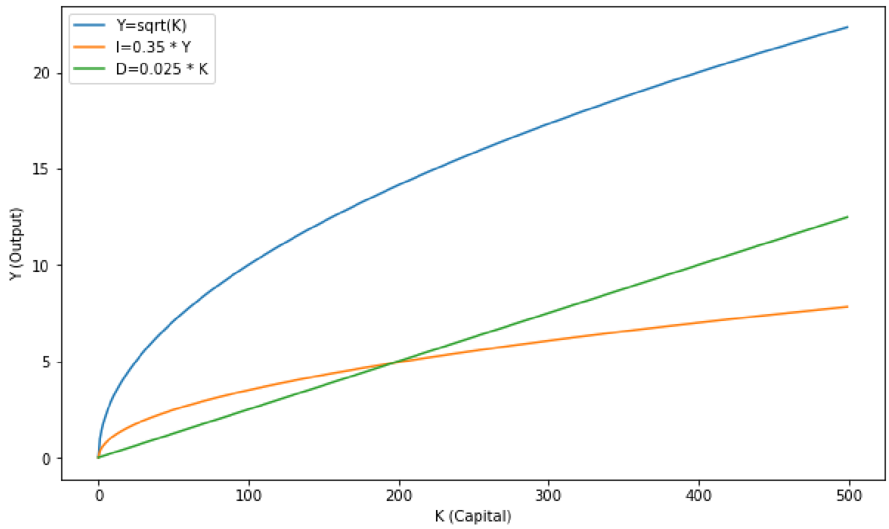
$$Y = \sqrt{K}$$

Coming back to the example of the furniture production line, if labour remains constant, say four workers, and technology doesn't change, the value of adding four power tools is evident. That means that no worker will have to use a screwdriver and that production rate will increase in comparison. Adding another power tool might then be of some use, especially if some other tool suddenly brakes and needs quick replacement, but it won't yield the same results in production. Adding a sixth will be of even less utility than the fifth, and so on. That is what the figure above describes; capital will progressively yield less and less output increase for the same amount of capital. That explains the phenomenon of catch-up growth (recall what happened to the Soviet Union during the '30s). Countries with low capital stock will experience enormous growth rates in comparison to more developed economies for the same amount of capital investment. This investment in capital stock is a proportion of the output Y and can be expressed as:

$$I = pY = p\sqrt{K}$$

being *p* the proportion of reinvestment or savings. To which we will give the arbitrary value of .35. This means that a capital (K) of 400 will give an output (Y) of 20 and, considering our proportion of investment, *I* will be equal to $0.35\sqrt{400} = 7$. Finally, the Solow model takes into account capital depreciation. Which is a constant fraction or proportion of the capital stock. This means that over time capital needs maintenance and replacement. Therefore an increase in capital stock entails an increase in capital depreciation and the subsequent incur of costs. Where *r* represents the rate of capital depreciation. In this case, 2.5%:

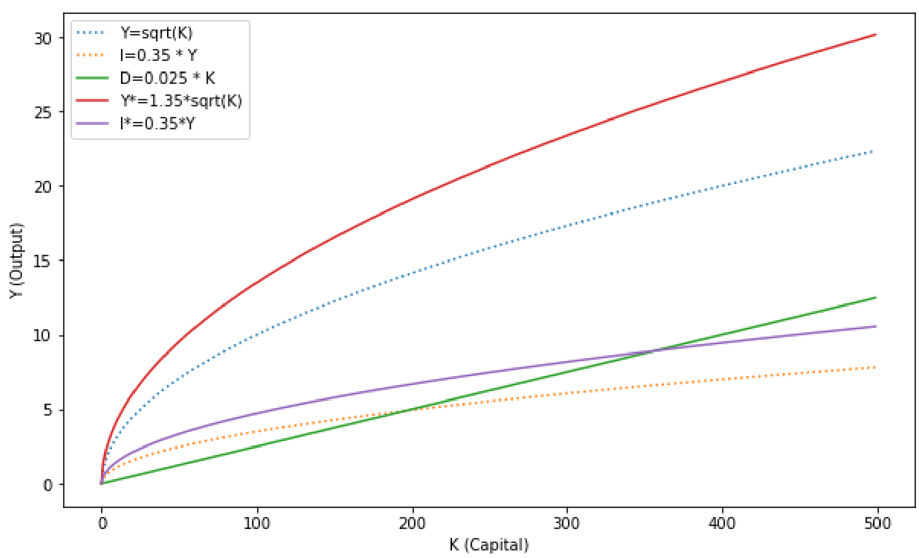
$$D = rK$$




An important aspect of the last figure is that, for the capital values where the investment curve (orange) is superior to capital depreciation (green), the economy is experiencing a positive rate of capital stock increase. But whenever the investment curve is below the capital depreciation line, the economy is experiencing a decrease in their capital stock due to the fact that depreciation is bigger than the investment made to maintain it. Hence, it would be natural that the amount of investment sticks to the point where investment is equal to depreciation. This point is called the *steady-state*, and economies tend to converge into that point. In the chart, it would be at around a value of 200 for the capital stock with an output of roughly 15.

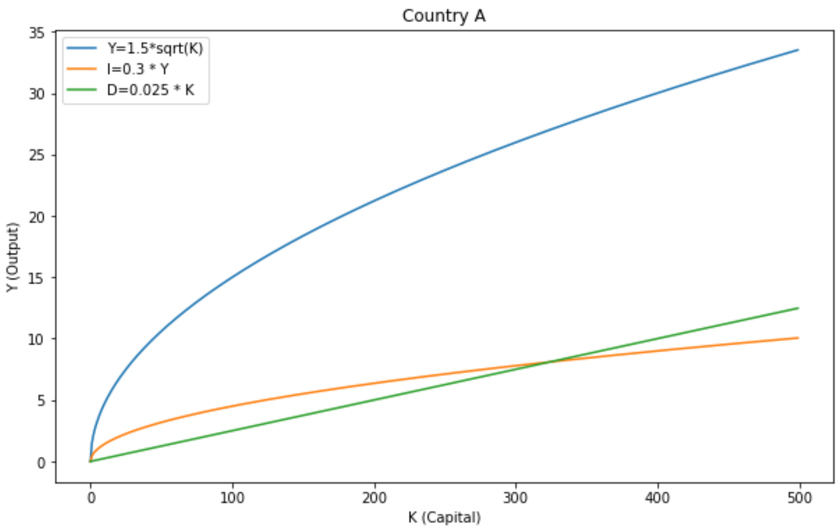
What would be the place of technology in this model then? Until now, the technology variable A has been omitted. 'A' also refers to ideas and productivity, or 'a bigger bang for your buck'. Again, an arbitrary value of 1.35 for A is given:

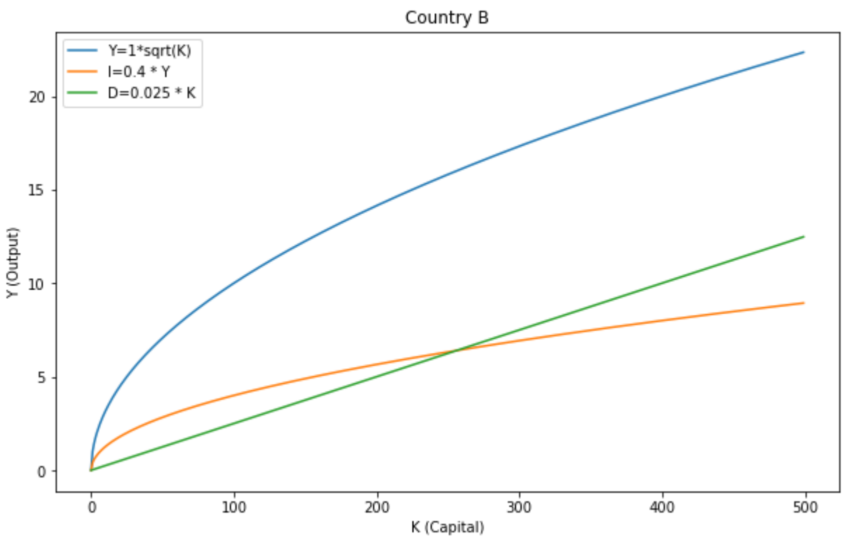
$$Y = A\sqrt{K}\ ,\ I = pY = pA\sqrt{K}, \text{ and } D = rK$$



The new production function (red) and the new savings curve (purple) compared to the old dotted lines show how an increase in productivity can greatly shift the output to the right (in the case of a country, its GDP) and encourage more capital accumulation and investment. Capital will in this case converge to the new steady-state at around 370 for capital stock.

Recalling from the introduction section where the idea that technological failure was one of the reasons why the Soviet Union couldn't keep up with the west, it is now easy to simulate this narrative through the Solow Model.[3] Suppose country A and country B. Country A has a productivity factor of 1.5, invests 30% of production, and shares with country B a steady rate of depreciation of capital of 2,5%. On the other hand, Country B has a productivity factor of 1 due to a lack of technological advancement, but invests 40% of production:




[3] For this I made a python model that produced the images with the matplotlib library based on the equations presented here.

This would explain how, even though country B is investing a bigger proportion of its output, country A is achieving a greater yield. Steady-state for country B gives an output of around 16 and for country A, 26. According to this model, productivity, ideas and hence technology is not just another variable for growth, it is a decisive factor for the economic success of countries. Ideas and their proper application are key to making economies robust and successful. As Romer puts it: "(...) technological change —improvement in the instructions for mixing together raw materials—lies at the heart of economic growth (...) Technological change provides the incentive for continued capital accumulation, and together, capital accumulation and technological change account for much of the increase in output per hour worked" (1990, p.72).

One of the most criticised aspects of the Solow model is that technology is an exogenous factor. That is, technology is never explained as a phenomenon that comes from within the model, but as a 'given'. In the following section, the Romer Model will be looked at as an 'enhanced' version of the Solow Growth model, in which human capital and R&D are both endogenous factors of production. As stated by Ulku in her research, the Romer model is based on three premises: firstly, that technological change drives economic growth. Secondly, technological change is not exogenous, as argued before, but the result of human action in response to market incentives. And lastly, that 'blue prints (designs) used to produce new products are nonrival, i.e. they can be replicated with no additional cost". (2004, p.6). The Romer model holds three different sectors:

- R&D sector
- Intermediate goods sector
- Final output sector

The production of new ideas in the R&D sector is given by the following equation:

$$\dot{A} = \delta H_A^{\theta} A$$

Where Å signifies the new designs, $H_A$ is the total human capital and A the total knowledge stock.

It will then be assumed that technological innovation is produced in the R&D sector with the use of human capital and the existing knowledge stock, and that this innovation is 'used in the production of final goods and leads to permanent increases in the growth rate of output' (Ulku, 2004, p.4). Demonstrating the clear importance of human capital in the production of new ideas and hence technological innovation. It is then evident why these two (R&D and human capital) will be looked at in the next section.

# Empirical chapters

1. What is the evidence of the effect of R&D investment in economies?

In Ulku's research empirical data on OECD and non-OECD countries regarding investment in R&D, patent stock and GDP was carried out. OECD countries refer to the Organisation for Economic Co-operation and Development, where "37 democracies with market-based economies collaborate to develop policy standards to promote sustainable economic growth" [4]. A chart depicting the ranking of countries by per capita GDP, investment, patents, and R&D expenditure from 1981 to 1997 give a clear view of the positive correlation between income level and market size with per capita R&D and patents. (2004, p.13):

Table 4. Rankings of Countries by per capita GDP, Investment, Patents, and R&D Expenditure, 1981–97

| Rank | Investment | | GDP | | Patents | | R&D Expenditure | |
|---|---|---|---|---|---|---|---|---|
| 1 | Japan | 10,153 | Switzerland | 42,824 | Switzerland | 176 | Switzerland | 870 |
| 2 | Switzerland | 8,863 | Japan | 36,138 | Japan | 157 | Sweden | 730 |
| 3 | Norway | 7,417 | Denmark | 30,889 | Sweden | 95 | Japan | 705 |
| 4 | Austria | 5,823 | Norway | 29,152 | Canada | 68 | France | 466 |
| 5 | Finland | 4,980 | Austria | 26,054 | Finland | 64 | Iceland | 442 |
| 6 | Iceland | 4,875 | Iceland | 25,492 | Netherlands | 58 | Norway | 436 |
| 7 | Denmark | 4,546 | Sweden | 24,996 | France | 49 | Finland | 436 |
| 8 | France | 4,539 | Belgium | 24,555 | United Kingdom | 45 | Denmark | 390 |
| 9 | Netherlands | 4,536 | France | 24,397 | Austria | 44 | Netherlands | 376 |
| 10 | Belgium | 4,096 | Finland | 23,507 | Denmark | 42 | United Kingdom | 375 |
| 11 | Sweden | 4,039 | Netherlands | 23,173 | Belgium | 36 | Belgium | 306 |
| 12 | Australia | 3,842 | Canada | 18,401 | Norway | 29 | Canada | 297 |
| 13 | Canada | 3,347 | Australia | 18,056 | Australia | 26 | Austria | 272 |
| 14 | Italy | 3,177 | Italy | 17,183 | Italy | 20 | Australia | 267 |
| 15 | New Zealand | 2,952 | United Kingdom | 17,040 | New Zealand | 16 | Italy | 216 |
| 16 | United Kingdom | 2,700 | New Zealand | 15,423 | Iceland | 15 | New Zealand | 150 |
| 17 | Ireland | 2,509 | Ireland | 13,729 | Ireland | 14 | Ireland | 137 |
| 18 | Spain | 2,504 | Spain | 12,617 | Spain | 3 | Spain | 88 |
| 19 | Greece | 2,106 | Greece | 10,487 | Greece | 1 | Greece | 61 |
| 20 | Portugal | 2,061 | Portugal | 9,005 | Portugal | 1 | Portugal | 52 |

Sources: GDP and Investment (WDI (2002)), R&D (OECD (2002)), Patents (NBER Patent Citation Database).
Notes: All series are in 1995 U.S. dollars and averaged over 1981–97, Patents are in per million people.

Image retrieved from Ulku's paper. (2004, Page 11)

In the words of the author, this data suggests that "income level and the market size are positively associated with the growth rate of R&D expenditure". (2004, p.13). This becomes clear when the consistency of declining values across all columns for each country is observed. Nevertheless, this does not entail causation; it is not possible to derive from this information that countries with larger markets and bigger GDP per capita owe it to a proportionally bigger R&D expenditure. But it suggests that bigger economies tend to go hand-in-hand with increased R&D expenditure and patent stock, as they probably depend on the production of new ideas.

[4] https://www.state.gov/the-organization-for-economic-co-operation-and-development-oecd/

Moreover, a fixed-effects regression analysis suggested that a "1 percent increase in per capita R&D stock increases innovation by 0.40 percent in the G-7, and the large market countries, and 0.50 percent in low-income OECD countries" (2004, p.18). There is the suspicion that countries that lack a strong R&D sector take advantage of the innovation of other countries. This is known as 'knowledge spillovers', defined here as the leakage of knowledge and ideas on technology: "Another important observation from table 7 is that most of the countries that do not have effective R&D sectors have significant coefficient on import share of trade in manufacturing goods. This might imply that these countries import the know-how of other OECD countries to promote their innovation, instead of investing in formal R&D sectors" (Ulku, 2004, p.20) .

Table 7. General Methods of Moments (GMM) Regression Analysis of Per Labor Patent Flows, 1981–97[1]

| | Full | Non-G-7 | G-7 | Large Market | Small Market | High Income | Low Income |
|---|---|---|---|---|---|---|---|
| Second lag of R&D stock | 0.080<br>(0.94) | 0.015<br>(0.14) | 0.162<br>(2.52) | 0.231<br>(3.44) | 0.073<br>(0.53) | 0.130<br>(1.06) | 0.298<br>(3.09) |
| Second lag of Secondary school | 0.039<br>(0.17) | -0.012<br>(0.04) | 0.184<br>(1.84) | 0.104<br>(1.06) | -0.169<br>(0.35) | 0.362<br>(0.83) | 0.047<br>(0.20) |
| Expropriation risk Index | -0.314<br>(0.63) | -0.522<br>(0.89) | 0.297<br>(1.02) | 0.455<br>(1.90) | -0.715<br>(0.72) | -0.289<br>(0.29) | 0.356<br>(0.71) |
| Manufacturing import/trade | 1.844<br>(2.89) | 1.761<br>(2.17) | -0.315<br>(1.04) | 0.178<br>(0.81) | 2.633<br>(2.29) | 4.226<br>(3.72) | 0.057<br>(0.09) |
| U.S. trade/GDP | -0.066<br>(0.38) | -0.164<br>(0.80) | 0.340<br>(3.77) | 0.154<br>(1.75) | -0.095<br>(0.32) | -0.650<br>(2.28) | 0.339<br>(1.96) |
| Openness | -0.169<br>(0.52) | 0.034<br>(0.08) | -0.171<br>(1.42) | -0.046<br>(0.43) | -0.323<br>(0.51) | -0.583<br>(1.17) | -0.697<br>(2.05) |
| First lag of per labor patent | 0.297<br>(4.26) | 0.304<br>(3.72) | 0.309<br>(2.42) | 0.576<br>(6.99) | 0.228<br>(2.36) | 0.191<br>(1.94) | 0.317<br>(3.89) |
| Second lag of per labor patent | -0.178<br>(2.71) | -0.188<br>(2.44) | 0.354<br>(2.80) | -- | -0.178<br>(1.89) | -0.187<br>(1.92) | -- |
| Third lag of per labor patent | 0.135<br>(2.01) | 0.133<br>(1.66) | -- | -- | -- | 0.359<br>(3.28) | -- |
| Constant | 0.030<br>(3.05) | 0.005<br>(0.27) | 0.071<br>(2.23) | -0.024<br>(5.59) | 0.062<br>(3.66) | -0.122<br>(1.05) | 0.010<br>(0.89) |
| Sargan test[2] (*p-value*) | 0.00 | 0.09 | 1.00 | 1.00 | 0.96 | 0.99 | 0.93 |
| AR(2) test[3] (*p-value*) | 0.38 | 56 | 0.56 | 0.27 | 0.62 | 0.38 | 0.37 |
| Observations | 247 | 182 | 70 | 126 | 112 | 117 | 112 |
| Number of countries | 19 | 14 | 5 | 9 | 8 | 9 | 8 |

The results of the paper suggest that; first, market size and income levels influence the 'intensity of R&D'. Second, large market OECD countries are the ones that seem to increase innovation through investment in R&D. Third, there are no constant returns to innovation. And finally, technology spillovers are significant for countries that do not have enough R&D or that R&D isn't an effective producer of innovation.

Moreover, there is a 'strong positive relationship between innovation (patent stock) and per capita GDP in both OECD and non-OECD countries' (2004, p.27).

2. What is the effect of investment in human capital and education?

If we accept the premise of a positive correlation between R&D investment (technological innovation) and economic growth, it will come as no surprise that the quantity and quality of the knowledge acquired by the labour force in a given economy will greatly determine not just the production of new ideas, as stated in the equation by Romer, (Ȧ is depends on human capital and knowledge stock), but also the success of the newly created technologies. From this perspective human capital becomes one key factor of the economic outcome of a nation. Someone will have to use and take advantage of the existing technology stock. But as technology progresses it also becomes more complex to operate and understand. This prompts to question the extent to which human capital influences economic growth.

In *The impact of human capital on economic growth: a review* it is clearly stated that "regardless of the precise model that is adopted, there is strong evidence that higher educational inputs increase productivity and so produce higher levels of national growth". More precisely, "an overall 1% increase in school enrolment rates leads to an increase in GDP per capita growth of between 1 and 3%. Through the use of only OECD data, it was also proved that secondary school enrolment rates are one of the 'only three' significant determinants of labour productivity growth. (Wilson & Briscoe, 2005, p.42).

Another paper by E.A.Hanushek and L.Wöbmann also refers to the significant association between schooling and GDP: "To provide an idea of the robustness of the basic association, primary schooling turns out to be the most robust influence factor (after an East Asian dummy) on growth in GDP per capita in 1960-1996 in the extensive robustness analysis of 67 explanatory variables in growth regressions on a sample of 88 countries by Sala-i-Martin et al.(2004)" (2010, p.245). In the image below, a scatterplot that represents the association between years of schooling and economic growth. In it, each year of schooling is associated with long-run growth 0.58 points higher. (p.245)

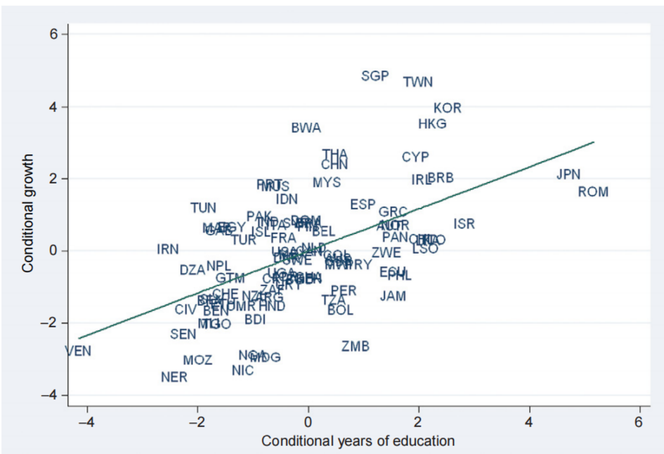



**Figure 1** Association between years of schooling and long-run economic growth. Added-variable plot of a regression of the average annual rate of growth (in percent) of real GDP per capita in 1960–2000 on average years of schooling in 1960 and the initial level of real GDP per capita in 1960.

The association in the figure above is somewhat clear, though it only refers to the quantity of education in terms of time. Looking at the chart it is safe to say that years spent in education are related to economic growth. The problem with this chart is that it assumes that every year of education yields the same increase in knowledge in every country for every person, which is evidently not true. Therefore the importance of education can not just be referred to as a function of time spent learning, but also the quality of what is being learnt, of education itself. There is “a statistically and economically significant positive effect of the quality of education on economic growth in 1960-1990 that is far larger than the association between the quantity of schooling and growth”. (2010, p.247)

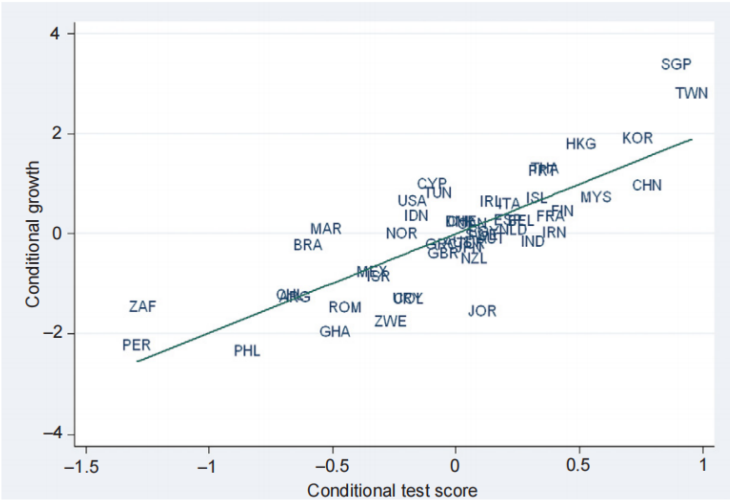



**Figure 3** Test scores and long-run economic growth. Added-variable plots of a regression of the average annual rate of growth (in percent) of real GDP per capita in 1960–2000 on the initial level of real GDP per capita in 1960, average test scores on international student achievement tests, and average years of schooling in 1960. Calculations from Hanushek, E. A. and Woessmann, L. (2008).

When it comes to test scores, as seen in figure 3, the scatter plot correlation seems to increase significantly. Specific types of knowledge will yield better economic outcomes. It would seem that human capital that enables the correct use of technological innovation and/or the production of new ideas will improve the economic prospects of individuals. They are more capable of providing high value production to society in comparison to those with more traditional and static kinds of knowledge that can still provide value, but not with the exponential potential of advanced technologies: “The allocation of talent between rent-seeking and entrepreneurship matters for growth: countries with more engineering students grow faster and countries with more law students grow more slowly” (2010, p.250).

This establishes a significant precedent on the importance of education for the correct development of society. If technology is one of the key factors on economic growth, then it necessarily follows that human capital has to increase with this technological stock. Human capital is then concerned with providing the knowledge required to bring technology to its best possible and most efficient use. Technology without humans operating it serves no purpose. It must come hand in hand with the proper education and human capital necessary for it to work.

# Conclusion

The previous chapter has briefly explored the relation between R&D and GDP growth. It has been concluded in more advanced studies that there is a clear positive correlation between R&D and the income level and market size of the economies. This doesn't imply causation. But it suggests that there is a well founded reason for which these economies would invest increasingly more in the production of new ideas and technologies. This might have to do with the effect of increased productivity in production functions like the one shown in the theoretical framework; economies with high capital stock might have to rely more on the productivity factor to overcome the law of diminishing returns of capital.

The relation between technology and ideas becomes blurry once we look at them more closely. At the end of the day, technology seems to be the application of those ideas that were adequate to explain the world and could be used in order to increase the productive potential of societies as a whole. On the other hand, there is also evidence suggesting that countries with weak or non-functional R&D sectors might be benefiting from the import of those technologies created in more advanced economies. In this case, the importance of the value of human capital becomes clearer. For technologies to work countries need people capable of using them. That is probably why, as shown in the previous chapter, countries with better test-scores tend to belong in countries with higher levels of GDP per capita. This can be considered one of the key 'findings' of the present paper: economic growth greatly depends on technological innovation, but this technological innovation, at the same time, greatly depends on education. Without the human capital necessary, there is no creation or use of the new ideas. Suggesting that countries should never overlook the importance of the educational system and the great impact it can have in a country's economy.

Education could, in fact, improve the living conditions of people in situations of poverty. Market economies benefit those who can offer higher levels of productivity, and as seen in the paper, productivity greatly increases when people have access to technologies. This entails understanding them. It begs the question of whether governments are doing as much as they can to improve the schooling system of those in lower social classes in order to increase the overall baseline of human capital and productivity potential across the country.

As a concluding remark, the paper has found evidence that suggests that investment in the R&D sector, and most importantly, in the educational system, is key for the economic outcome of societies, and should be regarded as such by policy-makers.

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