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Education and economic growth

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Abstract
This paper summarises the literature that has linked education and economic growth. It begins with an overview of the key concepts in neoclassical and endogenous growth models, and discussion on how these have been tested in the data. Issues with respect to specification, the measurement of human capital and causality are discussed, together with studies that have sought to address these. A more recent and growing literature that explores the links between firm level human capital and productivity, including externalities, is then summarised. Beyond studies that link human capital to economic performance directly, there are numerous studies that have explored the relationships between human capital and the determinants of growth including investment, technology adoption and invention. Key findings from this literature are drawn out, together with a summary of the literature that has linked the activities of universities (key producers of both human capital and innovation) to their local economies. The paper concludes with discussion of policy implications stemming from this body of research, and promising areas for future research.

Key words: human capital, growth, innovation
JEL codes: O30; O40

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1 Introduction

It is generally accepted that education, as a key means of building human capital, matters for both individual and economy-wide prosperity. On the individual side, work stemming from Schultz (1961), Becker (1964) and Mincer (1974) has shown that education is important for improving earnings and productivity. In micro estimates, the individual returns to education have been shown to be large. The return to an extra year of schooling is around 9% on average globally, and this has been relatively stable over the decades (Psacharopoulos and Patrinos, 2018). But wider economic externalities and benefits to society are not captured in these analyses. In particular, they do not capture the potential spillover effects of an individual's education on other individuals working in the same firm, industry, region or country.

Marshall (1890) was among the first to recognise the social interactions among workers that can create learning opportunities and enhance productivity. Since then, many have highlighted human capital externalities as the key driver of economic growth (Lucas, 1988). Moreover, human capital can generate other positive externalities, including lower crime or improved health outcomes, which are socially desirable and also likely to have further positive impacts on productivity. Indeed, it is the presence of such positive externalities that provides an economic justification for governments to provide support for education. Macro-level analyses of the relationships between human capital and growth are therefore particularly relevant for capturing the economy-wide indirect or spillover effects of investments in human capital (Sianesi and Van Reenen, 2003). In recent years, sector or firm-level productivity regressions have found that the returns to human capital appear to be larger for firms than for individuals (Dearden et al., 2006; Konings and Vanormelingen, 2015). Moreover, spillovers have also been estimated in individual wages or firm productivity generally by considering a measure of the human capital that individuals or firms are exposed to in their geographic setting (see, for example, Moretti, 2004a,b).

Overall, there is little doubt over the centrality of human capital for growth and development. However, there have been disagreements over the mechanism and puzzlement over the apparently weak results in several cross-country studies. In general, such weak results stem from measurement or specification issues, some of which have been addressed in the literature by using improved measures of human capital, in particular, accounting for its quality. More recently, as better data have become available, analyses conducted at the region and firm-level have found that the human capital (of both workers and entrepreneurs) is an important driver of economic growth and its determinants.

This paper reviews the literature on human capital and economic growth, with a particular emphasis on the empirical evidence. While human capital is a broader concept than educational attainment, also consisting of underlying ability, personal characteristics (including health) and learning experiences (both pre and post-school) that build knowledge and help people to be productive, much of the empirical literature has focused on widely available comparative measures of education such as years spent in the schooling system or enrolment rates. The main focus here is on the education component of human capital, and through much of the discussion, the term “human capital” is used interchangeably with education. However, advances in the measurement of skills more directly, for example, using comparable international assessments of student achievement (Hanushek and Woessmann, 2015) are also discussed at length.

The paper begins with an overview of the literature on human capital and growth as conceptualised in the neoclassical and endogenous growth models, showing how these have been taken to the data in growth accounting exercises and growth regressions respectively. Next, and in the context of these analyses, it discusses issues with respect to the measurement of human capital - in particular how differences in the stage, type or quality of education can be captured and how this can clarify the empirical relationships. Next, challenges in establishing causal relationships between human capital and growth are discussed, together with studies that have sought to address these. While much of the literature on education and growth focuses on average education levels at some relevant economic unit, more recent literature has linked educational inequalities and the allocation of resources to economic performance.

Due to improvements in data availability in recent years, numerous studies have now explored the links between firm-level human capital and productivity (or other measures of performance), followed by a discussion of studies that link human capital to the determinants of growth including investment, technology adoption and invention. Finally, and given the importance of universities as institutions that produce both human capital and innovation, key relevant findings from studies that link universities and their activities producing graduates and research to local economic outcomes are explored. The paper concludes with a discussion on what the evidence set out in the paper implies for policy, and highlights areas where further research is needed.

2. Human capital and growth – macro frameworks and approaches

The main macro approaches for modelling the relationship between human capital and growth are the augmented neoclassical model and the new growth theories. In this section, the basic features of each are outlined together with a discussion of the key messages that have emerged where these have been taken to the data.

2.1 The Neoclassical model

The standard neoclassical growth model (Solow, 1956) considers the output of the macroeconomy as a direct function of just its capital, labor and exogenous technical progress. Mankiw et al. (1992) augment this basic production function to include the human capital stock in the labour force, stressing its role as a factor of production. A Cobb-Douglas production function is often assumed and can be set out as follows (Jones, 2016):

$$Y_t = A_t M_t K_t^{\alpha} H_t^{1-\alpha} \quad (1)$$

This relates GDP (Y) to human capital (H) and physical capital (K). Human capital can be expressed as H = hL, where L represents the quantity of labour (hours worked or the number of workers) and h = human capital per unit of labour. α and (1 – α) are the output elasticities of capital and labour, and A_t M_t represents Total Factor Productivity (TFP). Within this, A_t denotes the economy's knowledge stock and M_t is anything else that influences TFP.

This specification exhibits constant returns to scale – doubling all the factors of production will also double output. Generally, it is assumed that production factors are paid their marginal products in which case α and (1 – α) are also the shares of profits and wages in income, respectively.

In this framework of constant returns to scale and no externalities, growth, in the long run, is driven by technical progress which is treated as exogenous. Accordingly, a one-off permanent increase in the human capital stock will be associated with a one-off increase in the economy's growth rate during a transition, until productivity per worker hour has reached its new and permanently higher steady-state level. Growth in human capital would be required to drive economic growth in the long term. Overall, in this model, the role of human capital is limited, because there is a natural constraint on the amount of schooling that a society can invest in.

2.2 Growth accounting

The neoclassical model has been taken to the data via accounting exercises. In growth accounting, a country's growth rate is decomposed into the effects of input accumulation and TFP. While accounting exercises were traditionally derived from Equation 1 directly, several papers (for example, Klenow and Rodríguez-Clare, 1997; Hall and Jones, 1999) express the growth accounting equation in per worker or per hour terms. Dividing both sides of equation (1) by Y_t^{α}, solving for Y_t and dividing by L_t (total number of workers or total hours worked) gives the expression for labour productivity:

$$\frac{Y_t}{L_t} = \left(\frac{K_t}{Y_t}\right)^{\frac{\alpha}{1-\alpha}} \frac{H_t}{L_t} Z_t \tag{2}$$

where $Z_t = (A_t M_t)^{\frac{1}{1-\alpha}}$ is TFP measured in labour augmenting units.

Labour productivity tends to be the variable of interest in such exercises, since in general, we want to understand why output per unit of labour input differs across countries, leaving aside differences in the size of the labour force. In addition, using the capital-output ratio in the decomposition also has the advantage that differences in input intensity induced by differences in TFP are credited to TFP.[1]

Taking logs and differencing gives the following expression.

$$\Delta ln\left(\frac{Y_t}{L_t}\right) = \frac{\alpha}{1-\alpha}\Delta ln\left(\frac{K_t}{Y_t}\right) + \Delta ln\left(\frac{H_t}{L_t}\right) + \Delta ln(Z_t) \tag{3}$$

[1] If a country experiences an exogenous increase in TFP, holding its investment rate constant, then over time its capital-labour ratio will rise. This implies that some of the increase in output that is due to the increase in TFP is attributed to capital accumulation in a framework based on the capital-labour ratio (Hall and Jones, 1999).

Thus, the rate of growth in output per hour worked is decomposed into the contributions of growth in the capital output ratio, growth in human capital per hour worked, and growth in labour augmenting TFP. The model can be extended to include different types of labour so that H_t/L_tcaptures composition effects. In development accounting, a similar logic is applied to explain cross country differences in GDP per capita (for an overview, see Caselli, 2010).

In these exercises, the parameters of the production function are typically imposed or calibrated based on micro evidence. Therefore, in an accounting framework, the answer to the question of much output would increase following an increase in human capital is determined a priori.

Earlier studies (see, for example, Jorgenson and Fraumeni, 1992; Mankiw et al., 1992) found a relatively large contribution of human (and physical) capital to growth, as compared with TFP. But later studies, for example, Hall and Jones (1999) as well as Klenow and Rodríguez-Clare (1997), claimed that TFP was by far the most important component, with differences in TFP accounting for over 60% of differences in productivity between countries, and differences in TFP growth accounting for up to 90% of differences in growth rates. These earlier studies used measures of educational attainment (average years of schooling or attainment rates at different levels).

Jones (2016) reports the growth accounting decomposition for the United States corresponding to Equation 3 over the period 1948-2013 using data from the BLS. Over this entire period, the average annual growth of output per hour was 2.5%. TFP accounts for 2 percentage points; and labour composition 0.3 percentage points (the contribution of capital was only 0.1 percentage points). Similarly, in a development accounting exercise using Penn World Tables data for 2010, he shows that differences in TFP are the largest contributor to differences in GDP per worker.

In the development accounting literature, a number of studies over recent years have sought to improve the measurement of factor inputs, but still, these have not made much of a dent in the contribution of TFP (Rossi, 2018). At the same time, a large body of research has emerged seeking to understand differences in TFP, and a key contribution has been the work on misallocation. The basic idea is that when resources are misallocated at the micro-level, the economy will not be able to operate at the production possibilities frontier and hence TFP will be lower. This is discussed further in Section 5.

To conclude, while these analyses show that TFP is the largest contributor to differences in growth rates over time or income differences across countries, they generally find a non-trivial contribution of human capital to both growth and development. A drawback of the neoclassical approach is that technological progress is exogenous, unexplained and unrelated to the stock of human capital. This implies that the indirect effects that education can have on output levels or growth via investment in capital and R&D and labour force participation are not captured.

2.3 New Growth Theory

New growth models emphasise the endogenous determination of growth rates via an improved understanding of the drivers of innovation. Such models provide the theoretical frameworks for human capital to affect national growth via two main channels (Sianesi and Van Reenen, 2003). In the first channel, human capital is incorporated in the production function as a factor of production by explicitly modelling individual educational investment choices (Lucas, 1988), as well as allowing human capital to have external effects – thus departing from the constant returns to scale assumption. This type of framework predicts that output growth is a function of the accumulation of human capital over time (rather than its level), a prediction that is observationally equivalent to the augmented neoclassical model.

The second channel relates technological change and growth to the stock of human capital. In endogenous growth theory, human capital is an essential input into a research sector which generates new ideas and technologies (Romer, 1990; Aghion and Howitt, 1992[2]). A given level of education can produce a continuous stream of innovation so that the level of education can affect long-term growth rates. Another view focuses on the roles of human capital in facilitating the diffusion and adoption of new technologies (Nelson and Phelps, 1966; Welch, 1970; Benhabib and Spiegel, 1994). In particular, education facilitates the transmission of knowledge that is required for implementing new technologies.

[2] See also Aghion and Howitt (1998).

Again, in this view, an increase in the level of human capital can raise the economic growth rate into eternity- even after the human capital stock has adjusted to its new long-run level.

2.4 Macro growth regressions

The empirical analysis of new growth theories has taken the form of macro growth regressions, often called "Barro regressions". These differ from growth accounting as they estimate rather than impose the parameters (output elasticities) of the aggregate production function. As such, this type of analysis seeks to explain cross country variation in TFP rather than leave it as a residual.

Typically, the dependent variable is the GDP per capita growth rate, and explanatory variables include the stock of human capital – often average years of schooling, initial GDP per capita, investment ratios, geographical and institutional factors. Such regressions have been described as ad hoc, where the choice of explanatory variables is "largely driven by previous results in the literature and a priori considerations" (Sianesi and Van Reenen, 2003).

A key aim of macro growth regressions is to identify statistically significant, robust relationships between various factors and economic growth with a view to claiming such relationships to be causal. While initial studies were based on a cross-section of countries, later studies have used panel data (see for example Barro, 2012) – with the benefits of controlling for time-invariant unobservables at the country level, but at the cost of exacerbating measurement error. Growth regressions have also been estimated at the subnational region level (Gennaioli et al., 2014).

Macro growth regressions have usually, but not always, found a positive relationship between human capital and growth. Hanushek and Woessmann (2015) highlight that while a strong association between human capital (as measured by average years of schooling) and growth is apparent in the data, the effect is sensitive to model specification. In fact, Benos and Zotou (2014) conduct a meta-analysis of 60 studies published over 1989-2011 and find that around 20% of reported coefficient estimates on human capital are negative. In general, differences in sample, human capital measures, use of stocks or flow measures of human capital make it challenging to compare estimates across studies (Sianesi and Van Reenen, 2003).

As yet there is no consensus in the literature on whether the growth or level of human capital is the key driver of growth. Sunde and Vischer (2011) argue that if the two channels through which human capital impacts growth are important, i.e. growth in human capital as a factor of production and the existing stock of human capital as a determinant of innovative capacity, then estimates that omit one of these will suffer from omitted variable bias (assuming that changes in human capital are correlated with initial levels). Replicating some key studies but including both terms, the authors find consistently positive and significant effects of human capital in levels and changes – whereas, in isolation, each term can often appear insignificant.

Several studies have found that differentiating between stages of education or capturing the quality of education, rather than using the standard average years of schooling measures has helped clarify the positive relationships between human capital and growth. However, even with more refined measures of human capital, a major criticism of macro analyses is that they show associations between human capital and growth but not necessarily causation. Bils and Klenow (2000) suggest that reverse causality (higher growth leading to additional education) could be at least as important as the causal effect of education on growth in these relationships. The importance of getting other things right as well – in particular institutional frameworks – has also been highlighted (see, for example, Acemoglu et al., 2005b, 2014).

Whether or not there is a casual relationship is an important issue from a policy point of view. However, this problem is not easily solved by using standard econometric techniques since the potential instruments for education are often correlated with institutional features (Glaeser et al., 2004). Examining growth across regions in countries with more reliable data is a way of reducing the impacts of measurement error, and controlling for country or even sub-national level unobservables that are fixed over time. Some papers have exploited natural experiments at particular points in history to evaluate the effects of exogenous changes in education. Progress across all these dimensions is outlined below.

3 The measurement of human capital

The measure of human capital used in country-level studies – most often average years of education – implicitly assumes that an additional year delivers the same increase in knowledge and skills regardless of the stage of education and the type of education being provided. Some studies use enrolment rates, differentiating between primary, secondary and tertiary education or the proportion of the labour force that has received education at these different levels. But even these more detailed measures do not account for differences in the quality of provision or non-school factors which are likely to vary in different settings.

3.1 Stages of education

A series of papers consider the effects of educational attainment or investment at different levels, and how these vary for countries at different stages of development.

Krueger and Lindahl (2001) stick with years of education as the measure of human capital, but depart from the implicit assumption in many analyses that its relationship with growth is linear. They find evidence of non-linearities with an inverted U-shaped relationship between years of education and growth. The peak is at 7.5 years of education, and given that the mean of OECD countries in 1990 was 8.4 years, this is interpreted by the authors as implying that "the average OECD country is on the downward sloping segment of the education growth profile". This analysis suggests that education is positively and significantly related to growth only for countries with the lowest levels of education.

Addressing this puzzle, a number of studies differentiate between primary, secondary and tertiary stages of education revealing that the impacts of increases in these vary according to the level of a country's development (Sianesi and Van Reenen, 2003). In particular, while primary and secondary skills appear to be related to growth in the poorest and intermediate developing countries respectively, it is tertiary skills that are important for growth in OECD countries (see, for example, Gemmell, 1996).

Aghion et al. (2006) find a pattern consistent with this even within a sample of 19 OECD countries, where tertiary education appears to be more important in countries that are more technologically advanced. Theoretically, the authors show that the contribution of human capital to growth can be separated into a level effect and a composition effect. If the composition of human capital is held constant, an increase in its aggregate level is always growth-enhancing. However, holding its level constant, the growth-enhancing properties of human capital depend on both its composition and the distance to the "technological frontier". Empirically, they find that the growth-enhancing impact of skilled labour (those with tertiary education) increases with a country's proximity to the frontier (where proximity is measured by the ratio between the total factor productivity in the country and the corresponding variable in the United States). This paper uses panel data and instrumental variables to address concerns that reverse causality drives the results.

Pre-school education does not tend to feature in the macro literature, though there are several experimental or quasi-experimental studies in the micro literature that have evaluated the impacts of pre-school programmes – in particular those aimed at children from disadvantaged backgrounds – on individual labour market and social outcomes (for a review, see Duncan and Magnuson, 2013). In a key paper in this literature, Cunha and Heckman (2007) highlight how skill building and investments from family, pre-schools, schools and other agents are interactive, and that skills developed in early stages boost the development of skills in later stages and increase the productivity benefits of these.[3]

3.2 Quality of Education

Another issue with using quantity-based measures of education, such as years of schooling, is the implicit assumption that an additional year of schooling delivers the same increase in knowledge and skills regardless of the education system. Issues of differing quality remain even in studies that take into account the stages of education (for example, via enrolments or spending) as outlined in the previous section. Moreover, volume-based measures based on the schooling system ignore variation in non-school factors that affect human capital, including the influence of family or cultural factors.

Hanushek and Woessmann (2015) summarise a series of their papers in which they emphasise the positive effect of the quality of education on growth. They argue that measurement issues in the previous

[3] Gibbons and McNally (2013) summarise evidence on the causal effects of resources on student outcomes across school phases.

literature which employed quantity measures of human capital such as years in schooling, or even attainment of different levels of education, have obscured the underlying relationship between education and growth. Their focus is on the cognitive skills of the population, or "knowledge capital", measured using international student achievement tests over the decades since the 1960s[4] (and adjusted to make them comparable). They find that this significantly improves the ability to explain differences in growth rates.

The authors' core growth regressions are estimated using data from fifty countries over the period 1960-2000. The dependent variable is the average annual growth rate over this period, and the cognitive skills measure is the average of all observed mathematics and science scores between 1964 and 2003. They find a strong relationship between cognitive skills and economic growth: the main result is that a one standard deviation increase in student attainment (equivalent to the difference between the average Mexican student and the OECD average) is associated with a 1.7-2 percentage point uplift to annual growth rates. The model with student attainment explains around three-quarters of the variance in growth rates, as compared to the model, including only initial years of schooling (which explains only one-quarter of the variance). Moreover, the coefficient on cognitive skills is unchanged when years of schooling are also included in the model. In such a model, years of schooling itself has no significance, which the authors interpret as suggesting that "investing in further schooling without ensuring improvements in cognitive skills does not lead to economic returns."[5]

Hanushek and Woessmann (2015) show that these estimates are broadly robust to a range of

[4] The main measure of cognitive skills in Hanushek and Woessman (2015) is based on standardized mathematics and science scores from international student achievement tests in which countries participated. These include the OECD's Programme for International Student Assessment (PISA), the Trends in International Mathematics and Science Study (TIMSS), and their predecessors.

[5] Breton (2011, 2015) argues that due to lags between the attainment of a particular cohort and this being a proxy of a nation's human capital, the measures of schooling attainment and cognitive skills employed by Hanushek and Woessman are incomparable. He adjusts for this issue of vintages, and includes the financial stock of human capital (monetary investment) per adult in his analysis. His analysis confirms the Hanushek and Woessman finding that test scores matter for growth, and also finds that measures of investment can explain growth rates (in fact, the variation explained by the two methods is similar once private tutoring is taken into account). However, in contrast to Hanushek and Woessman, he finds that increases in average years of schooling do matter.

alternative specifications, estimation on subsets of countries, time periods and use of alternative measures of cognitive skills. Acknowledging the limitations of cross-country growth regressions, the authors also conduct focused analyses to provide evidence countering opposing explanations based on omitted variable bias, reverse causality, institutions and cultural factors.

While their main focus is on explaining variation in growth rates, the authors also show that knowledge capital helps explain variation in GDP per capita levels in a development accounting exercise. Specifically, they show that while 24 per cent of the variation in cross-country GDP per capita is attributable to differences in school attainment; the share attributable to total human capital rises to around forty per cent when cognitive skills are considered.

Hanushek and Woessmann (2015) also set out how results vary when considering separate subsamples of countries. The effect of cognitive skills on growth is higher for non-OECD countries, and that this is not only driven by the “East Asian Tigers” which increased human capital and grew rapidly over the period 1960-2000. The authors also consider how the share of students reaching basic literacy, versus the share of top performers affects growth. They show that basic skills appear to have similar effects across all countries, but that higher skills appear to be more important in poorer countries, which they argue supports the idea of technological diffusion (Nelson and Phelps, 1966). But they also show that there is a positive and significant interaction between the shares of students in both categories suggesting that “to be able to implement innovation and imitation strategies developed by scientists, a country needs a workforce with at least basic skills”.

Some studies have also considered the links between non-cognitive skills and economic growth. Balart et al. (2018) highlight the fact that performance on cognitive tests (as set out in Hanushek and Woessmann, 2015) is not only the result of cognitive ability but also is influenced by non-cognitive skills.[6] Moreover, the types of noncognitive skills that are important for test scores also tend to be important for individual productivity and other social outcomes (see, for example, Heckman et al., 2013).

[6] Other papers that link noncognitive skills with economic outcomes include Falk et al. (2018); and Hübner and Vannoorenberghe (2015) who include measures of patience in a development accounting framework.

They suggest, therefore, that noncognitive skills could be an omitted variable in the relationships between cognitive skills and growth. The authors decompose performance in international test scores – specifically PISA scores - into two components. Starting performance in these tests is assumed to be related to cognitive abilities, and the decline in performance during the test is assumed to be related to noncognitive skills such as motivation and ambition (it is acknowledged that it is empirically difficult to entirely separate cognitive and noncognitive skills, but evidence to support these assumptions is provided). The authors then include both components in Hanushek and Woessman type growth regressions and show that both have a positive and significant association with economic growth of similar magnitude. Moreover, the coefficient on cognitive skills is around 40 per cent smaller when non-cognitive skills are included in the regressions. The authors also explore the use of cultural measures (Guiso et al., 2006) as an instrument for noncognitive skills at the national level to try to get at more causal relationships between noncognitive skills and economic growth.

3.3 Types of education

Generally, the macro literature has focused on human capital investments that are made in the education system, rather than in the workplace. There has been rather less focus on the role of training in economic growth though there are several firm-level studies that explore these issues. Some relevant studies are discussed in Section 6

Another important distinction is between the general human capital of the workforce and that of entrepreneurs or managers. Thanks to the development of new data that systematically measure management practices – in particular, the World Management Survey (Bloom and Van Reenen, 2007), there is now much greater understanding about firm-level relationships between management practices and productivity (Bloom et al., 2016), and also on the relationships between worker and manager skills and management practices (Bender et al., 2018; Feng and Valero, 2020). Section 7 considers the evidence the relationships between workforce education and other determinants of growth, including management practices.

Gennaioli et al. (2013) explore the relationship between human capital and development using data on subnational regions. The authors develop a model describing the channels through which human capital influences growth which they call the “Lucas-Lucas” model because it incorporates both the allocation of talent between entrepreneurship and work (Lucas, 1978) and human capital externalities (Lucas, 1988). In this model, the human capital of the workforce is a standard input in the neoclassical production function, but the human capital of manager influences productivity independently. The model also incorporates the mobility of labour across regions within a country, so has spatial elements. In a development accounting framework with country fixed effects and geographic, cultural and institutional variables at the region level, the authors find that educational attainment accounts for a large share of regional income differences. They then combine firm-level production function estimation with calibration to show that worker education, manager education and externalities all contribute to productivity. They conclude that focusing on workers alone can underestimate the returns to education.

4 Towards Causal Relationships?

As previously discussed, there are several sources of endogeneity in macro growth regressions. First, there is an issue of reverse causality – as an economy grows, the demand for education grows, both from individuals themselves and from industry requiring a more highly skilled workforce as countries become more developed. In practice, both the supply side and demand side are likely to be important forces (Sianesi and Van Reenen, 2003). Second, omitted variables such as institutions or other growth-enhancing policies, are likely to affect both human capital accumulation and growth, together with other standard growth regression variables such as investment. Third, there are issues of measurement error in cross country studies driven by variation in data quality (for example, between advanced and developing countries). Subnational or firm-level analyses and exploitation of natural experiments in education expansion or reform can go some way towards addressing these concerns.

4.1 The role of institutions

The relationships between human capital, institutions and growth are debated in the literature. Hall and Jones (1999) consider that the fundamental causes of differences in economic performance between countries relate to institutions and government policies, which they term “social infrastructure”. This can impact on growth via the proximate sources of input – physical and human capital accumulation, and can also have a direct impact through TFP. According to Hall and Jones (1999), “A social infrastructure favourable to high levels of output per worker provides an environment that supports productive activities and encourages capital accumulation, skill acquisition, invention, and technology transfer”.

In a series of papers, Acemoglu et al. (2001, 2002, 2012, 2019) and Acemoglu et al. (2005b) have argued that institutions provide the fundamental building blocks of growth and development. These papers use instrumental variable strategies for institutions (in particular, those relating to strong property rights) based on colonial history to address concerns about the endogenous development of institutions.

However, others have claimed that human capital is the basic source of growth, and the driver of democracy and improved institutions (see, for example, Glaeser et al., 2004). The basic argument is that colonists brought with them both human capital and institutions, and that human capital led to improved institutions and economic growth. The relationship between education and institutions is contested by Acemoglu et al. (2005a) who show that the effects found in the cross-section of countries are not robust to including country fixed effects and exploiting within-country variation. And on the role of human capital in growth regressions, Acemoglu et al. (2014) argue that specifications at the national (or subnational) level that treat human capital as exogenous overstate its impact on growth. Once historical determinants of institutions and human capital are controlled for, or when these are both treated as endogenous, the estimates of the effect of human capital on long-run development decline significantly. In contrast, the impacts of institutions are robust to the inclusion of human capital and when historical determinants of education are directly controlled for. This evidence provides support for the view that institutions are the fundamental cause of long-run development, working not only through physical capital and TFP but also through human capital.

Noting that these studies have tended to use attainment based measures of human capital, Hanushek and Woessmann (2015) show that their measure of cognitive skills maintains a positive and significant coefficient in growth regressions that include two common measures of institutions (openness to trade and the strength of property rights). However, the coefficient is smaller in magnitude than in specifications that exclude institutions (the impact of a one standard deviation rise in cognitive skills being around 1.3 percentage points versus closer to 2 in their core regressions). This is interpreted as a lower bound of the effect of cognitive skills since institutional effects will capture the effects of cognitive skills in improving institutions themselves. The authors also show that there are positive interaction terms between cognitive skills and institutions.

Overall, the literature that has explored these issues has found that both human capital and institutions affect long-term growth, are endogenous to development, and are correlated with each other. Whether or not human capital is a fundamental or proximate source of growth, there is little doubt over its importance for growth and development as an input into the production function.

4.2 Subnational growth regressions

One way to address concerns about unobservables or difficult to measure features at the country level is to analyse the relationships between human capital and growth at a more granular level, so that country fixed effects can be absorbed (though this comes at the cost of capturing spillovers that might occur between regions). In a development accounting framework, Gennaioli et al. (2013) show that regional years of schooling is important for explaining differences in regional GDP per capita in a cross-section of regions across 110 countries. The authors also find that the human capital of entrepreneurs increases output at the firm and regional levels. The within-country comparisons in this paper allow the authors to control for unobservable factors varying at the country-level, such as national institutions, national culture and national language. In addition, a number of region-level institutional and cultural variables are controlled for.

In the regional regressions, average years of education emerges as the most important predictor of regional economic performance, and regional institutions have little explanatory power. Given that human capital in a region may be endogenous because of migration (more skilled workers might move to more productive regions), the authors also estimate firm-level production functions. They find that entrepreneurs' and managers' human capital plays a particularly important role in explaining differences in firms' productivity, and they also find that regional human capital has a positive and significant coefficient supporting the presence of human capital externalities.

However, in a critique of the regional regressions, Acemoglu et al. (2014) argue that country fixed effects are not sufficient to eliminate omitted variable biases, and that the measure of institutions used by Gennaioli et al. (2013) miss meaningful subnational variation in institutional quality. Moreover, they show that when differences in average years of schooling are treated as endogenous and instrumented with Protestant missionary activity in the early twentieth century, the coefficient on human capital becomes smaller in magnitude and significance.

In a subsequent paper that focuses on trying to understand convergence in GDP per capita between subnational regions in the same country, Gennaioli et al. (2014) build their regional data into a time series and estimate Barro style growth regressions. They find a positive and significant coefficient on years of education, but this is dependent on the specification (in particular, the coefficient is significant in regressions controlling for geographic features or region fixed effects, but not when additional controls such as life expectancy, investment-to-GDP and fertility are included).

Ciccone and Papaioannou (2009) help to shed light on the mechanism through which human capital affects economic performance by employing sector-level data within countries. Specifically, they combine data on value-added and employment at the sector level for 28 manufacturing industries across 66 countries with industry-level human capital intensity measures (based on the United States as a benchmark). Their regressions, therefore, analyse the link between initial education levels in a country and sectoral growth and how these differ for higher versus lower-skill sectors. Industry and country-level controls and fixed effects are included in the regressions, and this helps to address a number of endogeneity concerns. The key finding is that value-added and employment growth in human capital intensive industries was significantly faster in countries with higher initial levels of schooling, and these results are robust to including numerous controls and using alternative measures of education. Such results are consistent with the endogenous growth models where human capital accelerates innovation and adoption of new technologies and production processes. The benchmark measure of country-level human capital in this paper is average years of schooling of the population, but in sensitivity analysis, these authors use proxies of human capital that are based on the share of the population with a completed secondary education and the Hanushek and Kimko (2000) indicator based on test scores.

Focusing on the United States, Aghion et al. (2009) analyse the relationship between state-level education funding and growth using political instruments for different types of education spending. The authors find support for the hypothesis that some investments in education raise growth. They find positive growth effects of exogenous shocks to investments in four-year college education for all states, but they do not find that exogenous shocks to investment in two-year college education increase growth. Exogenous shocks to research-type education have positive growth effects only in states fairly close to the technological frontier. In part, this is because research-type investment shocks induce the beneficiaries of such education to migrate to close-to-the frontier states from far-from-the-frontier states. They show that innovation is a very plausible channel for the growth effects of research and four-year college type education: exogenous investments in both types of education increase patenting of inventions.

While studies at the macro country or region level can seek to capture both the individual and wider societal returns to education, a series of studies in the micro literature have sought to obtain causal estimates of human capital externalities directly - generally by considering the extent to which average education levels in the relevant subnational geographic area (often a city) relates to individual's wages, over and above their education (some studies have also done this with firms – see discussion on Moretti (2004b) below). The first paper of this type was Rauch (1993), which considers differences in average schooling across cities in the United States, and suggests that human capital externalities can be in the order of 3-5%. But there are issues of endogeneity in this analysis, higher incomes could cause higher schooling, and cities with higher schooling might have higher wages for a variety of other reasons. Acemoglu and Angrist (2000) use an instrumental variables strategy to estimate the effect of the average schooling level in an individual's state. This strategy exploits differences in compulsory attendance laws and child labour laws across U.S. states between 1920 and 1960. Their IV regressions find that externalities are around 1-2%, and significantly smaller than those implied in the basic OLS specifications. Moretti (2004a) has also provided causal evidence of (city-level) human capital spillovers in wages, using two strategies to instrument for the city level supply of college graduates.[7] The author finds that spillovers are felt by individuals of all education levels, but are higher for less-educated groups. Glaeser and Lu (2018) also employ an IV strategy for city-level education to estimate human capital externalities in China. Winters (2014) considers the externalities from STEM and non-STEM graduates on the wages of other workers in the same metropolitan area within the United States, finding that while both groups create positive wage externalities, these are larger for STEM graduates.

4.3 Lessons from economic history

The literature on human capital and growth outlined above has been mainly focused on the post-World War II period. In contrast, the literature on the transition from stagnation to growth in the context of the industrial revolution (for an overview see Galor, 2011) has, in general, concluded that human capital played a minor role.

However, as noted by Crafts (1996), "It is clear that British capabilities for the transfer and improvement of technology were strong and improving during the first industrial revolution, and no doubt was central to the (otherwise surprising) steady acceleration in TFP growth. This is not, however, captured by conventional measures of schooling, nor does it necessarily translate into a rapid increase in skills of the average production worker". The author suggests that "a more sensitive approach to measurement. . . is highly desirable".

Several papers focused on earlier periods have developed more sophisticated measures of education and exploited natural experiments arising from interesting historical episodes in particular countries. Squicciarini and Voigtländer (2015) differentiate between average worker skills (literacy/schooling) and upper tail knowledge (as proxied by city-level subscriptions to the Encyclopédie) in mid-18th century France and show that the initial level of upper tail knowledge appears to drive city growth by raising productivity in modern, innovative industries. Initial literacy levels – a measure of the

[7] The first is based on lagged city demographics and the second is based on the presence of land grant colleges.

skills of the average worker - on the other hand, are associated with development in the cross-section, but they do not predict growth. This analysis supports the importance of “density in the upper tail” (Mokyr, 2005) and the assertion that “the Industrial Revolution was carried not by the skills of the average or modal worker, but by the ingenuity and technical ability of a minority” (Mokyr and Voth, 2009).

Analyses based on Germany in the context of religious and institutional change provide further evidence supporting the link between human capital and growth. Cantoni and Yuchtman (2014) argue that medieval universities in 14th century Germany played a causal role in the commercial revolution (using distance from universities following the Papal Schism, an exogenous event which led to the founding of new universities in Germany). In particular, the authors argue that the new universities increased the stock of human capital which in turn led to the development of markets in medieval and early modern Germany. They highlight legal education as being a key channel. Becker and Woessmann (2009) use county-level data from late- 19th century Prussia to provide evidence to suggest that Protestant economies prospered because instruction in reading the Bible generated the human capital crucial to economic prosperity. Their findings are consistent with Protestants’ higher literacy accounting for most of the gap in economic prosperity. In an even earlier setting, Germany in the 1500s, Dittmar and Meisenzahl (2020) study the effects of new laws in German cities that led to greater public goods provision - including education - as the Protestant Reformation interacted with local politics. Cities that adopted the laws began subsequently to produce and attract human capital differentially and to grow faster. Using plague shocks as a source of exogenous variation in public goods institutions, the authors find support for a causal interpretation of the relationship between legal change, human capital, and growth.

Valencia Caicedo (2019) highlights the persistence of the effects of educational interventions in the context of Jesuit missions in he 1600s in South America. He finds that areas which had a former Jesuit presence had higher educational attainment at the time, and still have higher attainment and incomes today. The author provides evidence that the mechanism at work is consistent with theories of human capital accumulation, industrial specialisation and technology adoption.

5 Human capital inequalities and growth

5.1 Educational inequalities and growth

The empirical macro literature has found that income inequality is generally harmful to the pace and sustainability of economic growth (see for example Persson and Tabellini, 1994; Easterly, 2007; Halter et al., 2014; Berg et al., 2018). In a review of the literature, Galor (2011) explains that inequality may adversely affect macroeconomic activity and economic development in the short-run. Due to intergenerational transfers and their effect on the persistence of inequality, it may generate a detrimental effect on economic development in the long run as well. For this reason, basic education may be important for growth even in more industrialised economies.

In many studies, inequalities in education drive the relationships, but there is a separate literature that considers the impact of educational inequality on growth directly (Blanden and McNally, 2015). Castelló and Doménech (2002) consider educational inequality directly using data across 108 countries between 1960-2000 and show that inequality in education, as measured by the Gini coefficient in the years of schooling has a negative relationship with economic growth. They conclude that educational inequality might be more important than income inequality for economic growth, though the two are closely related.

A key driver of human capital inequality is credit market imperfections which lead to suboptimal investment in human capital amongst the credit constrained. Deininger and Squire (1998) find that initial inequality of assets has a significant adverse effect on education and economic growth and that credit constraints have a larger effect on the investment decisions of individuals with lower income. Such issues apply even in cases where education is publicly provided. Parental investments in the home matter and material and educational disadvantage can prevent parents from choosing the best schooling environment for their children, because of unequal investment opportunities.

A number of studies also emphasise demographics as another channel, particularly in the case of developing countries. Castelló-Climent and Doménech (2008) focus on how human capital inequality can dampen growth by reducing life expectancy and investment in education, while Castelló-Climent (2010) shows rising human capital inequality reduced GDP per capita growth rates in developing countries over the period 1965–2005, and show that life expectancy and fertility channels seem to play a prominent role.

5.2 The allocation of educational resources and talent

In general, the macro regressions investigating the relationship between education and economic growth have given little consideration to how educational resources are allocated. An early study that considered such issues is Murphy et al. (1991). Focusing on countries with a large student population, they find some evidence that the relative importance of engineering in education (as captured by the ratio of college enrolments in engineering to total college enrolments) has a positive impact on growth, while the relative importance of legal studies has a negative effect.

Judson (1998) evaluates the efficiency of the allocation of educational spending between primary, secondary and tertiary education chosen by several countries over the period 1970 to 1990. The basis is a micro theoretical model of the returns to education, where efficiency is defined as the ratio of the achieved rate of return to the maximum possible rate of return the country could obtain given its actual overall education budget and actual relative costs for each level of education. Using UNESCO data on educational enrolments and spending, she finds that the correlation between human capital accumulation and GDP growth is not significant in countries with poor allocations but is significant and positive in countries with better allocations.

A key insight from the recent growth literature has been that a misallocation of factors of production at the micro level due to various frictions, can result in lower TFP at the macro-level (for an overview, see Restuccia and Rogerson, 2017). With respect to human capital, misallocation can lead to a welfare loss if it prevents talented individuals from being in jobs where their economic contribution can be fully realised. In Hsieh et al. (2019), the misallocation of talent results from barriers to entry into certain occupations by distinct demographic groups. They estimate the impact of the misallocation of talent on growth in the United States using a Roy (1951) model of occupational choice where frictions prevent the optimal accumulation of human capital amongst white women, black men and black women, and also their occupational choices. They estimate that 20-40% of growth in aggregate output per worker in the US (over 1960-2010) can be explained through an improved allocation of talent.

Acemoglu et al. (2018) consider the misallocation of skilled labour in the context of R&D activity and heterogeneous firms. They extend the endogenous growth model to include endogenous exit and reallocation of firms. The basic argument is that too high a share of skilled workers will be employed in firm operations activities, especially in “low-type” incumbents, rather than R&D in more innovative “high-type” firms and this causes a drag on growth.

6. Human capital and the performance of firms

Following improvements in firm-level data availability over the past two decades, an extensive literature on the importance of human capital of workers and managers for organizational performance has emerged. Much of this work has been driven by the desire to explain the productivity differentials that exist between firms, even within the same country, region and sector (Syverson, 2011).

6.1 Total workforce human capital and productivity

Early studies at the firm level used survey data including information on human capital, merged with firm performance data. Using this type of approach, Bartel (1989) finds evidence that returns to training investments increase productivity by 16 percent. In a follow-up study using longitudinal data on manufacturing firms, Bartel (1994) found that lagged training investments rather than current training yield positive effects on productivity. Black and Lynch (1996) highlight issues with previous studies, for example the low survey response rates and the fact that the surveys involved were at the establishment rather than firm-level (while performance data was available at the firm level). They analyse an establishment-level survey that contains data on average education levels and training activities, establishment performance and workplace practices which enables them to estimate production functions including human capital variables. In particular the authors find that the average educational level of an establishment is positively and significantly associated with productivity in both manufacturing and non-manufacturing sectors. The results for training are less clear overall, though certain aspects of training programmes appear to have positive effects.

More recent work at the firm level has exploited matched employer-employee datasets, which allow individual workers to be tracked across plants or firms over time. A clear benefit of these richer data is that they allow for more detailed measures of human capital in firms – differentiating between education, experience and skills of workers, and also a consideration of the distribution of skills within firms.

Haltiwanger et al. (1999) was the first large-scale study of this type using longitudinal matched employer-employee microdata from the United States. The authors analyse the relationship between labour productivity and the composition of the firm's workforce as measured by observable worker characteristics. To do this, they aggregate individual worker data into summary measures for each firm, such as the share of workers with low, medium, and high amounts of education (where these categories roughly correspond to less than high school, high-school graduates and those with some college, and college graduates). The data relate to the population of firms in the State of Maryland between 1985 and 1997. Controlling for year and industry fixed effects, the authors find a positive and significant relationship between the share of high education employees in the firm and sales per employee – in levels. However, there is no relationship between workforce education and productivity in a differenced specification. The authors argue that while this might be due to timing issues or measurement error, it might also be that high productivity businesses consistently have the best workers; and low productivity businesses the least-educated workers.

Subsequent papers have created more sophisticated measures of individual-level human capital for inclusion in firm-level production function estimations. Abowd et al. (2005) set out early evidence from these types of datasets. They exploit measures of human capital that have emerged from methodologies in Abowd et al. (1999) and Abowd et al. (2003) which can be estimated when data on the universe of all firms and all workers are available. Specifically, a measure of an individual's human capital can be retrieved from wage regressions which include a worker specific fixed effect, time-varying observable characteristics and firm fixed effects. An individual's human capital at time t can therefore be thought of as a time-invariant component plus the experience component. Firm-level estimates of human capital are then constructed based on kernel density estimates of the within-firm distribution of human capital.

The authors find that there is a large variation in human capital both within and across industries and go on to relate this to productivity controlling for other relevant factors such as capital intensity. They find that firms with a fraction of workers above the economy-wide median human capital level are much more productive, and this relationship holds for both the person-effect measure and the experience component. In addition, they find that the fraction of workers at the tails of the distribution matters, suggesting that the dispersion of human capital is important for performance. Several studies use matched data from Scandinavian countries to relate human capital to firm productivity. For example, Ilmakunnas et al. (2004)) use Finnish matched worker–plant data to show that productivity is increasing in workers' education as well as age, and Fox and Smeets (2011) use matched employer-employee records from Denmark to control for worker education, gender, experience, and industry tenure in production function estimation finding that these measures of labour quality have significant coefficients in the production function.

Matched employer-employee data have also been employed to estimate human capital externalities. Using data on firms and workers in the United States, Moretti (2004b) estimates production functions that include firm-specific human capital together with city level human capital. He finds that the productivity of plants in cities that experience large increases in the share of college graduates rises more than the productivity of similar plants in cities that experience small increases in the share of college graduates (though these productivity gains are offset by increased labour costs). According to the most robust estimates, a 1 percentage point increase in the city share of college graduates is associated with a 0.5-0.7% increase in output.

While endogeneity concerns are addressed by using panel data and controlling for state-industry-year fixed effects, the influence of time-varying unobserved factors at the city level cannot entirely be ruled out. But in support of the findings reflecting a causal relationship, the author finds that between industries in the same city are stronger when the sectors are “economically close” (defined using a number of methods including technological closeness) and that similar effects are not found for city-level physical capital. So, the results in the paper are unlikely to be explained by general agglomeration effects.

6.2 Managerial human capital and productivity

There is empirical evidence that managers matter for firm performance. In the case of senior leaders, Bertrand and Schoar (2003) show that individual CEOs matter for firm policies and performance, and that some characteristics of CEOs (including whether they have an MBA) are important drivers of these relationships; and Bandiera et al. (2017) find that their CEO behaviour index, which is positively associated with productivity, tends to be higher for CEOs who have an MBA.

Using matched employer-employee data from Portugal, Queiro (2018) finds that firms with more highly educated top-level managers have better growth performance and suggests that the mechanism for this involves educated managers being more likely to introduce new technologies or management practices (consistent with a Nelson and Phelps (1966) view of human capital and technology diffusion). This is supported by the finding that effects are strongest for managers with degrees in science, technology or business courses.

For further discussion about management practices more generally (as distinct from the human capital of managers), and their relationship with human capital, see section 7.

6.3 Training and firm productivity

Traditionally, the macro literature has tended to ignore the role of training in economic growth (Sianesi and Van Reenen, 2003), and the connection between the level of education and subsequent investments in human capital accumulation on the job. Standard human capital theory predicts that individuals with higher levels of education have a stronger incentive and are offered more opportunities to accumulate additional human capital through on-the-job training, and this has been supported in the data. A body of micro literature has focused on estimating the individual wage returns from training and has found that more highly educated individuals also enjoy enhanced work-related training later on in working life (see, for example, Blundell et al., 1999).

There are fewer studies that explicitly link training to firm performance. Dearden et al. (2006) use sector-level data to examine the effects of work-related training on direct measures of productivity and find that a 1 percentage point increase in training is associated with an increase in value-added per hour of about 0.6% and an increase in hourly wages of about 0.3%. Several firm-level studies have also related workforce training to productivity. As discussed, earlier studies include Bartel (1989, 1994), Black and Lynch (1996). On firms in Portugal, Almeida and Carneiro (2009) estimate the rate of return to firm investments in formal on-the-job training, finding that this is substantial, at 8.6%. More recent work includes Konings and Vanormelingen (2015) on Belgian firms. The authors estimate the impact of on the job training on productivity and wages. This paper finds that the effects of training on productivity appear to be larger than the effects on wages (suggesting that firms keep more of the rents associated with training), consistent with theories that explain work-related training by imperfect competition in the labour market (Acemoglu and Pischke, 1999). In general, there is a need to know more about the impacts of training or informal on-the-job learning on productivity.

7. Human capital and the determinants of growth

Over and above its direct impacts on economic growth, human capital can also impact on growth via its indirect impacts on other productive inputs such as physical capital, technology transfer or management practices. A number of studies at various levels of aggregation (country, region, sector or firm) have shown that there are positive relationships between human capital and these other determinants of economic growth. There is also a body of literature that links human capital to innovation outcomes at the individual level.

7.1 Human capital, investment and technology

A number of the macro studies have shown that human capital appears to be associated with significantly larger investments and that in OECD countries the stock of secondary human capital appears particularly important in stimulating investments, while direct growth effects come through the increased tertiary human capital stock and accumulation (Sianesi and Van Reenen, 2003). As discussed in Section 2, the endogenous growth literature emphasises human capital externalities for innovation. According to Romer

(1990); Aghion and Howitt (1992), human capital is an essential input into a research sector which generates innovation. The link between education and the innovation outcomes of individuals is explored in the next subsection. A more general discussion of the links between the research activity carried out in universities, and the economic performance via spillovers is to be found in Section 8.

Nelson and Phelps (1966) focus more on the process of diffusion or technology transfer. They argue that "production management is a function requiring adaptation to change and [...] the more educated a manager is, the quicker will he be to introduce new techniques of production". While the focus here is on production efficiency and technology adoption, these ideas can be applied to other drivers of TFP highlighted in recent research, such as management practices (Bloom and Van Reenen, 2007).

Benhabib and Spiegel (1994) provide empirical support for a Nelson and Phelps (1966) technological diffusion process at the country level. They argue that human capital may encourage the accumulation of physical capital due to complementarities. In particular, the marginal product of physical capital in developing countries may be low, despite its scarcity, due to a lack of complementary factors such as human capital (Lucas, 1990). In the cross-section (for the year 1965), they regress the ratio of gross investment to capital stock on factor stocks: human capital, physical capital, and the labour force, and a number of other covariates. They find a positive and significant relationship between capital investment and human capital, suggesting that human capital is an important feature in attracting physical capital.

In a sector-level analysis, Griffith et al. (2004) relate the growth in R&D, human capital (and trade) to TFP growth. Using country and sector level measures of human capital, they show that both R&D and human capital have positive and statistically significant effects on TFP growth. The authors find that human capital operates through both innovation and technology transfer, with the innovation channel being the more important channel in countries closer to the technological frontier, and technology transfer being more important for those further from it.

A series of papers at the city or firm level have provided support for human capital – technology complementarities using various measures of skill supply. For example, in firm-level analysis, Bresnahan et al. (2002) provide evidence that human capital, information technology and a decentralized organizational structure are complementary; Beaudry et al. (2010) find that cities in the United States with low skill premia (the ratio of skilled to unskilled wages) adopted computers more intensively and Garicano and Heaton (2010) find evidence of complementarity between Information Technology and skilled workers in police departments. More broadly, Caroli and Van Reenen (2001) provide evidence for "skill biased organisational change" (in this context, referring to the decentralisation of production processes). Using panel data on firms from France and the UK, the authors show that firms facing cheaper or more plentiful supply of skilled workers are more likely to be decentralised.

There is also evidence that higher human capital is associated with greater adoption of productivity-enhancing management practices (Bloom and Van Reenen, 2007), which can be thought of as a type of organisational technology.[8] Arguments supporting this are set out in Bloom et al. (2016), where it is also shown that across countries, management practices explain on average around 30% of the gap in total factor productivity with the United States (Bloom et al., 2016). Several experimental studies support a causal interpretation (see, for example, Bloom et al., 2013, 2020). In firm-level analyses that seek to explain the observed variation in management practices, it has been found that workforce education (of both workers and managers) is an important driver (positive and significant associations between human capital and management practices are documented in Bloom and Van Reenen, 2007; Bloom et al., 2014).

To address a number of the endogeneity concerns arising in firm-level correlations between human capital and management practices, Feng and Valero (2020) combine international data on management practices in small and medium-sized manufacturing firms with newly constructed skills measures that are external to the firm. At the plant level, distance to the nearest university provides a measure of the supply of skills, and at the region level, skill premia are calculated using international labour force surveys or administrative data for the countries where this is possible. Estimating "factor

[8] In the sense that management practices reflect something more than managerial ability - though this is clearly an important factor determining the quality of management practices in an organisation.

demand” equations (Brynjolfsson and Milgrom, 2013) this paper finds that firms facing more abundant – and cheaper – skills have both higher human capital (share with a university degree) and higher management scores. These results are interpreted as evidence that human capital is complementary with modern management practices - increasing the marginal benefit or reducing the marginal cost of their adoption.

Bender et al. (2018) link management practices data on German plants to administrative employee earnings records, enabling a richer analysis of worker features than is possible using the surveyed measures of education (generally, plant level college share). Specifically, using longitudinal data on earnings of workers, including their pay at previous or subsequent employers, the authors decompose wages into worker and establishment effects using the AKM approach (Abowd et al., 1999). The worker effects allow for the measurement of the worker skill or ability, together with analysis of the relative quality of different employee subgroups - the authors assume that those in the top quartile of earnings are managers. They find a strong relationship between employee ability - in particular managerial - and management practices, conditioning on firm size and other standard firm covariates, which they also interpret as evidence of there being a complementarity between management practices and skills.[9]

7.2 The education of innovators

Two strands of the literature are particularly relevant in considering the influence of an individual’s education on innovation outcomes. The first are studies that consider the background of inventors based on linking patents data with other records on individuals and the second are studies that examine the factors that determine the likelihood of becoming and succeeding as an entrepreneur. Understanding better the drivers of the small fraction of start-ups that become high growth firms or “gazelles”

[9] Showing that the causality is likely to flow both ways, Bender et al. (2018) also show that plants with higher management scores are more likely to recruit higher ability workers, and are less likely to lay off such workers. Using a similar approach, Cornwell et al. (2019) link WMS data to matched employer-employee data from Brazil. They find that better managed firms recruit higher ability workers, and this is particularly the case with managers. Such firms are also better at retaining higher quality hires, and that they fire more selectively. Lee (2018) analyses data on South Korean manufacturing firms in the years following the Asian financial crisis and links the adoption of “modern” WMS-style management practices (which accelerated in that period as South Korea opened up to foreign firms) to increased demand for technical skills.

(Haltiwanger et al., 2017) is important from a growth perspective. Such firms are considered to be key drivers of job creation and productivity growth and are part of the dynamics of reallocation that characterise growth in advanced economies, but have been in decline in recent years (Decker et al., 2016).

In the first category, a number of papers have studied the relationship between individuals' education and invention, as measured in patenting. Toivanen and Väänänen (2016) consider how the education of individuals influences their propensity to innovate. More specifically, the authors study the causal effect of MSc engineering education on the patenting of Finnish inventors, using distance to the nearest technical university as an instrument for education. They find a positive effect of engineering education on the propensity to patent. Also linking scientific education to innovation, Bianchi and Giorcelli (2019) exploit a change in enrollment requirements in Italian STEM majors that expanded the number of graduates. They find that this led to more innovation in general, but also led some STEM graduates to work in sectors that are not particularly focused on innovation (for example, finance).

Other recent studies consider the origins of inventors more broadly. Bell et al. (2019) examine the factors that determine who becomes an inventor in the United States, focusing on the role of inventive ability versus the environment. Using patents data (linked with tax and education records), they show that children from high-income (top 1%) families are ten times as likely to become inventors as those from below-median income families and these gaps persist even among children with similar maths test scores in early childhood (a strong predictor of future innovation). This finding suggests that the gaps may be driven by differences in the environment rather than abilities to innovate. The authors, therefore, suggest that the welfare costs of distortions in the allocation of talent may be even greater than predicted by models such as Hsieh et al. (2019) since some of the individuals do not become innovators to a lack of exposure could have had high-impact patents. More broadly, the findings in this study suggest that improving opportunities for children from disadvantaged backgrounds could improve not only their labour market outcomes but also economic growth by improving the allocation of talent. Other key papers that consider the relationships between educational, wealth and other influences on becoming an inventor include Akcigit et al. (2017) and Celik (2015) on U.S. data and Aghion et al. (2015) using data on inventors in Finland.

In the entrepreneurship literature, education does appear to be related to positive outcomes. For example, using data on the universe of firms and workers in Portugal, Queiro (2018) finds that firms started by more educated entrepreneurs are larger at entry and exhibit higher growth throughout their life cycle. Education has also been found to be particularly important when combined with other factors suggesting that a more broad notion of human capital might be relevant here. Levine and Rubinstein (2017) consider self-employed individuals in the United States and distinguish between those that are incorporated versus those that are unincorporated. They consider that the incorporated self-employed are closer to what is commonly thought of as productivity-enhancing "entrepreneurs" - engaging in activities that demand stronger non-routine cognitive skills and earning more. Using survey data, they find that individuals who become incorporated self-employed tend to be more educated, and in their teens, tend to score more highly on aptitude tests, have stronger self-esteem, and also engage in more illicit activities than others. In particular, they find that those who are "smart and illicit" have a much greater tendency to become incorporated business owners. Furthermore, amongst incorporated business owners, those with these traits also appear to earn more. The authors conclude that it is high-ability individuals that also break the rules as youths that are especially likely to become successful entrepreneurs.

Backes-Gellner and Moog (2013) also consider how the composition of an individual's human and social capital affects their likelihood of becoming entrepreneurs. Using survey data on students in Germany, they find that it is not individuals with a higher level of human or social capital (based on social contacts of an individual), but rather individuals with a more balanced and combined portfolio of human capital, social capital and experiences that are more disposed than others to become entrepreneurs, as opposed to becoming employees.

Related literature considers the role of immigration of skilled individuals in boosting innovation, in particular in the context of the United States where the relatively open immigration policy historically has helped to attract talent from worldwide, see Bloom et al. (2019) for a discussion of this literature in the context of policies to promote innovation. A series of studies have exploited immigration policy changes to estimate the impacts of skilled immigrants on innovation, including also spillovers (see, for example, Hunt and Gauthier-Loiselle, 2010) who find that a one percentage point increase in the share of immigrant college graduates in the population increases patents per capita by 9 to 18 per cent. Kerr and Kerr (2020) focus on the links between immigration and entrepreneurship, finding that prominent tech clusters display a pronounced share of immigrant entrepreneurs.

8 Universities and the economic performance of firms and regions

When thinking about the relationship between human capital and economic growth, it is natural to consider the role of universities. A striking feature of the last hundred years has been the enormous expansion in the university sector worldwide (Valero and Van Reenen, 2019). In 1900, only about one in a hundred young people in the world were enrolled at universities, but over the Twentieth Century, this rose to about one in five (Schofer and Meyer, 2005).

Universities are producers of highly skilled labour: college graduates and postgraduates. Such graduates and postgraduates are more productive via a direct Neoclassical channel and form key inputs into the research or diffusion process as per the New Growth theories. Furthermore, as locations of R&D activity themselves, universities employ a particular class of highly skilled workers - academics and research staff - who produce innovations via their research activities, and often in collaboration with industry. There is a spatial dimension in this effects: areas characterised by a high share of innovative industries and entrepreneurship, such as Silicon Valley in the United States or the Cambridge cluster in the United Kingdom, surround universities and appear to benefit from agglomeration economies and associated knowledge spillovers.[10] For these reasons, universities tend to be an important feature in national and regional growth policies worldwide.

There is a body of literature that has linked university activity to innovation. The literature on university innovation spillovers stems from Jaffe (1989), who finds evidence of commercial spillovers

[10] For reviews of the literature see Carlino and Kerr (2015) or Henderson (2007).

from university research (to firm patenting or R&D). Several subsequent papers provide evidence of localisation in such spillovers (see, for example, Jaffe et al., 1993; Anselin et al., 1997; Belenzon and Schankerman, 2013). Andrews (2021) exploits the quasi-random allocation of universities to US counties over the period 1839-1954 to estimate their causal impact on patenting. Interestingly, this paper also examines the channels driving these effects, and finds that the largest share of induced patenting came from inventors who migrated into the university counties, rather than from staff or graduates from the new universities. In an analysis of the impacts of the opening of more applied research institutions on patenting, Pfister et al. (2018) employ a difference in difference approach and find that the establishment of "Universities of Applied Sciences" in Switzerland had positive impacts on patenting quantity and quality.

A number of papers link university research activity to more broad measures of economic performance in their surrounding regions: employment, pay, productivity or start-ups. Some of these papers analyse the effects of research spending at universities. Aghion et al. (2009) finds that increases in research investments at universities affect growth and patenting in US states. Kantor and Whalley (2014) employ an instrument for university research spending based on endowment values, and find a positive but small effect on labour income in large urban US counties, with a larger effect for sectors that are technologically closer to nearby universities.

Other papers exploit natural experiments which have arisen due to policy changes. Hausman (2017) exploits variation induced by the Bayh-Dole Act (1980), which gave US universities property rights to innovations and therefore raised incentives to patent. She finds that employment and pay increased in sectors closely tied with university innovative specialisms and that the effects are larger in larger cities. Andersson et al. (2009) exploit the natural experiment of decentralisation of the higher education sector in Sweden and find that output per worker and patenting has been greater in Swedish municipalities where more university researchers are employed, and that the effects are strongly localised.

Linking data on international universities with the regional economic data of Gennaioli et al. (2014) over the period 1950-2010, Valero and Van Reenen (2019) find that increases in the number of universities (measured according to when they are founded) within regions are positively associated with the future growth of GDP per capita. These relationships are robust to controlling for a host of observables together with unobserved regional trends. The authors show that part of the effect of universities on growth is mediated through an increased supply of human capital and greater innovation and that there is also evidence of spillovers between neighbouring regions. Using more contemporary administrative data on firm outcomes and university enrolments in the UK over the period since the 1990s, Valero (2019) finds that local areas that saw high growth in students enrolled in nearby universities have also experienced an increase in start-up activity, particularly in high-tech sectors. Effects appear to be stronger for higher quality, research-intensive institutions, and in areas with higher initial human capital.

Overall, there is compelling evidence that universities have positive economic impacts on their surrounding areas, but that these effects are felt in particular where there are links between university research and the structure of the local industry.

9 Conclusions

Although the role of human capital as a fundamental determinant of growth and development has been debated in the economics literature, its importance as a proximate cause, that is, an essential input in the production function is not generally disputed. This paper has summarized the empirical literature that has sought to explain the relationship between human capital and economic performance of countries, regions and firms, and how this literature has evolved over time as more and better data have become available.

In general, the macro literature has found that empirical relationships appear to become clearer when the notion of human capital is broadened to go beyond educational attainment or “quantity” measures, to incorporate differences in the quality of education. While these analyses have been at the country (with some recent papers at the subnational region level) and using data since the 1960s, recent empirical work has focused more on microdata, often using matched employer-employee data that allow individual workers to be tracked across plants or firms over time. This has provided evidence on the importance of human capital in firm-level productivity and has also allowed researchers to capture evidence of spillovers from the general human capital in the geographical areas in which firms are located. Several papers exploiting natural experiments from episodes in more distant history also support a causal interpretation of the relationship between human capital and economic growth.

There is strong evidence supporting the links between education and the determinants of growth in terms of investment in technology, and in generating innovation itself - the driver of growth in the long-run. Highly skilled individuals are key for the invention of new technologies, and for establishing and managing high performing businesses. More general workforce education improves productivity directly via the Neoclassical channel and enables the diffusion of technologies and productivity-enhancing practices through the economy.

Beyond average education outcomes, the literature on educational inequalities and the misallocation of talent has revealed that there are significant economic gains to be made from improving the opportunities of more disadvantaged groups. Given the evidence on the importance of the early years, such opportunities must be made available early on through high-quality provision from childhood onwards, but improvements in accessibility to high-quality education are required at all levels to achieve an improved allocation of talent to productive activity.

There is still relatively little evidence on the relationships between training, productivity and growth. Training to deliver re-skilling or up-skilling for the existing workforce in light of technology-induced changes in the demand for skills is an area of increasing policy focus in many countries, and this is becoming all the more important given the largescale displacements faced by many due to the COVID-19 economic crisis. The importance of informal learning on the job is also less understood. There is strong potential to learn more on these topics from experimental policymaking, for example, in business support policies, that allows for robust evaluation.

While there have been advances in understanding the nature of human capital spillovers, including estimation of such spillovers in firm productivity, more work is needed to understand the mechanisms that drive these, and the extent to which spillovers operate within and across regions and countries. Moreover, due to technological advances and the rise of remote working, it might be that in the future, spillovers might become less sensitive to geographic boundaries than in the past.

Finally, while the literature has shown that universities, as producers of both human capital and innovation tend to generate positive economic impacts on their surrounding economies, understanding better the precise mechanisms through which these effects occur, and how policies can seek to promote this, is an important area for future research.

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