Education, Innovation, and Growth –

Critical Appraisal and Cliometric Analyses with Implications for Present Economic Policy

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Normann Mueller

aus Groß-Gerau

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Dekan/in:	Professorin Dr.rer.pol. Kerstin Pull
Erstberichterstatter/in:	Professor Dr.rer.pol. Jörg Baten
Zweitberichterstatter/in:	Professor Dr.oec.publ. Dr.h.c.mult. Eberhard Schaich
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[1] DFG = Deutsche Forschungsgemeinschaft.

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1 Introduction

"I do not think we can understand the contemporary world without understanding the events that have given rise to it."

Robert E. Lucas, 2002

1.1 Motivation and general comments

Four independent projects have emerged from my academic research as a doctoral candidate, each of which is documented in detail by one chapter of this thesis. In principle, these research reports are conceptually designed for separate publication. For this reason, within the chapters, I often refer to the respective report as 'essay', 'paper', 'article' or alike. At the time of writing this introduction, one chapter was under review at an economic journal, whereas one was rejected after the first attempt, and two are potentially intended for publication at a later point in time.[2]

All projects are very generally motivated by my interest in the design of education and innovation policy. Both, 'education' and 'innovation' have been recognized as important drivers of long-run economic development since the arrival of endogenous growth models in the late 1980s (e.g. Lucas, 1988; Romer, 1990). Also, they can hardly be treated separately. The overall concept of the dissertation, however, has undergone an evolution in the course of the research process. Starting with the goal of quantifying growth externalities of education, the outcomes of my research demanded recurring accommodation of the research questions. In particular, the ideas for the projects, which constitute chapters 3 through 5 of this thesis,

[2] The exact status will be stated at the beginning of each chapter.

emerged as a consequence of the first project. In this respect, the papers are all somehow related with each other, and, in fact, the ordering of the papers in this thesis reflects the evolution of my personal understanding. Clearly, the findings do not qualify for an assessment of the complete innovation and education policy spectrum; but they are pertinent regarding very specific aspects of these policies. Also, to obtain results with relevance for policy analysis, the analyses have been concentrated on a broad context rather than very specific regions or periods. For instance, case studies would be unsuitable in this respect. Rather, the objective has been to derive predications that are valid in general, i.e. at all times and places. If the results do not permit such generalizing statements, it is said so in the conclusions of the individual chapter; nonetheless, the intention remains.

The analyses in this dissertation - again with the exception of the first chapter - have in common a cliometric focus. That is, they emphasize the quantitative analysis of historical data. Naturally, the latter may not always fulfill the strong requirements of waterproof econometric analyses. Technical issues are thoroughly discussed in each chapter, but frequently, the derived evidence may be too weak to build a strong case upon it. Nevertheless, historical information is valuable and should not entirely be neglected, especially when it comes to analyzing long-run economic development. This view is expressed formidably in the initial quote by Robert E. Lucas (2002). Exploiting these data econometrically can at least give important hints, even though the latter may need further validation. Hence, this thesis is aimed at incorporating them in the efforts of finding answers to current economic issues. Each of the three quantitative projects rests on a database that was either newly constructed or augmented by adding crucial information, or used for the first time in the respective context. Hence, on the one hand, the thesis adds to the cliometric literature by making new data available. On the other hand, by offering theoretical considerations as well as contemplations over the econometric results, it contributes to economic theory in general. All econometric analyses in this dissertation, for the most part count data regression analysis and panel data analysis, have been performed using the StataCorp software package StataSE 10. In general, standard Stata commands were applied. The use of non-typical commands for estimation or testing is indicated either in footnotes or in the notes of the respective regression tables.

Further, the array of topics of the dissertation is wide, touching the fields 'public finance', 'political economy', 'growth theory', 'human capital theory', and 'innovation-driven growth theory'. This broad coverage made it easier to avoid redundancies between the chapters. On the other hand, the provision of a thorough literature review for each of those fields would have gone beyond the scope of this work. Instead of spending much time and space on such an effort, I only provide a justification of each project and a brief overview of the relevant literature at the beginning of each chapter. As an exception, the first chapter contains a much more thorough discussion of the respective literature. Altogether, however, the focus is clearly on the new results.[3]

Finally, the results partly provoke interpretations, which call into question conventionally unchallenged principles. It may seem bold to offer such interpretations as a doctoral student, especially if they are based on the analysis of historical data that are subject to criticism in some respects. Nevertheless, scientific progress depends crucially on attempts of falsification. Hence, I decided to put my interpretation of the findings up for discussion, even though they are controversial. I strongly believe that this is the best I can make of the results. I find it an obligation to take the latter seriously and be courageous in interpreting them rather then neglecting conflicting evidence or hesitating to point to it. Research outcomes may be disproven by future works. But being anxious in light of controversial results would come close to denying scientific progress from the outset.

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[3] Instead of providing a list of references at the end of each chapter, the bibliography is appended at the end of the thesis to avoid duplication and make it more convenient for the reader to find references.

The next section gives a brief overview of the thesis. It puts the individual projects into a common context, sketches the most important outcomes, and documents the evolution of the research concept. A more detailed summary of each project is given by an abstract preceding the respective chapter. Chapter 6 summarizes the implications of my doctoral research for contemporaneous economic policy.

1.2 Content and summary of findings

My doctoral research emanated from the interest in education externalities. It was the original goal to empirically quantify the latter - specifically growth externalities - in order to contribute to the debate on public education subsidies. Thorough contemplation, however, led to the insight of the research question being obsolete altogether. Chapter 2 of the thesis summarizes the relevant literature on education externalities, discusses why the prevailing notion of education externalities is misleading and why empirical quantification attempts are inadequate. Distinguishing between the concepts 'education' and 'teaching' is key to understand the main conclusion of this chapter, according to which growth externalities of education according to Lucas (1988) are likely to be internalized on the labor market. Education is argued to be a private good with well-defined property rights. Individuals may exploit those to receive compensation for their investment in education. Further, distinguishing between 'education' and 'knowledge' leads to the conclusion that growth externalities according to Romer (1990) are not directly related to education, but arise from the knowledge generation process.

These conclusions from chapter 2 are the starting point for chapter 3: If growth externalities of education do not exist and quantification efforts must fail because of this, what do governments use as a guideline to determine the extent of public educational spending? Chapter 3 is specifically interested in ideological aspects of different regime types.

Are democracies ideologically more dedicated to education finance than autocracies? Previous studies have ignored this aspect of regime type influence on public education subsidies. An analysis of worldwide government spending during the interwar period, which controls for the influence of other political drivers of government scope, reveals that in the long run democracies do not seem to put a higher priority on public education. Rather, there are hints that the opposite is the case, possibly because the educational system is a channel through which an autocratic regime may transmit its ideology. On the other hand, the more advanced private systems of education in democracies may simply crowd out the public educational effort in the long run.

Also, chapter 4 is motivated by the outcome of chapter 2: If the education process does not yield growth externalities, but the knowledge generation process does, can those externalities be captured on the national level or does knowledge spill over internationally? Also, what is the exact nature of the knowledge generation process? What are the determinants of innovation? Can anything be done at all to influence knowledge generation and thereby technological process? These questions have been addressed theoretically by many authors. An empirical foundation of the theoretical efforts remains to be delivered, however. Chapter 4 contributes to the exploration of the innovation process on the macro-level. Exploiting a literature-based measure of national innovative success, it finds that actual national economic growth depends less on a country's innovativeness, and more on its ability to adopt technologies, which is in turn given by average human capital and the institutional conditions. The potential for growth, however, is determined by the international technological frontier. Hence, growth externalities according to Romer (1990) precipitate only on an international level. The size of a country's contribution to frontier shifts depends primarily on population size. Also, institutions as measured by constraints on the executive make a significant difference. More constraints on the executive are better for the innovation climate. The human capital stock as measured by average years of schooling, however, does not seem to be relevant for the generation of new knowledge. This finding is at odds with many economist's central tenets. Hence, it makes sense to validate it based on micro-evidence.

Chapter 5 approaches this task by scrutinizing the biographies of historical inventors and testing quantitatively whether their formal level of schooling enhanced their contribution to technological development. Indeed, the results are in line with the findings of chapter 4. Formal schooling is found to be beneficial for innovative success only in very narrow biographical settings. Specifically, it may act as a substitute for financial security and job security. But there is no evidence that it actually enhances an individual’s innovative potential. To explain this finding, it makes sense to think about innovative individuals as characters who strive for creative self-realization and acquire the needed skills informally, if they are deprived of formal schooling.

2 (Mis-)Understanding Education Externalities[4]

This article reviews the current state of research on education externalities. It finds that much of the confusion regarding their magnitude results from conceptual misunderstandings about their nature. The concepts of 'education', 'teaching', and 'knowledge' need to be distinguished for a better understanding. Whereas the consumption of teaching services yields stability externalities on the primary and secondary level, only the production of knowledge may generate growth externalities. There is no reason to believe, however, that the pure accumulation of education has such an effect, too. Education is argued to be a private good with well defined property rights. Individuals should be able to exploit those and provide the production sector with the efficient quantity of human capital. Following this rationale, it is demonstrated that empirical studies, contrasting estimates of private and social returns to education, are unsuitable to substantiate the existence of growth externalities. As a consequence, full subsidization of tertiary programs is called into question.

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[4] An earlier version of this chapter has been submitted to the *Journal of Economic Surveys*. When this footnote was written, it was still being reviewed.

2.1 Introduction

The goal of research on education externalities has been stated by Moretti (2003) to be twofold. "First it should credibly assess the magnitude of spillovers. […] A second goal should be to empirically investigate the mechanisms that give rise to externalities." (p.3). It is not last owed to the failure of research to achieve these goals that international governments follow quite different strategies in terms of public education finance.[5]

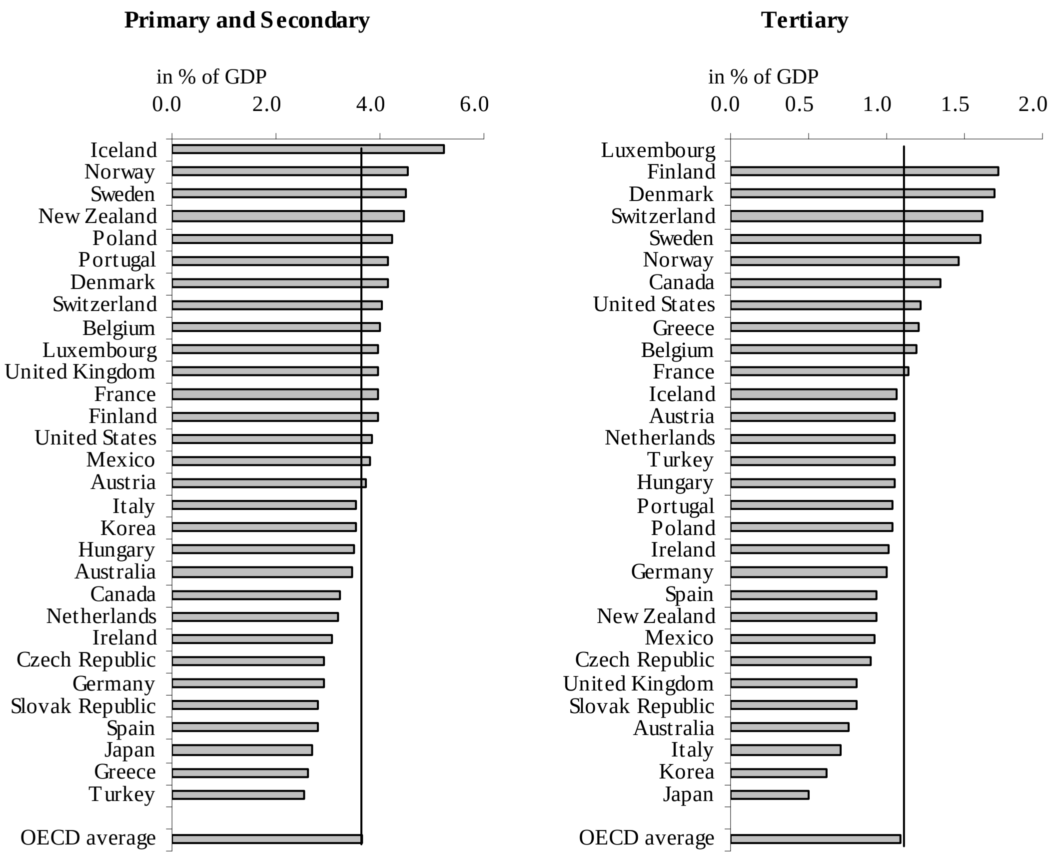

Figure 2.1. Public education expenditures as a share of GDP in OECD countries

Source: OECD (2006).

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[5] The term "education" is used in the introduction for what should more correctly be called "teaching". It will be argued in section 1.2 that the commingling of those two concepts is responsible for some lack of clarity regarding the existence of education externalities.

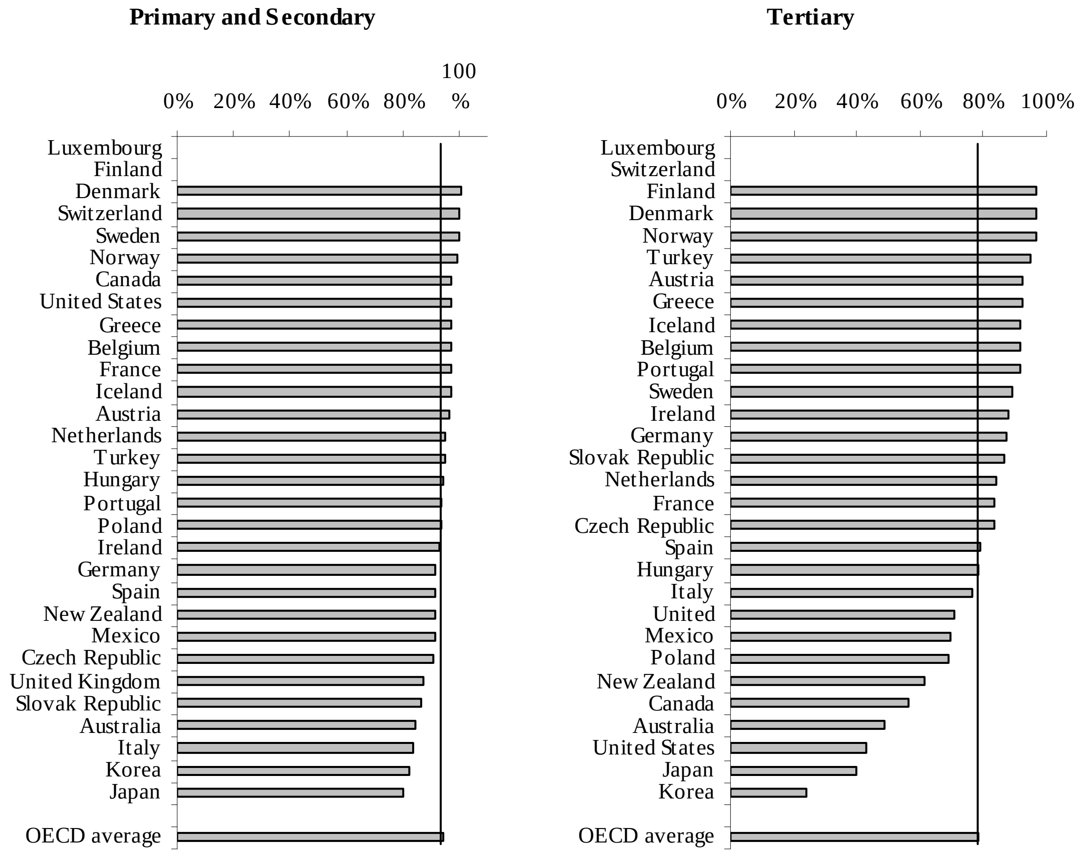

Figure 2.2. Public spending as a share of total spending on education in OECD countries

Source: OECD (2006).

Even though economists have spent some effort in quantifying externalities (Heckman and Klenow, 1997; Krueger and Lindahl, 2001; Gundlach and Woessmann, 2004; Rauch, 1993; Rudd, 2000; Acemoglu and Angrist, 2000; Moretti, 2004; Muravyev, 2006; Ciccone and Peri, 2006), as well as private and social returns to education (see Harmon, Oosterbeek and Walker, 2003; Sianesi and van Reenen, 2003), a mutual consent has not yet been achieved. Consequently, there is no accepted guiding principle pertaining to the optimal scope of public education subsidies. This is less evident in the case of primary and secondary expenditures, but much more visible when it comes to tertiary spending. Figure 2.1 depicts international public expenditures on primary and secondary, respectively tertiary teaching institutions as a share of GDP. Obviously, the variability in the right picture is higher. The coefficient of variation is 18.2 in the case of primary and secondary spending, and 28.5 for tertiary spending. Figure 2.2 shows public spending as a share of total spending on educational institutions across OECD countries. The respective coefficients of variation are 6.1 for primary and secondary spending, and 25.2 for tertiary spending.

In order to contribute to more unanimity in this matter, it appears vital to first of all suspend the ongoing quantification efforts for a moment, back-pedal and sum up what has been achieved so far. Conversations with fellow researchers have convinced me that quite a few different perceptions exist regarding the nature and existence of education externalities, and that everyone needs to be on the same page before research is continued. Not least, my own persistent misunderstandings encouraged me to make an attempt of bringing more light to the fogginess of the externality debate.

Consequently, this essay critically evaluates the current state of research on education externalities since their mention by Gary Becker (1964). No other contribution could be found, which narrows down previous work in a comparably concise manner and directs attention to the relevant questions, such as: Have we managed to come closer to the goal of our research as stated by Moretti (2003)? Do we actually understand the mechanisms that give rise to externalities? And if not, are we actually going where we ought to be going? Are we still on the right track with our efforts to assess the magnitude of presumed externalities? Are our methods suitable after all, or are we possibly in danger of spending much time and effort on obsolete analyses? However, the article is more than just a literature review. It diverges from long-lived thinking in some crucial points. In specific, it suggests that education is a private good with well defined property rights. Also, it emphasizes facts that seem to be obvious and are yet largely neglected. More precisely, for the case of tertiary education it is outlined that not the production of education per se, but its use in certain production processes, such as idea generation, is what yields externalities.

The essay has the following structure. Section 2.2 treats the basic concepts of teaching, education, human capital, and knowledge. It argues that education exhibits the properties of a private good, and it straightens up the common understanding of the educational production process. Subsequently, section 2.3 briefly repeats the essence of the externalities concept and reconsiders the role of potential externalities as the prime, if not the only, reason for a government to get involved with education finance. Section 2.4 looks at potential externalities of education in greater detail. First, it focuses on their nature. The effect of education – more precisely, tertiary education - on economic growth is found to be the most controversial externality. Then, section 2.4 contains a summary of the most relevant empirical contributions aimed at assessing the magnitude of those growth externalities. Eventually, a discussion is provided on whether the latter can be internalized on the labor market (section 2.5). It is pointed out that the concept of growth externalities may well be overemphasized in the context of education. On the contrary, idea generation activities may indeed yield uncompensated social benefits. Section 2.6 concludes the paper and makes suggestions for further research.

2.2 Clarification of concepts

There has been much contemplation, and also confusion, regarding the character of the good 'education'. Blaug (1970, p.16-22) argues that it may have consumption as well as investment characteristics. Also, there is no agreement as to whether education is a private, public or merit good (e.g. Rosen, 2005, p.70-71). If undergraduate microeconomic teaching is accepted to reflect the current doctrine, the least common denominator is that education is not publicly supported because of its potential public character, but because of its potential externalities (Pyndick and Rubinfeld, 2005, p.666).

From my perspective, the challenge to get at the character of the good 'education' primarily arises from the commingling of two different concepts. On the one hand, one could think of it as the educational programs provided by public and private educational institutions. I choose to refer to those as *teaching* or *teaching services.* On the other hand, the term 'education' might refer to the knowledge and skills inherent in a person after completing such a program of teaching. This is what will actually be called *education* henceforth. In my understanding, the latter is equivalent to the term human capital as coined by Mincer (1958), Schultz (1960) and Becker (1964). Both terms will be used interchangeably throughout the remainder of this work. Of course, there are broader definitions of human capital. Usually the concept is conceived to include factors such as health and life expectancy. However, for most macroeconomic applications involving the concept of human capital, such as growth regressions or growth accounting exercises, it seems more practicable to think of it solely in terms of education. Health and life expectancy can be argued to be reflected in the size of the labor force.

Teaching is a service offered for consumption to individuals who decide to get educated. If it is publicly provided and financed, and every individual is entitled to participate in the programs, it holds the character of a public good, being non-excludable and non-rival. In the case of primary or secondary education, for instance, excludability does obviously not apply, because schooling is mandatory. Higher education, however, is partly excludable given the existence of certain entrance requirements, making it at best a club good. One might argue that teaching is a rival good because a higher demand for teaching services increases class size and impairs the quality of the provided service. In the case of university programs, however, this argument is invalid, because the quality of a lecture does not depend much on the degree of teacher-student interactivity. I am inclined to reject this view for primary and secondary teaching as well. Empirical research suggests that class size is not an important determinant of how much a single student is able to take away from a course (e.g. Hoxby, 2000). Moreover, service providers are likely to offer the service to a fixed class size. Of course, in the case of a public provider, the administration may well have an incentive to reduce the number of teachers per student to a minimum. So, on average, the number of students in a class may tend to exceed the optimal size. Nevertheless, a threshold level probably exists, beyond which the loss of teaching efficiency is too high to be tolerable even for a public provider. Hence, usually teaching is a public good, if it is publicly provided. Because non-excludability is not guaranteed in the case of private provision, teaching turns into a club good in the latter case.

In order to delimit teaching from education, it is practicable to treat the primary as one of multiple input factors to the process of personal education creation carried out by each individual student. Apart from this fairly homogenous production factor, the student's time and effort are additional inputs of the individual education production process. Time is an investment that may be evaluated in terms of foregone income, which could have been earned on the labor market instead (see Schultz, 1960). Whether the usage of teaching services reflects consumption or investment is not of importance for the present analyses. Certainly, Blaug (1970) is right in stating that it may have both characteristics. Anyway, education is the outcome of this process. Contrary to what is widely believed (e.g. Rauch, 1993, p.380), it is a private good, for it can obviously not be shared and is perfectly rival and excludable. Every individual exclusively owns the property rights and has the ability to sell his/her personal human capital on the labor market. This is regardless of whether the teaching input was publicly or privately provided. Completing the production process analogy, the student may be viewed as the education producer. His/her *capability* is comparable to the production technology or a productivity parameter; the higher individual capability, the more efficient the use of a given amount of input factors. Thus, unlike the public good *teaching*, which is used as input, the final private good *education* (i.e. human capital) is of rather heterogeneous quality.[6]

On a macro-level, however, capabilities are expected to be equally distributed across countries. Hence, in empirical macro-economic applications it makes sense to use quantitative measures as proxies for average education, i.e. human capital. For instance, Barro and Lee (1993) suggest using the percentage of the population who has attained primary, secondary or tertiary degrees as the highest level of education. They also provide estimates of years of schooling at all levels of education. This measure of educational attainment basically combines the three percentages into one score, making it operable for quantitative analyses. Of course, international comparability is subject to national differences in the quality of teaching inputs, e.g. due to different requirements for a certain type of degree. Recently, however, the OECD Programme for International Student Assessment (PISA) has made a more direct and internationally comparable measure of human capital quality available.[7] The study, however, only covers children in school. It excludes those who do not consume teaching services. Additionally, it is limited to the assessment of compulsory education; voluntary efforts to produce education have not been evaluated. Alternatively, the index of labor force quality by Hanushek and Kimko (2000) may prove useful. Hence, an economy's stock of human capital should at best be estimated as a combination of quantitative and qualitative measures. For historical analyses, the concept of numeracy, which makes use of the age-heaping phenomenon, has been of help (A'Hearn, Baten and Crayen, 2006).[8]

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6 Carrying it to the extreme, the student's brain mass may be the raw material transformed in the process.

7 The data and more information are accessible at http://www.pisa.oecd.org.

8 The term "age-heaping" refers to the tendency of people to round their ages to even numbers or multiples of five. This phenomenon is more pronounced in less developed regions. A'Hearn, Baten and Crayen (2006) argue that it reflects the ability of people to deal with numbers. Besides that, of course, institutional factors may play an important role in determining the necessity to know one's age.

In order to further characterize the concept of education and/or human capital, it should be delimited from the concept of *knowledge*. For the purpose of this paper, the whole body of information that is sustainably available to mankind, because it has been written down and stored, is called the stock of worldwide knowledge. Even though some information or skills may become obsolete, it is still likely that the stock of knowledge that is relevant to operate an economy grows over time.

Education on the other hand denotes the output of personal knowledge and abilities a student was capable of creating. With perfect capability, the potential maximum amount of knowledge a student can own equals the whole stock of knowledge offered through a specific teaching program. Knowing that a bunch of other factors may cause heterogeneity in the final good, this simplification should illustrate the concept of a fictitious maximum quantity of education that can be produced from a given teaching input. Hence, education or human capital may be thought of as a fraction of taught knowledge inherent in a person. Because human mental capacity is limited after all it makes sense to assume that the amount of information transmitted during one year of schooling is relatively stable over time. The quality of the procured knowledge may change along with the development of technology, but not so much its quantity. With this, it follows that the concept of human capital, as evaluated by macroeconomic measures, such as average years of schooling, is intertemporally consistent. Romer (1990) puts it this way: "According to this specification, a college-educated engineer working today and one working 100 years ago have the same human capital, which is measured in terms of years of foregone participation in the labor market. The engineer working today is more productive because he or she can take advantage of all the additional knowledge accumulated as design problems were solved during the last 100 years" (p.S83-84). Hence, the assumptions made in this paragraph are crucial to have an operable concept of human capital at hand. This understanding of human capital is sensible, if the evaluation of policies regarding its quantitative aspects is the goal of research.

2.3 Externalities as a reason for fiscal intervention

2.3.1 The concept of externalities

The first mention of the externality concept is usually attributed to Alfred Marshall (1922) whereas both credit and blame for utilizing it to explain government intervention often goes to Arthur Cecil Pigou (1920). Modern microeconomics textbooks describe externalities as the costs (benefits) of a production (consumption) activity that accrue to another party and are not reflected by the market price (e.g. Pindyck and Rubinfeld, 2005, p.642). Typically they are thought to be the "consequence of the failure or inability to establish property rights" (Rosen, 2005, p.82). If they exist, the market solution is Pareto inefficient, because individuals who have an interest in the forbearance (realization) of the activity are prevented from demanding (offering) payment for it. Respectively, the produced (consumed) amount is higher (lower) than the social optimum. Ronald Coase (1960, p.7-8, 15-16) has stated that the efficient allocation may be reached independent of the prior assignment of property rights, if parties are able to negotiate about transactions at zero cost. Externalities will then automatically be internalized. This is of course under the premise that property rights do exist. If they don't, non-zero transaction costs are likely to suppress bargaining activities (Mueller, 2003, p.34-35).

If private bargaining solutions do not work, government intervention can contribute to correcting the market failure basically via three ways: taxation (subsidization), regulation (e.g. the setting of limits), and the definition of property rights (e.g. in the form of certificates). In an insightful working paper, Barnett and Yandle (2005), however, recognize that there may be "far fewer instances of unaddressed external costs" (p.2) than is commonly taken for granted.

From their point of view, the externality concept has frequently been misunderstood, which "leads to gross overemphasis on externalities as sources of 'market failure'" (p.6). They go as far as saying that "our understanding of the nature and importance of externality has advanced very little over the last 100 years" (p.3). As a result, they even find that "the externality problem has disappeared, but it has been replaced by the public goods problem" (p.3). In other words, an externality emerges only if a public good is either exploited or created by production or consumption activities. In this understanding, externalities are a consequence or symptom rather than a cause of market failure. They arise in relation with the presence of a public good. Hence, externality issues may really be regarded as public-goods-issue.

Irrespective of whether externalities due to the production (consumption) or the public character of a good are the reason for fiscal intervention, it is difficult for a government to assess the scope of support to achieve the Pareto optimal solution. It has been argued that certain voting rules in a democracy may serve to automatically generate the optimal level of spending on a public good. This case is related to the median voter argument harkening back to Downs (1957), according to which the preferences of the median voter decide over actual political decisions. Politicians are thought to be the marionettes of society; for the sake of staying in power they adjust their policy proposals to the preferences of the median voter. Additionally, if votes could be traded, side-payments to voters could "buy" deviations from the socially optimal decisions. Externalities might then be bargained away in the political process and the level of government subsidies would reflect the optimal choice of the electorate, which could in fact be guided by many other than just monetary motives. If this was true, further economic analysis attempting to quantify externalities would become obsolete. For a number of reasons, however, this does not reflect the truth. Politicians and parties possess some power over the political agenda and offer only a limited range of choices to select from. Moreover, voters’ behavior is probably far from rational in many cases. It seems that, often, personal characteristics of politicians or the general ideology of parties are more important for voting decisions than political agendas. And not rarely, topics completely unrelated to other agenda points, dominate election campaigns and thereby voting decisions. Also, the specific bundling of public service offers in a political proposal may make it impossible to achieve Pareto optimal outcomes for every public good. And finally, spending on public services could be inefficiently high because of X-inefficiency or bureaucracy. A more extensive treatment of collective decision making and its role for public service provision can be found in Mueller (2003), Cullis and Jones (1998, p.45-70) or Rosen (2005, p.111-140). As a consequence of this policy failure, economists keep spending much effort on assessing the magnitude of externalities to give governments a guideline regarding the optimal scope of fiscal activities.

2.3.2 Other reasons for fiscal intervention

At the outset of this article it was argued that the equivocality regarding the magnitude of externalities is responsible for the irregular patterns of spending on teaching purposes across countries. This can only be true if externalities are the only - or at least prime - reason for a state to get involved with the financing of teaching services. But are there no other objectives a state might pursue through its financial activities? Musgrave (1959) names three major functions of fiscal actions: distribution, allocation, and stabilization. Musgrave and Musgrave (1984, p.7-16) essentially summarize those functions as follows.

The distribution function justifies fiscal interventions that aim at altering the income distribution, usually in a progressive way, by channeling resources from the wealthier to the less wealthy individuals in the population. The exact definition of a just or fair distribution is subject to philosophical considerations. Certainly, the actual scope of redistributive government spending depends on how the electorate perceives the degree of inequality in the economy. Meltzer and Richard (1981) argue that voters demand a greater extent of redistribution activities if the income distribution is less equal. Nevertheless, it is not obvious that subsidies to teaching institutions serve this purpose well. In general, redistribution is implemented most directly by a tax-transfer-scheme. Usually, progressive income taxes or taxes on luxury goods are revenue side instruments of the public fiscal system to ensure that resources for public service provision are mainly derived from the wealthy. Additionally, looking at the expenditure side, public services or transfers may be targeted at particularly deserving groups. It seems, however, that transfers like social welfare or public housing are much more self-evident instruments in this respect than publicly provided teaching services. Primary and tertiary programs are not restricted to the poor and, tertiary teaching has in fact been argued to entail regressive re-distributive effects (Hansen and Weisbrod, 1969; Blaug, 1982). In other words, if redistribution is the goal of fiscal activity, there are certainly more efficient ways to achieve it than financing teaching services. Hence, the distribution function does not play an important role to justify public education subsidies. Further on, if the existence of externalities requires public subsidies, the entailed re-distributional effects may have to be tolerated; in fact they would have to be interpreted as desirable in this case.

The stability function describes the intention to mitigate substantial fluctuation of the economy and maintain objectives like high employment and price level stability. No separate activity, however, can be named as an instrument to achieve this goal. Rather, it is the scope of the whole budget, respectively the budget deficits or surpluses, which exerts the stabilizing influence. Consequently, thinking of teaching expenditures as a financial activity intended to smooth out short-term economic development does not seem plausible.

Finally, the allocation function justifies financial intervention in order to correct market failure. The latter may be due to the public character of a good or due to externalities arising from its consumption or production.[9] Because teaching programs are not per se public goods, but obtain this character only if they are indeed provided publicly, solely externalities are suitable to validate the allocation function when sorting out a reason for publicly financing those programs. Or, as Pyndick and Rubinfeld (2005) put it, "public education is provided […] because it entails positive externalities, not because it is a public good".

Hence, if there was any reason for the government to get involved with the financing of teaching institutions, it follows from the discussion that it could only be potential externalities. In the political discussions concerning tuition fees, other reasons have frequently been exploited as arguments against a private contribution to university education. For instance, the imperfection of credit markets may prevent students to borrow money against their human capital, and parents may be guided to make decisions that are disadvantageous to their children. Both cases, however, do not necessarily justify financial intervention. Solutions, which involve regulatory policy, are much more self-evident. This is why externalities are the essential concept when it comes to judging the scope of public subsidies.

2.4 Education externalities

2.4.1 Nature

Section 2.2 has straightened up the concepts *teaching*, *education* and *knowledge*. Obviously, the pure consumption of teaching does not guarantee the successful production of high-quality education. With this in mind, the question arises whether potential externalities are generated by the *consumption* of teaching services or by the *production* of individual

[9] This is the case in the conventional understanding, which does not view externalities as symptom of a public-goods-issue but as an alternative source of market failure.

education. The answer depends on the type of externality. I distinguish stability externalities and growth externalities.

First consider *stability externalities*. Educated people are supposed to have a lower probability of performing criminal activities and make more informed political decisions. Both effects presumably contribute to the stability of a society. They are commonly linked to primary and secondary education. The individual education producers, however, are not compensated for those external benefits, which is why the produced amount of primary and secondary education is generally thought to be lower than the social optimum. The Pigouvian way to solve this problem is to subsidize the production of education. One might go as far as saying that the grants should be bound to the success of the production process. In practice, however, not the production of education but the consumption of teaching services is publicly supported. And indeed, in the case of primary and secondary programs, even the pure consumption of teaching services may cause the mentioned externalities. If families had to pay for teaching services at those levels, there would be no way to make their consumption mandatory. Of course, private institutions would emerge, probably offering very diverse and rather expensive teaching services. Wealthier families would send their children to private schools; the poorer would go to cheaper public schools. Some, however, would not attend school at all. There are a couple of reasons why parents might not necessarily act in the interest of their children and send them to school, if it was not mandatory. Of course, this cannot be in the interest of a society, because it jeopardizes its stability. Public financing gives society the possibility to control curricula and ensure that children receive a social imprint compatible with the prevailing formal and informal institutions (Rosen, 2005, p.71). These benefits, however, do not depend on the success of the education process. The pure presence of children in schools allows for some control over their development. It must be for this reason, why most societies have decided to provide primary and secondary teaching on a public basis. The literature frequently mentions other social benefits, such as the reduced likelihood of an educated person to receive public transfers, or the positive environmental effects (Moretti, 2003). Other examples include longevity, health and fertility. In some cases it is disputable whether those effects can be internalized or not. Nevertheless, altogether it seems to be widely recognized that public financing of primary and secondary teaching is justified.

The most frequently cited external effect of education, however, is its important role in the process of economic development. More specifically, educated individuals drive the growth of an economy. Endogenous growth theory has been investigating this aspect since the late 1980s; the respective literature usually applies the term *human capital*. Deferring the question whether these *growth externalities* are really just side-effects that remain uncompensated, the next paragraphs treat two accepted ways in which human capital influences the growth process.

According to Lucas (1988), it takes on the role of an additional production factor besides physical capital and uneducated labor. It augments the productivity of workers. In his model, enduring economic growth can only be achieved via growing amounts of inputs. For instance, a larger human capital stock takes an economy to a higher level of income per capita. Some authors have referred to this as the *level effect* of education. In a way, the model simply splits up the exogenous productivity parameter of the well-known model by Solow (1956) into an exogenous and an endogenous part. The latter in principle reflects the human capital stock. Of course, unlimited growth potential of the human capital stock is a premise for the feasibility of sustainable growth rates. Hence, it is assumed in Lucas' model that the existing human capital stock exhibits constant marginal returns in the production of further human capital. The speed of human capital accumulation further depends on the fraction of time a worker spends in the *education sector* as opposed to the *production sector*. Repeated level effects take the economy to ever new levels of output in each period. The growth path is determined by the fraction of human capital diverted from the production sector in every period. The characterization of human capital as being able to grow without bound has its origin in the adaptation of an early endogenous growth model by Uzawa (1965). Additional to education, Uzawa explicitly considers other labor-efficiency improving factors, such as technological knowledge, health, etc.; in other words, everything that is included in the exogenous productivity parameter in the Solow model. Of course, it is plausible to assume that, in sum, these factors can grow boundlessly. Borrowing this assumption and applying it to his concept of human capital, however, Lucas (1988) disregards the difference between an economy's aggregated stock of human capital and its state of technology, respectively stock of knowledge (also see Romer, 1990, p.S79). Given the grasp of human capital introduced in section 2.2, human capital cannot grow without bound, because it is defined in terms of individuals' foregone labor market participation. Changes in skills do not necessarily augment a worker's productivity. They may merely reflect advancements of technology and knowledge, which require different skill sets. Only if the new production technology is more efficient, worker productivity is carried to a higher level on average. Hence, rather than seeing in human capital an explanation of lasting growth effects as in Lucas' model, it makes sense to look at it as attributing some of the productivity shifts, which were entirely exogenous in Solow's theory, to the improved worker productivity. Lucas (1988) further distinguishes two different types of the described level effects. He calls the effect of an individual's human capital on his own productivity the *internal effect*, but argues that it may also have a productivity enhancing *external effect* on all other production factors that might not be considered in wages of educated workers.[10] Hence, too little human capital may be

[10] Calling the latter an external effect, however, may be misleading. It will be argued later that it is hard to imagine why productivity enhancing effects of human capital would not be recognized by the employer and

accumulated. Obviously, such growth externalities would require that individuals successfully produce education. The pure consumption or investment clearly does not go along with those type of external benefits. If anything, the free-rider problem associated with public goods may entail negative externalities from the consumption activities. For instance, unsuccessful university students harm the economy by staying away from the labor market and evading their contribution to the fiscal system.

Lucas’ (1988) model highlights that an economy can move to a higher level by increasing the stock of human capital. It improves workers' productivity, because the latter are able to operate more advanced technologies, which can now be adopted from abroad. Improvements of production technologies remain exogenous, however. Admittedly, this partly makes sense, because technology (i.e. knowledge) may be developed on the world market with a single economy's influence being marginal. Nevertheless, to a certain extent, homemade technology may drive growth in an economy. Romer (1990) explains why even in this respect, human capital might play a crucial role. Here, the decisions of potential labor force members concern the allocation of human capital to the *research sector* and the *production sector*. The share allocated to the former determines an economy's capability of creating new ideas or innovations. The fraction allocated to the production sector decides on the level of technology that may be employed in the production of goods. Just like the education sector, the research sector should not be defined in terms of institutions such as universities, but rather in terms of activities that are directed towards the development of designs for producer durables. Those may include research at universities, at public or private research institutes or the R&D efforts in private enterprises. Note that the size of the human capital stock is exogenously given in Romer (1990). The fraction in the research sector

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taken into consideration in wage bargaining.

determines the knowledge growth rate, which is equal to the economic growth rate, and acts as a scale factor. Hence, according to Romer (1990), education - and tertiary education is the most relevant in this context - also exerts a *growth effect* due to its employment in research activities. Now, the optimal allocation of human capital between the production and the research sector is one that maximizes the total (i.e. present and future) consumption possibilities. If both usages of human capital were compensated according to their marginal productivity, one would not need to worry about externalities. In Romer's model, for instance, the price of a design (patent price) mirrors the potential effect of an innovation on growth. Hence, one might argue that externalities from applied research can be internalized and that only basic research is problematic. However, knowledge spillovers entailed in idea generation increase the productivity of every future researcher. This fact is not reflected in the patent price, because ideas and innovations have the character of a public good. This is true for basic research as well as applied research. After property right protection has expired, ideas are non-rival and non-excludable.[11] Even though a more or less extensive time lag may be involved, sooner or later everyone will have access. Romer (1990) himself states that "there is little doubt that much of the value to society of any given innovation or discovery is not captured by the inventor […]" (p.S89). Also, he argues that "an additional design raises the productivity of all future individuals who do research, but because this benefit is nonexcludable, it is not reflected at all in the market price for designs. […] these effects cause human capital to be undercompensated" (p.S96). In his model, even if human capital is

[11] Even if property right protection exists, the gains from an idea or innovation may accrue to the client of the research activity, unless an inventor is self-employed. The full gain may not be forwarded to the idea generator. This, however, is irrelevant in terms of externalities. The sharing of profits from an innovation between a private employer and a private employee is subject to their relative bargaining power. Again, there is no reason to think that an employee might not be able to exert his property right. The employer must compensate researchers appropriately to give them an incentive to engage in this type of activity. Non-monetary effects associated with it, such as recognition and self-realization, may admittedly contribute to keeping salaries lower than implied by the actual monetary value of innovations. Nevertheless, from an externality point of view, the relevant issue is that too few research activities might be initiated by employers, because firms do not take into account potential knowledge spillovers.

accumulated in a socially optimal way, the cited effects get in the way of its socially efficient allocation to the research sector. Anyway, it is important to note that actual growth externalities arise from the production of innovations and ideas (i.e. the use of human capital in the research sector), not from the pure production of education, and even less from the consumption of teaching services. Romer (1990) expects "that too little human capital is devoted to research" (p.S96). He puts forward that public subsidies can be a way to achieve the optimal allocation. Unfortunately, Romer (1990) does not make clear what should actually be subsidized. On the one hand, he writes that the "social optimum can be achieved by subsidizing the accumulation of A" (p.S97), i.e. knowledge. In different places, however, he expresses a preferences to "subsidize the accumulation of human capital" (p.S99) or advocates "a subsidy to employment in the research sector" (p.S96). According to Barnett and Yandle (2005, p.11), failure to recognize what exactly is the "asset for which use gives rise to external effects" is responsible for much disagreement regarding the nature and existence of externalities. In the present case, this asset is the public good *knowledge*, not *education* or *teaching* services! Pigou himself mentions scientific research as the "most important" source of positive externalities: "Lastly and most important of all, it is true of resources and activities devoted alike to the fundamental problems of scientific research, out of which in unexpected ways discoveries of high practical utility often grow, and also to the perfecting of inventions and improvements in industrial processes. These latter are often of such a nature that they can neither be patented nor kept secret, and therefore, the whole of the extra reward which they at first bring to their inventor is very quickly transferred from him to the general public […]" (1920, p.161). Education, however, remains unnoticed.

In summary, stability externalities are associated with the pure consumption of primary and secondary teaching services. They are in general thought to justify full public financing of programs on these levels. Further on, growth externalities of education have been proclaimed by theoretical economists. They take two forms: Level effects according to Lucas (1988) would apply to all levels of education. Successfully produced education is what generates them. Hence, strictly speaking, merely subsidies to successful students are justified rather than to anyone who is enrolled at a university. And finally, growth effects according to Romer (1990) are most closely linked to tertiary programs. But actually, they arise from knowledge generation processes and are neither directly associated with teaching nor with education. Hence, even when following these theoretical proclamations of externalities, it is questionable why the consumption of university teaching receives considerable subsidies in many countries. The next section shows that empirical studies, too, do not deliver the respective justification.

2.4.2 Magnitude

In order to assess the scope of public subsidies, education externalities need to be quantified. As exemplified, public financing of primary and secondary programs is widely accepted because of stability externalities. In consequence, the empirical attempts of quantification are limited to the influence of education on economic growth. There is an extensive body of literature that empirically investigates the latter via different methods, such as growth accounting (e.g. Young, 1995; Hall and Jones, 1996) or growth regressions (e.g. Mankiw, Romer and Weil, 1992; Benhabib and Spiegel, 1994; Barro, 2001; Pritchett, 2001); Sianesi and van Reenen (2003) provide an overview over this literature. The vital question, however, is whether education owners actually receive remuneration for these side-effects of deploying their human capital. This aspect has been the subject of research efforts much less frequently. Two types of studies will be discussed subsequently. Both focus solely on the proposed Lucasian level effect of human capital. The principal idea underlying these approaches is to contrast the *private return* to education (i.e. the effect of individual education levels on individual income) with the *social return* (i.e. the effect of average human capital levels on everyone's income).

The first type of approach basically aims at reconciling micro-estimates of the private return to education and macro-estimates of the social return to education. Some endeavors include the work by Heckman and Klenow (1997), Krueger and Lindahl (2001) as well as Gundlach and Woessmann (2004). The private return is argued to be in line with what Lucas (1988) calls the internal effect of human capital. Most studies derive it by applying the standard earnings equation suggested by Mincer (1974) to micro data. It can be interpreted as the increase in personal income associated with one additional year of schooling, when experience is controlled for in the equation. For instance, Psacharopoulos (1973; 1994) has contributed much to the evaluation of private returns to education. Harmon, Oosterbeek, and Walker (2000) provide a summary of the literature on microeconomic returns to education. As an example, one year of schooling in the United States increases individual income on average by 10% (see Psacharopulous and Patrinos, 2002, Table A.2). The social return, as estimated by the mentioned studies, is thought to include both the internal and the external effect of human capital modeled by Lucas (1988). In order to obtain a coefficient that is comparable to the private return, usually the authors make use of what Heckman and Klenow (1997) call the macro-Mincer equation. Essentially, this is a Mincer-equation applied to countries instead of individuals. Nevertheless, due to technical issues there is considerable dissension on the size of the estimated social return. Comparing this macro estimate with the widely recognized 10%-estimate of the micro return, Heckman and Klenow (1997) reject the existence of externalities. Gundlach and Woessmann (2004), instead, obtain a figure for the social return in excess of that for the private return and conclude that externalities do exist. Similarly, Krueger and Lindahl (2001) estimate a macro effect which is about four times the size of the micro effect. But precisely this huge difference makes them suspicious of their own results. They argue that the finding was most likely a result of endogeneity bias, which leads them to recommend focusing on natural experiments causing increases in educational attainment.

A second strand of literature focuses solely on evidence from micro data. Basically, these studies estimate the effect of average level of education in a city or a state on individual wage levels within this regional unit, while at the same time controlling for individual education. Observation units are individuals, clustered by cities, states or countries. The estimation equations could also be interpreted as Mincer equations augmented with the regional average level of human capital. Important examples include Rauch (1993), Rudd (2000), Acemoglu and Angrist (2000), Moretti (2004), Muravyev (2006), as well as Ciccone and Peri (2006). Because individual education is controlled for, the effect of average education on individual wages represents social benefits that go beyond the private return. Hence, the authors typically interpret it directly as the size of externalities. In other words, both the internal as well as the external effect of the Lucas (1988) model are estimated based on a single equation. Given the differing empirical specifications between the studies, their results are not directly comparable. Rauch (1993) finds that a one percentage point increase of average education in US cities raises wages by 3-5%. Acemoglu and Angrist (2000) are sceptical in light of their weak evidence for an effect of compulsory secondary schooling laws on the US state wage levels. Also, Rudd (2000) finds no support for an effect of average education on individual wages in a panel analysis for US states. Eventually, Muravyev (2006) exploits a natural experiment provided by the economic transition process in Russia and concludes that a one percent increase of the college share in Russian Cities raises residents' wages by 1.5%. A criticism brought forward against these studies states that increases of wages in a firm, a region, or a state may just be due to the imperfect substitutability of uneducated labor, given the production technology. If a given state of technology requires a fixed amount of uneducated labor, increases in the average share of educated workers drive up the wages of uneducated workers and possibly the average wage, too. As long as educated and uneducated workers are paid according to their marginal productivity, a positive coefficient of average education indicates by no means an externality. Moretti (2004) attacks this problem by estimating the effect on the wage levels for three separate groups of workers: high school drop-outs, high school graduates, and college graduates. He finds that not only wages in the first two groups, but also salaries of the latter, rise with a higher share of college graduates. A one percentage point increase in the supply of college graduates elevates the wage level in the same group by 0.4%, which is a rather weak effect. Eventually, Ciccone and Peri (2006) tackle the problem of imperfect substitutability by applying what they call the constant-composition approach. This method estimates the effect of changes in the supply of human capital on the (log-)change in average wages holding the skill-composition constant. It does not reveal any evidence for positive externalities.

Summarizing, the empirical evidence on educational growth externalities is limited to Lucasian level effects. There are (to my best knowledge) no studies which try to empirically reconcile the Romer-type growth effects with the private return to researchers. Typically, the surveys are based on comparisons of the private and the social return to education. Unambiguous results, however, have not been achieved so far.

2.5 Discussion

2.5.1 Internalization of level effects

In light of the ambiguity with regard to potential Lucasian externalities and the lack of empirical studies on Romerian externalities, it is imperative to ask whether there is actually a-priori-reason to suspect that education owners do not receive the appropriate compensation for supplying human capital on the labor market. What should prevent the internalization of external benefits that is expected to take place, if property rights are well defined?

Intuitively, most researchers would probably agree that there must be something like an optimal size of the human capital stock for production purposes. Depending on a country's state of technology, employers in this country may have a rather well defined need for educated labor. Neither do they want too little, nor too much of it. In the original model by Lucas (1988), this point is not illuminated sufficiently, because the notion of human capital is one that incorporates knowledge. Whereas technology remains exogenous, human capital - including knowledge - is viewed as a production factor, which may grow without bound and thereby drive productivity. Romer's (1990) model on the other hand, distinguishes between knowledge and human capital. It clarifies that technology is equivalent to the knowledge of an economy and that its growth rate is scaled by the level of human capital. Nevertheless, the size of the human capital stock is exogenous. It may not change along with technology. Merely the amount of human capital allocated to the production sector is allowed to adjust endogenously in the process of technological development. Hence, notwithstanding both models' strengths in illustrating growth and level effects of human capital, they fail to capture the fairly intuitive notion of an optimal size of the human capital stock that may be directly associated with the state of technology.

The amount (or time respectively) of uneducated labor invested in the education sector, determines the rate of change in the human capital stock. Note, by the way, that this view deviates from Lucas' (1988) model, where not uneducated, but educated labor is allocated between the education and the production sector. Much more realistically, however, it ought to be uneducated workers, who make the decision how to allocate their time. During the time in the education sector they create human capital, which ultimately enters the production sector. The education sector encompasses all types of individual activities that may lead to an officially accepted educational degree. Now, if much uneducated labor is diverted from the production sector in order to build human capital, there may be too little left to pursue the optimal path of output growth. The amount of educated labor needed in the production sector depends on the state of technology, but a technological innovation is not bound to lead to a higher need for educated labor in relation to uneducated labor; the opposite may well be the case.[12] More specifically, the amount of human capital produced in each period ought to be just right to keep the human capital stock at its optimal level, depending on the level of technology.

Given the understanding of education laid out in section 2.2, the fraction of time an uneducated worker spends in the education sector until successful completion of a program is a close proxy for his or her level of education. And assuming that the distributions of individual capability and students' effort as well (as the quality of teaching inputs) are equal in all countries, 'years of schooling' is a very suitable measure of human capital in cross-country applications. Based on this measure, Krueger and Lindahl (2001) have delivered empirical evidence for the notion of an optimal human capital stock. They detect a curvilinear relationship between average years of schooling and GDP growth rates for the OECD countries. In fact, they argue that the optimum level of education may have already been surpassed in the average OECD country (p.1130).

The notion of an optimal human capital stock can easily be reconciled with the adoption of Lucas' model stated in section 2.4: rather than interpreting the level effect of human capital on aggregate output as a driver of productivity growth, I prefer to look at it as an adjustment reaction of the human capital stock to its optimal level determined by technological progress. The latter may either be due to innovations being adopted from abroad, or based on

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[12] Nevertheless, it is likely that technological progress is skill-biased, i.e. leads to higher requirements in terms of educated labor.

improvements created by the economy's own research sector. Typically, catch-up growth of less developed countries is explained that way. Because technology is available worldwide, all that is needed for those countries to catch up is a functioning education sector.[13] Admittedly, some applied research activities might also be required to adopt technologies. But apart from that, it is important to have a labor force skilled to operate new technologies.

Getting to the point, however, the productivity enhancing effect of human capital in the presence of technological advancements, and the entailed adjustment of national output levels, is likely to be compensated on the labor market. Given the notion of an optimal stock of human capital in the production process, it is hard to think of obstacles that could prevent individuals from exploiting their property rights when offering human capital on the labor market. After all, employers decide how much a certain type of education is worth to them. An excess supply of tertiary education in the production sector might drive down its price. Vice versa, if only few educated workers are available, their ability to negotiate higher wages rises. A priori, the price mechanism is expected to work and provide for the optimal supply of human capital.[14] Nothing suggests that wage differentials between educated and uneducated labor do not reflect actual differences in marginal productivities. According to Lucas, educated individuals stimulate each others' productivity simply by communicating with each other. This may be true. However, if spillovers occur within a firm, they are likely to be compensated by the employer. That should remain true for spillovers in cities, or regions arising from this type of interaction. If educated workers really have a higher probability to learn from each other, even beyond firms and cities, employers should be well aware of this specific characteristic of human capital. At the end of the day it is implausible to assume that

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[13] This is of course neglecting the important role of institutions.

[14] Of course, due to the long duration of the production process, which takes up to 20 years considering all types of education, there may be pig-cycle-like fluctuations around the optimal level of human capital.

this feature is not recognized and compensated for, given the existence of well-defined property rights.

2.5.2 Criticism of empirical surveys

Based on the previous discussion, some criticism is advised regarding the method of comparing private and social returns to education for the purpose of assessing the magnitude of externalities.[15] First, consider the studies reconciling micro- and macro-Mincer equations. Whereas this approach appears rather intuitive and elegant at first glance, it is not at all clear why it should have the ability to prove the existence of externalities. Imagine a positive social return to education; say it was estimated from a cross-section of countries. It states, as a percentage, by how much a country's national income would grow, if average years of schooling in the population increased by one year. This shift reflects the higher productivity of workers, or in other words: the possibility to employ more advanced technologies in the production process because workers are better trained to implement those. The higher output level is the result of a more efficient aggregate production process. As previously argued, however, there is no reason to believe that this increase in worker efficiency would not be recognized and compensated by the employer. At least some suspicious fact would be needed as a hint that human capital property rights are not fully owned by the individuals. Now, the private return makes a statement about how current labor incomes depend on the level of individual education. Assume, it was zero or at least very low, estimated based on a Mincer-type equation. Because income differentials reflect expectations of employers regarding the future productive value of educated and uneducated labor as well as the scarcity of educated labor, the low return might simply be a hint on an excess supply of human capital in relation

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15 Also see Pritchett (2001) for a sceptical view on the social return to education.

to uneducated labor. In fact, it may well be compatible with the positive macro return estimated for a cross-section of countries, which reflects the whole past influence of human capital on the historical development of those economies. If the private return sags below the social return, this may be a reaction of the labor market to a human capital surplus. It does not indicate positive education externalities. Similarly, if wage differentials were high between educated and uneducated workers, and the private return surpassed the social return, this may simply illustrate how much employers value education, and not indicate negative externalities.[16]

Finally, the empirically determined wage differentials may be biased by already existing public subsidies. A flat wage structure may just be an indication of a potential crowding out. If compensation for growth effects is already provided by the market, government subsidies in the absence of externalities are expected to replace the market compensation. Wages of academics, for instance, might be substantially higher, if students had to pay for university teaching. Further, if a public contribution simply crowds out private resources, the potential level of education with no public intervention would be expected to be equally high. Hence, an empirical analysis needs to be based on a real world scenario where teaching finance is solely private. There is no such country, but a few come closer to this ideal case than others. In the United States, for instance, the public contribution to tertiary teaching is distinctly smaller than in most European countries (see Figure 2.2). If positive externalities of education did exist, one would necessarily expect a lower demand for teaching services, because of the lower teaching subsidies. Nevertheless, the demand for teaching services seems to be higher

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16 Furthermore, the macroeconomic relationship between average years of schooling and GDP per capita is strongly non-linear. At very high levels of education, further increases in average schooling lead to overproportionate changes in GDP per capita. Figure 4.9 illustrates this point. Hence, the presence of industrialized countries in a sample, upon which a macro-Mincer regression is based, would strongly bias the estimate of the social return to education upwards. In other words, the probability to detect alleged high externalities via this approach is higher in samples of already well-developed countries.

in the US. Even though students have to pay for tertiary programs, more of them decide to invest in college or university teaching than anywhere in Europe. Of course, one must bear in mind the fact that the US does not have a system of vocational training. In European countries, the latter soaks up many high school graduates whose counterparts in the US enjoy college teaching. Nevertheless, the high demand for tertiary teaching suggests that college education pays off for the individuals. This fact casts doubt on the existence of educational growth externalities. Much more likely, young individuals do seem to perceive the manifold benefits from education to outweigh the cost they need to incur for the teaching program. Hence, not unlikely, public subsidies in countries with high public contributions serve to crowd out private resources and flatten the wage structure. This effect can easily be reconciled with the Krueger-Lindahl finding of a schooling surplus in OECD countries: If there was too much educated labor on the market due to excessive subsidization, it would not be surprising at all to find flat wage differentials, i.e. private returns lower than social returns. Consider an exogenous increment in the fraction of time each worker spends in the education sector; say, for instance, the number of students increases. In consequence, the human capital stock outgrows its optimal level and when the first graduates of this new student generation hit the labor market, they will be confronted with lower than expected wages, because there are more graduates than required for the current production technology. That way, public subsidies to teaching programs substitute part of the labor market wage of university graduates.

Similarly, the micro-estimation of social and private returns based on a single equation has a caveat. Admittedly, this approach eliminates the conceptual problems associated with the comparison of coefficients from micro and macro regressions. Moreover, the authors of the surveys discussed in section 2.4.2 demonstrate creativity in exploiting natural experiments and utilizing instruments that allow dealing with the endogeneity problem. But they neglect that educated workers might nevertheless get compensated for their effect on others' productivity. Even evaluating the effect of average human capital levels on individual wages for three separate groups of workers (Moretti, 2004) does not rule out that wage differentials simply reflect actual differences in marginal productivities and scarcities. Of course, a higher share of educated labor in a regional unit may enable employers of this unit to implement a more sophisticated production technology, which augments the productivity of workers across all levels of education. Nevertheless, if this technology is available and an employer is waiting to apply it, he or she would be expected to take into account the productivity-enhancing effect of higher-skilled labor. Again, there is no reason to suspect that he or she would offer wages to educated workers, which do not reflect their marginal productivity in the renovated production process. An increase of wages in each of the three groups may well be in line with a wage differential that serves to compensate educated workers for their productivity enhancing effects. It cannot indicate externalities. The same argument applies to the remedy applied by Ciccone and Peri (2006). A positive reaction of changes in the overall skill level even after controlling for the skill composition may be due to the adoption of a technology that increases the productivity of all levels of education.

Concluding, apart from various technical deficiencies associated with both the estimation of the micro-effect and the macro-effect - above all endogeneity problems - the whole concept of comparing private and social returns is very misleading. By no means does it provide evidence for the presumption that workers are not compensated sufficiently for offering their human capital in the production sector. In summary, quantification trials to date cannot be viewed as successful. Furthermore, the recorded surveys highlight the Lucas-type level effects of human capital only. As argued in the previous paragraph, it is likely that those can be internalized on the labor market.

2.5.3 Assessing growth effects

Altogether, education may not per se yield growth externalities. Its level effects can most likely be internalized and the growth effects arise from idea generation. The market is expected to deliver the optimal solution for its allocation between production and education sector, because employers should compensate skilled workers for their ability to meet the demands associated with the application of complex production technologies. Subsidies to the pure accumulation of tertiary education could actually be detrimental, if the overall size of the human capital stock is pushed to an inefficiently high level and cause negative externalities.

In turn, supporting the idea generation process, which uses human capital as an input, would at the same time make it attractive for individuals to produce education. But what scope of subsidies is needed to achieve the optimal allocation of human capital to the research and development sector? What is the optimal allocation? How much more research activity at the expense of production activities is needed? This question is not easy to answer, especially, if non-monetary effects are taken into account.

Remember that national income or its growth rate may not solely determine the well-being of a nation. After all, growth might be perceived as a negative externality by a significant fraction of a state's population. If growth increases inequality, the less wealthy populace might actually feel threatened by economic growth. Similarly, environmental consequences of growth may be recognized in a negative way. When considering such intangible effects, the assessment of externalities becomes virtually impossible. The only indicator to rely on would then be public votes. True, the case that votes do not necessarily turn out Pareto efficient remains valid. But is there really any other way to judge the preferences of people? There is a reason why people vote the way they do. In partiuclar, the poor might vote in favor of public teaching subsidies for re-distributional purposes, because inequality is costly to them in a psychological way. If the electorate grants subsidies, this may happen for a reason. In this respect, the redistributional and the efficiency-related function of fiscal activity become identical. On the contrary, if in an election a society votes in favor of tuition fees, this may be nothing but a hint that either presumed externalities, be it future growth potential or crime reduction, are not perceived by the bulk of the populace, or are valued lower than the current level of subsidies would imply. In other words, if people primarily strive for happiness, and if material prosperity is not the prime determinant of happiness (Layard, 2005), then it is hard to see why votes should not reflect the multi-faceted needs of individuals in a society. In this case, all public finance problems would be degraded from a theoretical economic problem to a rather practical socio-political issue. And they would merely contain a positive, but no longer a normative dimension. Hence, when setting aside the argument of policy failure brought forward in section 2.3.1, looking at votes may provide a useful reality check to assess the preferences of the electorate.

Not only can intangible negative externalities lead to an overestimation of the optimal scope of research activities. Additionally, non-monetary rewards to workers performing research activities may cause underestimation of the return to this use of human capital. First, it is likely that motivation for research activities is primarily of an intrinsic nature. The reward comes through the satisfying character of the activity itself rather than through external incentives such as pecuniary compensation. Undoubtedly, research activities - more than others - require creative talent. Creativity, in turn, is presumed to be higher when individuals are intrinsically motivated. Hence, it makes sense to assume that researchers have a higher degree of intrinsic motivation than other workers. In fact, external rewards have been argued to crowd out intrinsic motivation and reduce creativity (Amabile, 1983). Second, even external incentives may be intangible. For instance, few would doubt that recognition is a crucial driver of researchers' motivation. In other words, even if large monetary externalities existed that researchers were not paid for (money-wise), a reason for fiscal intervention would not necessarily be established.

Given this criticism, it is moot whether quantification attempts of Romerian growth externalities can ever be successful. Ignoring the possibility that growth may not be the ultimate determinant of well-being, that collective choice may internalize any externality, and that intangible rewards may suffice to compensate researchers, there is a pragmatic way for a government to pursue the efficient allocation of human capital to the research sector. Intuitively, as long as the extension of research for the purpose of idea generation serves to increase growth rates, it is socially efficient to channel further subsidies into this sector to compensate researchers for these externalities. Following this insight, empirical surveys need to investigate the optimal level of research activities in order to maximize economic growth.

Intuitively, a rather low level of research activities might be required to generate economic growth, if a country is a technological follower. The example of Japan illustrates that an economy can achieve a high level of national income simply by adopting technologies from abroad and converging to the technological frontier. This strategy may not require research activities as extensive as generating innovations from scratch. Hence, for a follower country, the optimal allocation of human capital may imply a smaller share of human capital in the research sector than in the case of a technological leader. Actually, this point constitutes a disincentive for those countries to support the research sector, if knowledge spillovers from technological leaders benefit the research sectors in follower countries. Hence, after all, what can be termed externality seems to be in fact external to the economy, if knowledge is an international public good. The general free-rider problem applies and provides disincentives for national governments to invest in research. From this perspective, a common international subsidization strategy would be most appropriate to promote research.

2.6 Conclusions and research agenda

The main purpose of this article was to make a step towards more unanimity regarding the issue of education externalities. The findings can be summarized as follows.

Much of the confusion arises from the commingling of different concepts, such as teaching, education, human capital, and knowledge. Straightening them out makes it easier to get to the point of what mechanism actually gives rise to the frequently cited externalities, respectively what activity generates them. In terms of primary and secondary schooling, the pure consumption of teaching services may exhibit stability externalities. Hence, there is little doubt that full public financing at those levels is justified. For the reason of a stable and mature society it is usually advocated that the state provide every individual the opportunity to get educated. Participating in primary and secondary teaching is not merely a right, but even a duty for individuals. This strategy is applicable to any economy. As regards tertiary education, the pure investment in teaching services does clearly not yield positive externalities. Rather they are thought to stem from the contribution of education to economic growth. Two types of effects have been distinguished; level effects according to Lucas (1988) and growth effects according to Romer (1990). Nevertheless skepticism is advisable.

The Lucasian (1988) level effects are likely to be internalized on the labor market. Contrary to what is commonly assumed, education is a private good and there is no a-priori-rationale to worry about individuals not being able to exert their educational property rights. Empirical attempts to assess the magnitude of potential Lucasian externalities typically make use of the estimated private and social rates of return to education. This approach, however, has been shown to be unsuitable to testify growth externalities. Even if externalities do not exist, it is likely to yield the results, which are interpreted in favor of their existence by the authors. In light of the insufficient evidence, it seems unreasonable to proclaim the existence of a phenomenon without being able to name a potential cause. Further, the recognition that in the US - where public subsidies are relatively low, the demand for teaching services is relatively high - suggests that public tertiary teaching subsidies may merely crowd out private investment. Altogether, the optimal quantity of human capital needed to operate state-of-the-art technology in the production sector can be expected to be naturally provided.

The potential growth effects of education according to Romer (1990) have in turn not yet been at the center of empirical studies. They arise from the use of human capital in research activities. Ignoring intangible externalities as well as rewards and possibilities of internalization via political bargaining, it is likely that these effects cannot be fully internalized. In practice, however, it has been ignored for a long time that they stem from idea generation, and not from the production of education or even the pure consumption of teaching services. Future surveys should explore the empirical link between the scope of research activities and economic growth rates. This relationship determines the strategy for public subsidization policy. Subsidizing knowledge generation activities may be a means to attract the optimal amount of human capital to the research sector. The full public provision of tertiary teaching services, however, is a very questionable instrument.[17] And in fact, some countries have recently introduced a private contribution to higher education finance. Nevertheless, it is still a long way to overcome the long tradition of full public financing in many countries. Especially the imperfection of credit markets poses a major challenge in this context.[18]

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[17] Barnett and Yandle (2005) even doubt in general that the concept of externalities is helpful to justify fiscal policy. They attribute modern interest in externalities mainly to the facts that their nature and theory has been widely misunderstood and that externalities can provide a convenient rationale to justify fiscal intervention (p.6).

[18] It should be emphasized that the subsidization of the supply of vocational training by private enterprises is by no means questioned in this article. While vocational education is a private good as all other forms of education, the market may fail in providing the optimal supply of training service. This is, because enterprises have an incentive to free-ride on training efforts of other enterprises. Hence, in this case, subsidization can be meaningful.

At the end of this article one may wonder, whether externalities are in fact the only important determinant of public spending on teaching services. For instance, there are still substantial differences in primary and secondary public spending per student; even across countries where every student has the chance to attend a publicly financed primary and some secondary school. And this is in spite of unanimity regarding externalities. Of course, it may partly have to be attributed to differing levels of national income and the total scope of government spending as a share of GDP. Nevertheless, other factors might contribute to those discrepancies. For instance, Italy and Germany or Switzerland and Ireland are comparable in terms of GDP per capita. So wealth cannot be responsible for the vast differences in annual expenditure on educational institutions per student between those pairs of countries (see OECD, 2006). Hence, an additional line of research should focus on the empirical determinants of public subsidies. What drives public subsidies is even more thronging as money does not necessarily improve the quality of education (Hanushek, 1989). It could be suspected that political factors play a role. The nature of the political system, the characteristics of political decision making processes across countries, as well as the ideologies of political leaders may be of importance. Last, but not least, it may just be historical decisions, which force an economy on a path that leads to the establishment of a certain educational policy. These early decisions may not be easily challenged even after hundreds of years; questioning a policy with a long tradition always provokes resistance. To examine these influences, it is essential to build a history of educational spending for a diverse set of countries and combine quantitative analyses with case studies that take into account the specific institutional settings of countries. This endeavor has been started by Baqir (2002), Lindert (2004) and Stasavage (2005) and is resumed in chapter 3 of this thesis.

3 Democracy and Public Educational Spending[19]

Motivated by the ambiguous evidence on education externalities, this paper explores the influence of democratization on public education finance strategies. The analysis, based on new data from the interwar period (1925-1938) and an array of panel estimation techniques, raises doubts regarding the robustness of a contemporaneous positive effect of democracy. Moreover, it suggests that a strong democratic history may force an economy on a path that leads to lower levels of public educational spending in the long run. Controlling for franchise extensions and other democracy-related determinants of public service provision, this pattern might reflect democracies' ideological orientation towards more civil responsibility.

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[19] The content of this chapter reflects the current version of a working paper titled "Democracy and Educational Spending – Panel Evidence from the Interwar Period". It was submitted to the journal *Explorations in Economic History* in 2006, and presented at the 7th Conference of the European Historical Economics Society Conference (Lund, 2007) as well as the GlobalEuroNet Summer School "Why (Not) Europe? Sources of Modern Economic Growth in Historical Perspective" (Tartu, 2007). Comments of two anonymous referees as well as participants at the mentioned conferences are already considered in the present version.

3.1 Introduction

One of the most urgent contemporaneous problems in education economics is the question how much a government should contribute to the financing of education.[20] From an economic point of view, the optimal scope of subsidies is determined by the magnitude of education externalities. The empirical assessment of the latter, however, has turned out to be a major challenge. So far, no waterproof results have been accomplished. Krueger and Lindahl (2001), as well as Gundlach and Woessmann (2004), argue in favor of externalities. Conflicting evidence comes from Heckman and Klenow (1997). It is, hence, not unusual for economists to work under the assumption of zero externalities.[21] Mueller (2007, chapter 1 of this thesis) shows that this treatment is indeed plausible. In consequence, public authorities would be restricted to zero spending on education whatsoever.[22] But even if externalities did exist, the question arises, why governments' dedication to education differs and what determines their education finance strategies. This is especially urgent in light of the weak correlation between the quality of educational output and financial inputs (Hanushek, 1989). In consequence, it is promising to build a history of education expenditures and explore what drives the priority of education in public budgets.[23]

Quite a few studies examine the influence of economic and demographic factors on the public educational effort, such as per capita income and the fraction of the school-age

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[20] Note that the term 'education' as used in this chapter does not differentiate between 'education' and 'teaching' as in chapter 2 of this work.

[21] Many public finance studies examining the redistributional effects of higher education subsidies, such as Grüske (1994) for the German case, reason that potential externalities will automatically be internalized on the labor market.

[22] There are, admittedly, other reasons why governments may wish to get involved with the regulation of education and education finance, e.g. the imperfection of capital markets or the principal-agent problem between parents and their children. The only justification to pay for it, however, seems to be the existence of positive education externalities. Redistributive goals may be pursued more efficiently via different tools. See Musgrave (1959) for the general purpose of public financing activities.

[23] The terms "educational spending" and "education expenditures" refer solely to the public contribution to education finance throughout the chapter unless stated otherwise.

population (Nord, 1983; Fernandez and Rogerson, 1997; Poterba, 2002; Verbina and Chowdhury, 2004). Rather seldom and only recently, however, have the empirical endeavors been expanded to the exploration of political factors, in particular democratization. But why should we expect democracy to affect public strategies of education finance? Possible answers are given by public choice theory, which suggests that characteristics of political decision making processes are crucial for the scope of publicly provided services. These ideas constitute the theoretical framework of most empirical studies on public education expenditures. Two types of theories can be discriminated.[24] The first group covers models, in which voters or pressure groups dictate the government the desired level of public spending. In the second group of theories, political administrations and executives exert influence on the budget even beyond the control of the electorate.[25]

The first group of models has in common that vote-maximization of politicians according to Downs (1957) leads to the adjustment of policy programs on offer such that they accord with the preferences of the median voter.[26] Meltzer and Richard (1981) assume that the individually desired public expenditure levels are an inverse function of income, and that public redistribution streams generally flow from those with above-average income to those with below-average income. In consequence, the theory predicts an increase in public services when the income of the median voter falls off in relation to average income (Meltzer and Richard, 1981). If the income distribution is fixed, this can only happen when the fraction of voters on the receiving end of the public redistribution apparatus grows, e.g. due to the introduction or extension of voting rights. If the latter enfranchises a share of the population

[24] See Mueller (2003) for a very comprehensive overview over public choice theory. Chapter 21 explicitly treats competing theories of the size of government.

[25] There is another type of models which relates public spending levels to the given electoral system or constitutional setting. The latter is beyond the immediate control of either political executives, voters or interest groups (see Persson, Roland and Tabellini, 2000; Mileso-Ferretti, Perotti and Rostagno, 2001).

[26] The median voter concept can be traced back to a contribution by Harold Hotelling (1929).

poorer than the previous elective populace, the new median voter income is brought down. In order to adapt policies to the preferences of the new median voter, administrations need to increase redistribution activities.

A similar rationale underlies the pressure group model by Kristov, Lindert and McClelland (1992) developed in the tradition of Gary Becker (1983). It is more sophisticated in explaining how pressure groups exert influence on voters' preferences via lobbying (Becker, 1983, p. 392). In terms of democratization, however, the model does not add many new insights. Pressure groups in favor of education expenditures are likely to be strengthened when suffrage is spread. Additionally, the model implicitly allows democratic changes to have an effect, if they enhance the relative effectiveness of existing pressure groups favoring an extension of public education.[27] The median voter concept and the pressure group model are most useful to predict the consequences of extending or introducing voting rights.

Empirically, the impact of political voice has been confirmed by Husted and Kenny (1997), and - for the specific case of public educational services - by Lindert (2004). The latter analyzes two samples, one covering the period 1880-1937 and 24 countries, and the other containing the years 1962-1981 and 19 OECD countries. The estimation outcome for the first sample indicates a positive effect of extending the franchise share in the population. Interpretive power of the results, however, suffers from the use of enrollment rates as dependent variable. It serves as a proxy for education expenditures, which were not available for the observed period. When analyzing output measures, a positive result might just reflect the potentially greater efficiency of democracies in producing public services.[28] Further,

[27] Falch and Rattsø (1997) use an even more specific framework where teacher unions are the relevant pressure group. They influence the main cost drivers, i.e. number of teachers per class or teachers' wages.

[28] Similarly, Lake and Baum (2001) provide an analysis of the relationship between institutionalized democracy and various output measures of democracy such as enrollment rates. The focus, however, should be on inputs, if the goal of a study is to explain the extent of a state's dedication to educational matters.

Lindert's analysis focuses on the impact of the voting share rather than the influence of democratization in general. That is, democracies are the only eligible countries after all, which leads to a quasi reduction of the sample down from initially 24 countries. The second sample basically confirms his finding. Similar as before, however, the sample of OECD countries totally excludes authoritarian regimes. Focusing only on the voting share, the study can shed light only on this rather specific aspect of democracies and not on how other characteristics of democracies act upon education. Stasavage (2005) relies on a connatural rationale. He argues that electoral competition - which is de facto equivalent to the introduction of voting rights - is the most decisive feature of democracies when it comes to public educational spending. He tests this hypothesis for a set of 44 African countries during the period 1980-1996. A binary variable is used to measure democracy. It takes on the value one if multiparty competition is present in a country and a specific year. The coefficient implies a positive significant effect on public educational spending; this is regardless of whether the latter is taken as a percentage of GDP or as a share of overall government spending. Even though the analysis is quite convincing, it does not allow a universal statement about the impact of democracy.

The second class of models explaining the size of government holds public administrative behavior responsible for the level of public spending. For instance, Niskanen (1971) argues that bureaucrats tend to expand the size of budgets, and resist contractions respectively, in order to maximize the scope of responsibility and improve personal career perspectives. This is possible because a bureau's activities rather than its output are the basis for budget approval by the overseeing authority. Publicly provided goods are, due to their specific character, hardly measurable in output. A different, but related argument concerns the input-output relation. Applying the concept of "X-inefficiency" by Leibenstein (1966), one might argue that public administrations suffer from a loss of productive efficiency, mainly due to a poor incentive structure. Both arguments predict public expenditures on a specific service to exceed the demand of the median voter. Nevertheless, it cannot be presumed a priori how bureaucracy and inefficiency react to the degree of democracy. The latter depends on which effect democracy has on the ability of bureaucrats to misrepresent the true scope of provided services, and on the incentive structure within public administrations.

Romer and Rosenthal (1979a,b) propose a mechanism that, while still based on the assumption of budget maximizing bureaucrats, works through the ability of governments or public administrations to control the agenda and offer a limited choice of programs to be voted on. Even though Romer and Rosenthal apply their framework to a setting of direct democracy, it is probably even more appropriate for systems dominated by a single party, where political competition is non-existent (Fisher, 1996) and voting rights are hollowed out. Voters are then left with a take-it-or-leave-it decision. They will accept any scope of service provision offered by the government that is closer than the reversion amount to the one desired by the median voter. By offering reversion amounts lower and alternative proposals higher than the demand of the decisive voter, government with agenda control can ensure that produced amount of services is higher than what is favored by the median. In this way of thinking, democracy would lead to lower educational spending if it reduces the possibilities of agenda control.

The latter class of theories is applicable to regime changes in both democracies as well as autocracies that do not necessarily involve the extension of voting rights. Few empirical studies capture the potential impact due to very different features of democracy, such as reduced or enhanced bureaucracy or a reduction of politicians’ agenda control. Baqir (2002) applies a measure of institutionalized democracy capturing political regime characteristics in a wider sense, to a large panel dataset containing information for 167 countries. Covering the period 1985-1998, which includes the collapse of the authoritarian Eastern European regimes, the data is relatively rich in cross-country as well as within-country variation regarding the degree of democratization. Baqir (2002) finds a strong positive effect of democracy on educational spending. Similarly, Brown and Hunter (2004) provide evidence on Latin American countries for the period 1980-1997. They, too, find that democracy has a significant impact on educational spending; this time measured as per capita expenditures.[29]

This paper adds to the empirical literature. The contribution is threefold. Most importantly, the focus of the analysis deviates from previous studies. It is the goal of this work to make a statement on what priority public education has for different regimes. Hence, it is crucial to control in the empirical model for any influence due to democratization, which applies just as well to other publicly provided services, e.g. social welfare. Only then, the estimated impact may be attributed to yet other features of a more democratic regime, such as its ideology. After all, nothing prevents a benevolent authoritarian leader to be ideologically dedicated to education and allocate even more resources to training purposes than what the median voter would demand. Soviet Russia and Bismarck's Prussia are just two examples of such behavior (see Brown and Hunter, 2004). Further, the specification allows for a difference between the short-run impact and the long-term effect of democracy. It may take quite some time before the economic consequences of regime changes become evident. This thought has been ignored by previous studies. Next, the paper follows Baqir’s (2004) call to direct further research towards the historical development of social spending and provides new data for the interwar period. This time frame is attractive for two reasons. Not only were actual education

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[29] Lindert (2004a,b) and Baqir (2002) examine the effect of democracy on overall public service provision, treating education as just one type of public service. Their work is motivated by the branch of public choice theory which explores the size of government. The empirical work explicitly focusing on educational services, e.g. Brown and Hunter (2004) and Stasavage (2005), has been published in political science journals. Economists seem to have largely neglected this field. An exception is the work by Falch and Rattsø (1997). They provide time-series evidence for Norway. Testing various political economic factors, they find political stability, fragmentation in parliament, and ideology to be important determinants of educational spending over time. Their work, however, differs from the mentioned studies in that in does not explain educational spending itself but the main cost driving components of the latter, such as class size and teacher wages.

expenditures for this period unavailable so far (Lindert, 2004a,b); also, it turns out to be exceptionally rich in terms of changes in political regime characteristics, which makes it especially promising for econometric analysis. Finally, the estimation strategy is more comprehensive than in previous studies. Employment of a whole set of panel estimation techniques promotes confidence that the results are not artifacts. Of course, an in-depth analysis of countries and their specific institutional settings is needed to come to more detailed explanations for the revealed pattern. Before deploying the fine-tooth comb and telling individual country stories, however, this study takes a purely quantitative approach to test for tendencies that can be generalized for a diverse set of countries.

3.2 Data

3.2.1 Education expenditures

Education expenditures have been extracted from various issues of the "Statistical Yearbook for the German Empire".[30] These sources contain central government spending on education in national currency units and current prices for 47 countries all over the globe during 1925-1938.[31] The panel dataset is unbalanced, however. Altogether, 466 out of 658 observations, i.e. 70.8% of the cells, are non-missing.[32] Additionally, local authorities' spending is available for selected years. Any expense on a sub-national level, i.e. municipal,

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[30] See Statistisches Reichsamt (various issues from 1927-1941/42). The German title of this publication is "Statistisches Jahrbuch fuer das Deutsche Reich", see list of references.

[31] Data was available for the years 1939 through 1942 as well, but the exceptional situation during the war years makes it reasonable to exclude this information from quantitative analyses.

[32] For 16 countries, the entire period is covered. 12 countries have one or two missing observations, 7 countries have 3 to 7 (i.e. less than 50%) missing observations, and in 12 cases information is only available for few years during the observed period. In a few instances, two issues of the yearbooks gave differing figures for the same year. In those cases, the later published figures have been selected. As an exception, the older figure was used, when it seemed more plausible in the context of the whole time series for the respective country. Further, when the financial year overlapped two calendar years, the figures were assigned to the starting year. In some cases, the demarcation of the financial year was changed leading to extended or truncated settlement periods. The respective figures were adjusted to reflect 12-month periods.

provincial, regional or departmental spending, may be subsumed under this category. Local details, however, are much less complete than central government data. In some cases, they are restricted to one or few local authority types. Only 139, i.e. 21.12% of the cells are non-missing.[33] Furthermore, even the available local data points are suspected to contain incomplete information in many cases. The limited availability of local information imposes a peculiarity on the specification of the empirical model, which will be treated in section 3.3. Three other shortcomings of the data will be discussed subsequently.

First, the compilers of the data derived the education budgets by splitting up total government expenditures into seven categories: general administration, defense, education, welfare, economy and transport, debt service, and others. Therefore, it cannot be taken for granted that the educational figures are constructed in the exact same way for a variety of countries with possibly very different spending structures. However, the same problem would arise in using national sources for the individual countries. After all, the data compilers probably used those as references.

A further problem is that some of the figures represent proposed budgets as opposed to settled budget figures. It is theoretically conceivable that budget propositions are biased in a certain direction in order to maximize the probability of acceptance. Which direction this bias would take in terms of the educational positions in the budget is hard to tell a priori. Whenever both proposed and settled figures were available, the latter have been chosen. Nevertheless, the specification of the empirical model needs to account for this potential effect.

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[33] Most of the central state information is derived from the statistical yearbooks for the years 1936 and 1937, which provide time series data for 1925-1937 and 36 states. Later issues of the yearbook (1938 and 1939/40) do not continue these series, but cover selected years only for a broad set of countries, mostly years after 1935. Additionally, those issues include local information for selected years, in most cases years later than 1930. No reason is given in the source for this change in the reporting strategy. Potential selectivity problems will be considered in section 0.

Next, the budgets are given in national currency units and current prices. In order to make them comparable across countries, they have to be related to a reference quantity. The latter could be either total spending or gross domestic product (GDP) in current prices.[34] Total spending was computed as the sum of the mentioned seven categories.[35] This brings up another issue. Even if education expenditures in a country develop smoothly, the ratio of education expenditures to total expenditures may exhibit discontinuities when there are leaps in the total budget figures. Those could arise from the erratic and unsteady behavior of spending positions which may fluctuate greatly, e.g. due to debt service. To deal with this problem, total expenditure figures (state and local) have been corrected, if comments in the yearbooks indicated such distorting influence of certain budget positions. Nevertheless, this approach does certainly not eliminate all inconsistencies. There may be some noise left in the total budget figures and hence in the ratio of education expenditures divided by total expenditures.[36]

Table 3.1 presents average educational spending during the interwar period by country. The figures for the central state and the local level are related to GDP on the one hand, and to total spending on the other. The countries are ranked in terms of education expenditures on

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[34] Principally, the two eligible sources in terms of GDP are Maddison (1995) and Mitchell (1980, 1993, 1998). The use of Maddison's data requires conversion of expenditure figures to 1990 International Dollars. This is a quite lengthy, tedious and error-prone task, because of boundary and currency changes. Hence, Mitchell's national accounts data were employed. Unfortunately, in many cases concepts like net national product, net domestic product, gross national product, and aggregated personal income have been used instead of GDP, making comparisons very difficult. Also, in a few instances, figures were given in fixed prices. Here, estimates of the current price figures were achieved using Mitchell's "Cost of Living" index (1980, 1993, 1998). Sometimes, when the financial year straddled two calendar years, the GDP figures had to be backdated, because Mitchell assigns them to the latter year whereas in the case of the education figures they were assigned to the first year. Eventually, for a list of countries no GDP figures are available at all from the Mitchell publications.

[35] The yearbooks also report original figures for the total budget, which deviate from the sum of the seven cited categories, possibly because they contain positions that did not fit into one of the categories. Hence, to ensure international comparability, summing up the seven categories is the more reliable choice.

[36] For instance, another issue is that the reported figures may be based on nationally varying budget concepts, such as ordinary or extraordinary budgets. While this does not affect the reported education figures, it may well be a problem in case of reported total spending. Panel estimation techniques, however, would eliminate this source of unobserved heterogeneity. Sometimes, transfers to local authorities may be included in central state expenditures. This could lead to double-counting, if local expenditures include them, too.

the national level as a share of GDP. Thus, countries that focus primarily on local resources for education, such as Germany, appear in the lower part of the list.

Table 3.1 - Average education expenditures of 47 countries between 1925 and 1938

Country	*cee/y*	*N*	**Pos**	*cee/ce*	*N*	**Pos**	*lee/y*	*N*	**Pos**	*lee/le*	*N*	**Pos**
Soviet Union	3.14	11	1.	6.79	13	34.	4.24	4	1.	36.69	4	2.
Ireland	2.98	5	2.	15.66	14	8.	0.23	2	22.	2.80	5	30.
Netherlands	2.82	14	3.	18.67	14	1.	2.35	4	5.	12.18	4	23.
Hungary	2.49	13	4.	16.02	13	7.	1.12	4	13.	19.06	4	15.
Finland	2.45	13	5.	15.54	14	9.	2.15	6	6.	23.21	6	9.
New Zealand	2.27	2	6.	11.49	2	22.	0.00	2	39.	0.00	2	40.
Bulgaria	1.97	13	7.	16.34	13	5.	0.18	5	23.	5.13	5	29.
Belgium	1.90	7	8.	9.05	14	26.	0.92	5	15.	17.31	7	17.
Czech.	1.82	13	9.	10.42	14	24.	0.48	3	20.	21.96	3	12.
Greece	1.63	11	10.	7.24	12	32.		0	43.		0	44.
Sweden	1.60	14	11.	17.42	14	2.	1.66	6	9.	22.23	6	11.
Chile	1.42	8	12.	16.71	8	4.		0	26.		0	32.
Argentina	1.39	4	13.	12.78	4	18.		0	35.		0	37.
Uruguay	1.37	2	14.	13.38	2	15.		0	32.		0	34.
Norway	1.29	14	15.	14.82	14	10.	1.50	4	11.	20.59	4	13.
Denmark	1.23	14	16.	11.22	14	23.	1.18	7	12.	12.15	7	24.
Spain	1.19	9	17.	7.37	9	31.		0	42.		0	43.
Italy	1.17	14	18.	8.17	14	29.	0.34	3	21.	6.08	3	28.
UK	1.13	14	19.	6.85	14	33.	2.04	4	7.	23.76	4	8.
France	1.13	13	20.	6.29	13	36.	0.08	5	24.	1.59	5	31.
Japan	0.87	14	21.	8.53	14	27.	2.72	4	3.	24.15	4	7.
Mexico	0.79	7	22.	12.96	7	17.		0	34.		0	36.
Austria	0.72	13	23.	6.42	13	35.		0	44.		0	45.
Colombia	0.57	3	24.	7.74	3	30.	0.56	3	18.	17.50	3	16.
Brazil	0.49	10	25.	5.49	10	37.	0.67	2	17.	13.48	2	21.
South Africa	0.18	13	26.	2.64	13	41.	1.57	2	10.	58.09	2	1.
Switzerland	0.12	10	27.	2.17	14	42.	2.02	3	8.	20.02	3	14.
US	0.05	13	28.	0.81	13	44.	1.04	8	14.	25.59	8	5.
Germany	0.05	8	29.	0.46	8	45.	3.74	13	2.	25.49	13	6.
India	0.04	13	30.	1.62	13	43.	0.50	3	19.	14.98	3	19.
Canada	0.02	12	31.	0.21	12	46.	2.39	1	4.	27.16	1	3.
Australia	0.00	3	32.	0.00	2	47.	0.73	3	16.	9.70	3	25.
China		0	33.	4.29	1	40.		0	47.		0	47.
Egypt		0	34.	11.90	2	21.		0	38.		0	39.
Estonia		0	35.	13.61	14	14.		0	31.	16.39	5	18.
Iran		0	36.	4.79	1	38.		0	45.		0	46.
Latvia		0	37.	13.68	14	13.		0	30.	22.34	4	10.
Lithuania		0	38.	16.13	13	6.		0	27.	14.05	5	20.
Luxembourg		0	39.	13.80	1	12.		0	29.		0	33.
Paraguay		0	40.	13.17	1	16.		0	33.		0	35.
Peru		0	41.	10.34	3	25.		0	40.		0	41.
Poland		0	42.	14.57	14	11.		0	28.	12.23	4	22.
Portugal		0	43.	8.24	11	28.		0	41.		0	42.
Romania		0	44.	17.21	14	3.		0	25.	6.84	2	27.
Thailand		0	45.	12.17	2	19.		0	36.		0	38.
Turkey		0	46.	4.79	13	39.		0	46.	26.56	4	4.
Yugoslavia		0	47.	12.14	10	20.		0	37.	8.36	4	26.
Total	1.26	327		10.04	465		1.61	106		17.94	139	

Notes: Education expenditure ratios are in %. Italic figures indicate the number of non-missing observations in the mean calculation. Bold figures specify the rank of a country in the respective category. Abbreviations:
cee/y = central state education expenditures / GDP
cee/ce = central state education expenditures / total central state expenditures
lee/y = local education expenditures / GDP
lee/le = local education expenditures / total local expenditure
Information is also available for seven additional countries for years later than 1938. It was excluded from the econometric analysis. The countries' *cee/ce* ratios and their potential ranking are as follows in selected years: Philippines 30,78%, Pos. 1 (in 1941); Albania 17,88% , Pos. 3 (in 1941); Ecuador 16,53%, (*cee/y* 2.08%) Pos. 5 and Pos. 7 in terms of *cee/y* (in 1941); Serbia 15,27%, Pos. 13 (in 1942); Slovakia 11,28%, Pos. 25 (in 1941); Bolivia 11,09%, Pos. 26 (in 1939); Mandschukuo 3,57%, Pos. 45 (in 1939).

With these limitations in mind, it should be noted that the expenditure levels in Table 3.1 cannot be expected to match exactly with other well-documented figures for individual countries like the US, Australia, Spain, Italy or France.[37] The most drastic discrepancy regards the case of the US. Goldin (2006) reports public educational spending in relation to GDP of 2.8%. The respective figure in Table 3.1 is 1.04% on average during the interwar period. In this specific case, clearly the lack of local information is to blame for the largest part of the gap. The figure in Table 3.1 is based on observations, for which either state spending or municipal spending are available, but rarely both. Hence, a significant portion is not considered.[38] Similar reasons apply for the respective case of France. Flora et al. (1983) report a figure of roughly 1.8% on average, whereas Table 3.1 suggests that educational spending as a share of GDP during the period 1925-1938 was only 1.13%. However, the figures for the central government level match quite well, and also the development over time corresponds reasonably well in both sources. Here, the reason may lie in different demarcations of educational spending. It does not emerge from the Statistical Yearbooks what types of expenditures were exactly subsumed under the category 'education'. Eventually the discrepancies might be based on incongruity in the denominator, i.e. GDP. Further cases

[37] I wish to thank an anonymous referee for pointing out the most drastic discrepancies.

[38] The only observation for the United States that includes both, state and municipal spending on the regional level, is actually not that far off. Goldin (2006) reports 2,026 million dollars of primary and secondary spending altogether. The figure implied by various sources of the Statistical Yearbooks is 1,566 million dollars. The remaining gap is owed to the latter figure not including municipalities with less than 100,000 inhabitants.

could be explored, but in summary, it does not make much sense to compare the figures to other estimates. The potential reasons for incoherency are manifold and not traceable in detail. The regression analysis, however, controls for the lack of data quality, as will be explained more closely in section 3.3. Even though this approach is far from perfect, the available data offer the opportunity to perform a quantitative analysis that would be entirely impossible otherwise. After all, its attractiveness is not based on accuracy, but on the fact that, for the first time, information is available for a broad set of countries from a single source. Instead of leaving the data lie idle, it should be harnessed. Nonetheless, the outcome needs to be interpreted with care. One ought not to take it as the ultimate truth, but rather as an impulse for further discussion and analyses.

3.2.2 Democracy

For the purpose of this study, a broad measure of institutionalized democracy is needed. Among several frequently used indicators, such as the Freedom House or Przeworski et al. measures, only the datasets assembled by Marshall and Jaggers (2002) and Vanhanen (2000) furnish information for the interwar period. The latter constructs an index of democracy out of two quantitative measures for political competition and political participation. But mainly because important attributes of democracy are omitted from the index it seems more appropriate to use the Polity IV data by Marshall and Jaggers for this study.[39] It contains political regime characteristics and transitions for 161 countries from 1800 to 2002. The variable *POLITY2* reflects the degree to which political decision making processes are subject to constraints, be it due to the threat of replacement, parliamentary control or other features associated with the political system. It is constructed based on other component variables,

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[39] See Munck and Verkuilen (2002) for a comparative survey and a more detailed discussion of the strengths and weaknesses of various indicators.

which measure regulation, competitiveness and openness of executive recruitment, openness and competitiveness of political participation, and constraints on executives. Each country is assigned a score that ranks it on a scale from -10 to 10, -10 representing an autocratic regime and 10 being a democracy. Regrettably, variability during the short interwar period is still relatively low, which may restrict explanatory power of the indicator.[40] The correlation coefficient between *POLITY2* and the Vanhanen measure is 0.87 (see Gleditsch and Ward, 1997). So there is hope that the results of the econometric analysis will not vary substantially depending on the employed democracy measure.

Figure 3.1 clarifies that the interwar period is a specifically helpful time frame for the intended econometric analysis. It depicts the development of political regime characteristics in the aforementioned sample of countries using the simple average of *POLITY2* scores.[41] The years 1920-1940 were, as opposed to the postwar period, extraordinarily rich in political regime changes. More specifically, the sharp increase after WW I is succeeded by a drastic year-by-year decline in the average degree of democratization. This pattern mirrors the emergence of the Eastern European communist regimes and the Western European dictatorships. Only the period starting in the late 1980s - which has been analyzed by Baqir (2002) - exhibits a similarly strong wave of changes, here in the form of an upheaval. Moreover, the interwar period is the only phase that is characterized by a short-run development clearly in opposition to a long-term trend. This may be helpful to separate the effects of democracy from other determinants of educational spending that show continuous upward trending behavior.

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[40] See Gleditsch and Ward (1997) for a deeper critical re-examination of the Polity IV data.

[41] As an anonymous referee pointed out, aggregating the scores with equal weights for each country is arbitrary. Nevertheless, the chart serves to underline the message of political fluctuation during the interwar period.

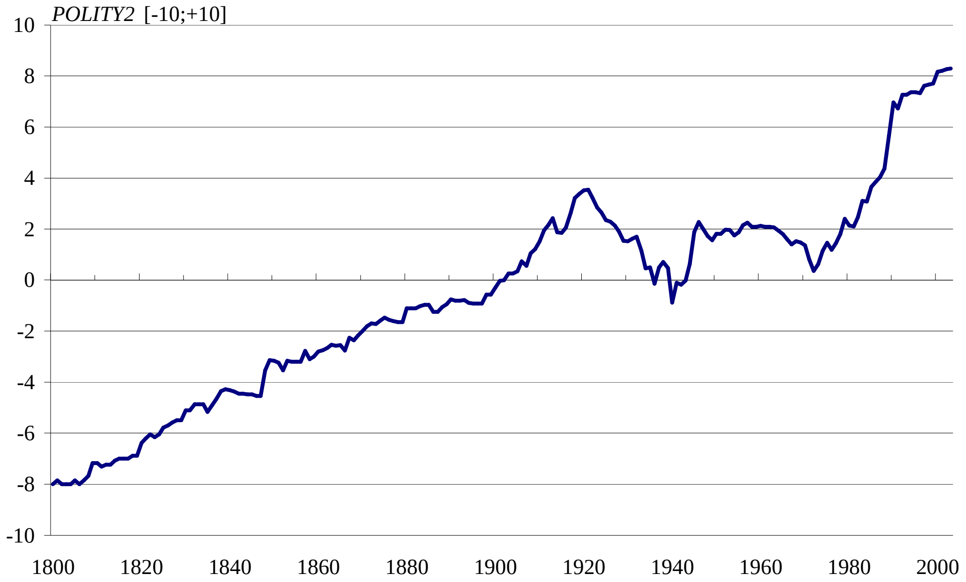

Figure 3.1. Average democratization in 52 countries, 1800-2000[42]

Source: Marshall and Jaggers (2002), Polity IV Project.

3.3 Methodology

3.3.1 Empirical model

When specifying the empirical model, the data peculiarities sketched in section 3.2.1 need to be considered. In principle, it would be desirable to explore the effect of democracy on total public educational spending. Given the available information, however, this would leave us with a very limited number of data points, because for the majority of observations local spending is missing. On the other hand, the available local information should not be completely disregarded. Its important role can be observed from Table 3.1. It is true that some countries, like the Soviet Union, the Netherlands, Finland, Sweden and Belgium, were among the high-spending nations on the local level as well as on the central state level. At the same

[42] The sample contains the 47 countries of Table 3.1 - Average education expenditures of 47 countries between 1925 and 1938 plus the countries mentioned in the notes of the table except Mandschukuo and Luxembourg

time, it becomes obvious many countries spent much either on the local or the central state level and little on the other. Striking examples are Germany, the US, and Canada, which focus on local resources for educational purposes, or Bulgaria and New Zealand, which were in favor of central state spending. Consequently, the fraction of local spending should be controlled for in a regression analysis.[43] To deal with this issue, two different specifications are estimated. In combination with the use of two reference quantities for educational spending, this yields the following four models:

$$(tee/te)_{it} = \alpha + \beta_1 dem_{it} + \beta_2 dstock_i + \boldsymbol{\delta Z_{it}} + \chi loc_{it} + \eta av_{it} + \varepsilon_{it} \quad (3.1)$$

$$(cee/ce)_{it} = \alpha + \beta_1 dem_{it} + \beta_2 dstock_i + \boldsymbol{\delta Z_{it}} + \chi loc_i + \varepsilon_{it} \quad (3.2)$$

$$(tee/y)_{it} = \alpha + \beta_1 dem_{it} + \beta_2 dstock_i + \boldsymbol{\delta Z_{it}} + \gamma (te/y)_{it} + \chi loc_{it} + \eta av_{it} + \varepsilon_{it} \quad (3.3)$$

$$(cee/y)_{it} = \alpha + \beta_1 dem_{it} + \beta_2 dstock_i + \boldsymbol{\delta Z_{it}} + \gamma (ce/y)_{it} + \chi loc_i + \varepsilon_{it} \quad (3.4)$$

where

i	=	1, …, I, with I = 47 (number of countries)
t	=	1, …, T, with T = 14 (number of years)
cee	=	central state education expenditures,
tee	=	total public education expenditures
y	=	GDP (Mitchell, 1980, 1993, 1998),
dem	=	Polity IV score (Marshall and Jaggers, 2002),
dstock	=	average Polity IV score since 1875,
ce	=	total central state spending,
te	=	total public spending,
loc	=	fraction of local money for educational purposes
av	=	completeness (availability) of local expenditure data (0-4),
Z	=	vector of control variables.

43 For instance, Baqir (2002) and Brown and Hunter (2004) use central state spending on the left-hand side and fail to control for local spending. Baqir (2002) recognizes that this omission is one of the causes for differences in the OLS and fixed effect estimations.

Following Baqir (2002) and Stasavage (2005), total public education expenditures are explained as a share of total public spending in (3.1). The equation controls for the ration of local educational spending by total public education expenditures, loc_{it}. This is the preferred specification. But because local education expenditure data are not widely available, the dependent variable suffers from measurement error, which may be correlated with democracy. Hence, the categorical control variable av_{it} accounts for the incompleteness of the local information. The observations were assigned to five categories based on plausibility. Those reflect the presumed degree of completeness of the available local information. The categories are as follows:

0 - probably > 25% of the scope of local expenditures are missing;
1 - probably < 25% of the scope of local expenditures are missing;
2 - data may be incomplete, scope of missing is unknown;
3 - probably complete;
4 - data complete.

Certainly this measure is rough and a little unfortunate. But it is hard to think of a more reasonable approach to make use of the little available local information without taking the risk of a serious bias. As an example, if municipal spending was available in the first year, and municipal plus regional spending in the second year, the observation for the first year would be assigned to the category 0 or 1, depending on the scope of regional spending in the second year. Or, if no information was given for any year on the regional level, but municipal spending was available for two or three years, the category would be 2, unless there was some certainty that regional expenditures were zero. This may be the case, if country size suggests that regional authorities did not exist or did not have this type of responsibility. Then, the observation would be assigned to category 3. Category 4 is applicable, only if it is safe to say an observation contains details for all types of regional authorities.

As an alternative solution to the data problem, (3.2) omits local spending from the left-hand side and employs central state expenditures only. In this specification, the fraction of local resources, loc_t, is time-invariant. It reflects the situation at a specific point in time, for which local data were available. The year featuring the presumably most complete local details was chosen for this purpose. As a second order criterion, it should be as close as possible to the year 1935 to achieve a maximum degree of comparability. Countries without any local information were not considered in this specification.

The remaining specifications (3.3) and (3.4) put education expenditures in relation to GDP.[44] This is in line with most of the mentioned studies. Nevertheless, if it is the goal to explain a state's commitment to education as opposed to other government spending, (3.3) and (3.4) call for the adoption of the government share in GDP in the equation. Again, this becomes obvious from Table 3.1. Whereas the educational budget may seem small in relation to GDP in some countries, it can still mean a significant effort in comparison to the overall budgets of public authorities. E.g. Chile and South Africa reserve a remarkable portion of their overall budgets (in Chile primarily national and in South Africa mainly regional resources) for educational purposes. It follows that the government share in GDP must be quite low in those countries. Similarly, the Soviet Union, although being by far the highest spender in terms of GDP, would only rank 34th when it came to the relative portion of education expenditures in the overall public budgets. Hence, the Soviet Union should have

[44] Alternatively, per student education expenditures or per capita spending have been used as dependent variables (e.g. Brown and Hunter, 2004). In the present case this is not an option. A money value is needed as reference quantity to make the figures in national currency units and current prices comparable across nations.

had a very high share of government spending in GDP. Thus, the latter is an important determinant of education expenditures in relation to GDP.[45]

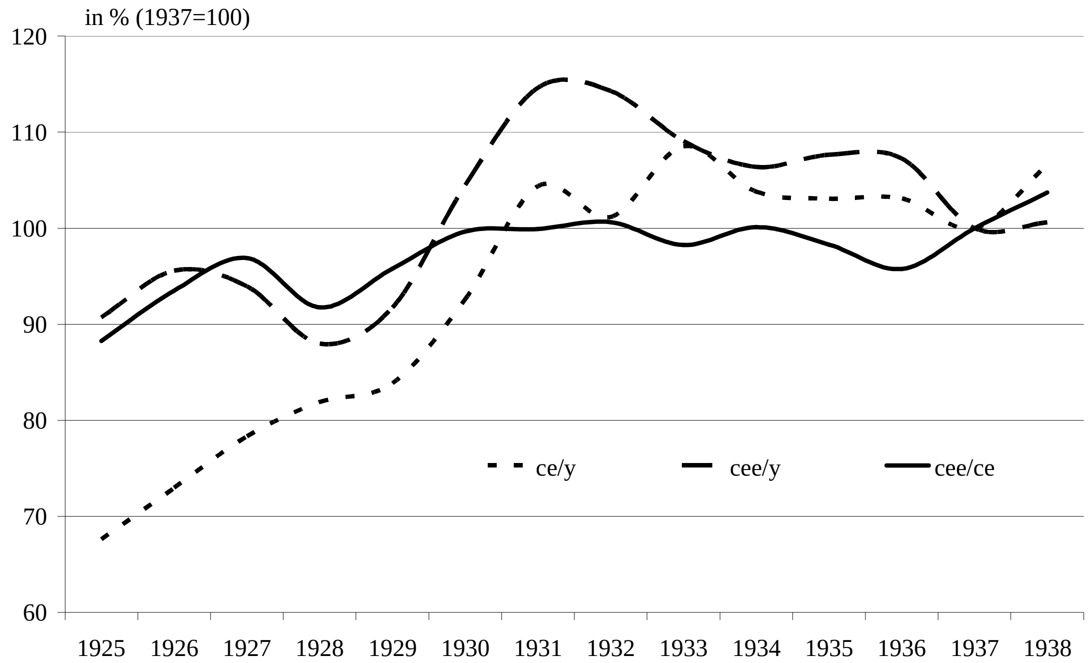

Figure 3.2. The influence of the government share in GDP on educational spending[46]

Source: Mitchell (1980, 1993, 1998), Statistisches Reichsamt (various issues)

This view is supported by Figure 3.2. It illustrates the largely parallel development of central state educational spending and total central state spending during the interwar period. Observe that the fluctuation of educational spending as a share of total central state spending is much less eminent. Therefore, government spending as a share of GDP needs to be controlled for. Otherwise the estimated coefficient of democracy is likely to reflect indirect effects that work through its impact on total government spending.

45 Among the other studies, only Baqir (2002) and Brown and Hunter (2004) adjust their models for the influence of the government's share in GDP.

46 The lines represent simple cross-country averages computed for every year. The *cee/y* and *ce/y* lines are composed of 32 countries for which GDP is available from Mitchell (1980, 1993, 1998). The *cee/ce* line contains all 54 countries. All lines are smoothed.

The first two specifications offer the advantage of a higher case number, because the sample size is not restricted by GDP data availability. On the contrary, the latter two specifications resolve the issue of unexplained discontinuities in total government spending, which was discussed in section 3.2. The combination of all four models ought to be capable of delivering the desired insights regarding the parameters of interest, β_1 and β_2, which provide information on the effect of democracy. The variable dem_{it} contains the indicator of political regime characteristics introduced in section 3.2.2. It has been lagged by one period, because current expenditures are not expected to be affected by regime changes. Additionally, the time-invariant variable $dstock_t$ represents the average indicator score since 1875, i.e. in the last 50 years before the beginning of the observation period.[47] This specification offers the possibility to distinguish between contemporaneous effects and the long-term impact of democracy. Also, as will be shown later, it has certain benefits when it comes to defending the model against the potential criticism of reversed causality.

The vector $\boldsymbol{Z}_{it}$ contains a list of control variables that are potentially correlated with democracy. First of all, following the discussion in section 3.2.1, a binary variable captures potential effects from the *type of the disclosed figures*. It takes on the value 1 when a figure stems from a settled budget and zero if it was taken from a budget proposal.

Next, conflicting relationship between certain budget positions may influence the budgeting decisions. Especially *military spending* has been under suspicion to reduce the public educational effort (Yilderim and Sezgin, 2002). Hence it is included in the regression as a covariate. Moreover, *welfare spending* is incorporated. This trick ensures that the

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[47] The idea to include this term was adopted from the draft of a paper by Gerring, Thacker and Alfaro (2006). They examine the effect of democracy on human development. Apart from the contemporaneous effect of democratization they consider a variable that contains the cumulated democracy score over one century. It is interpreted as the "stock of democracy". Taking the average, as done here, is basically equivalent, except that it is a safer measure when there are single years with missing scores.

coefficient of democracy does not reflect the typical effect of a reduced median voter income due to franchise extensions. The latter is captured by the social expenditures variable.[48] It also picks up the potential influence of changes in the degree of bureaucracy, efficiency or agenda control associated with democratization. Both variables are related to the same reference measure as the dependent variable in the respective model.

Virtually all of the cited empirical studies make use of *GDP per capita*, because it captures the wealth and thus financial possibilities of a society. It does, however, not seem natural to include it, when education expenditures on the left-hand side are already taken as a share of GDP. Nevertheless, some studies find a positive significant contemporaneous relationship, e.g. Stasavage (2005) or Baqir (2002). Since the educational budget of a period is determined at least one year before actual GDP is known, simultaneous decision making is ruled out. Political decision makers must either anticipate future GDP development, or base their decisions on past GDP development. In either case, this dependence implies that a negative short-run relationship between GDP and *cee/y* may well be observed, if GDP behaves unexpectedly. Figure 3.3 supports this view. It illustrates the development of average central state education expenditures, GDP and the ratio *cee/y* between 1925 and 1938. Central state educational spending exhibits an upward trending behavior between 1925 and 1929. Thereafter, the Great Depression causes a dent in GDP and CEE. As of 1933 the upward trend resumes. The decline in education expenditures seems to take place one year after the decline in GDP, and apparently it is less drastic. This relatively inelastic behavior of expenditure levels may be due to fixed expense, e.g. for the maintenance of existing educational infrastructure or the pay of teachers. Those factors cannot be reduced instantly. Payments are not independent from previous period's payments. Hence, in the short run, or

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[48] Husted and Kenny (1997) provide empirical evidence for the Meltzer-and-Richard hypothesis that franchise expansion leads to increasing redistributive government consumption, i.e. welfare expenditures.

contemporaneously, a decline in GDP would be expected to cause an increase in *cee/y*. Because the dependent variable has the character of a ratio, the log of GDP is applied. This way, the coefficient has a more meaningful interpretation.[49]

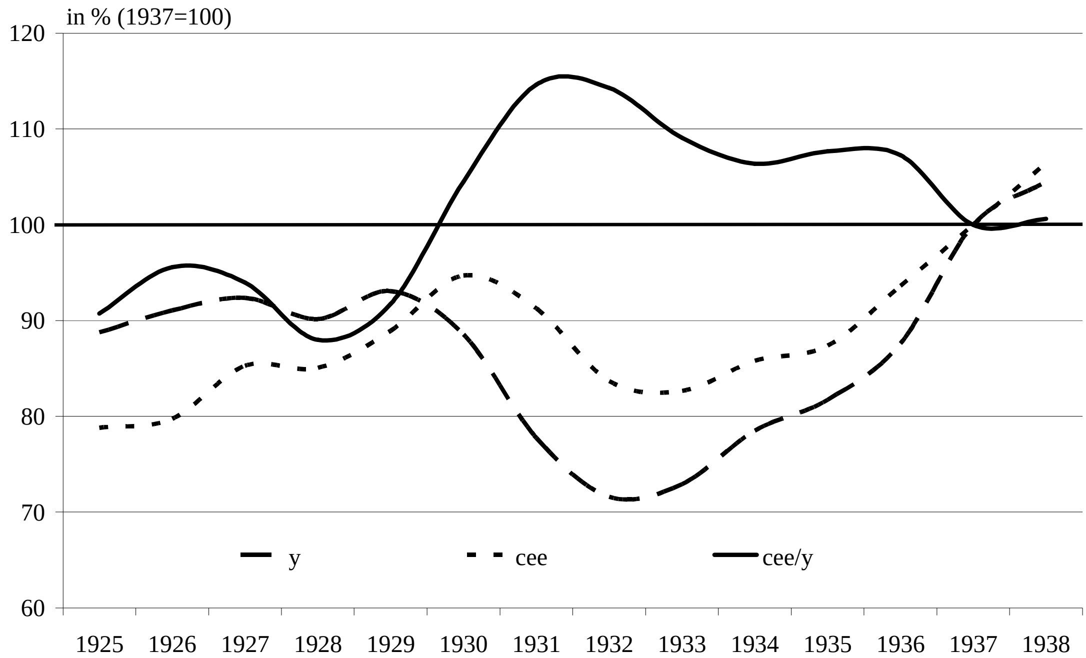

Figure 3.3. Development of GDP and central state education expenditures, 1925-1938[50]

Source: Mitchell (1980, 1993, 1998), Statistisches Reichsamt (various issues)

Further, it seems natural to consider the *number of students as a share of the population*.[51] A state would be expected to spend more on education the higher is the fraction of students in the total population. It would also be plausible to assume that part of the

[49] For the use as a control variable in the regression analysis, GDP per capita needs to be internationally comparable. For this purpose the data compiled by Maddison (1995) was preferred over Mitchell's data.

[50] The lines represent simple cross-country averages computed for every year. The *cee* line is composed of all 54 countries, for which *cee* is available. The GDP and *cee/y* lines contain only 32 countries, for which GDP was available from Mitchell (1980, 1993, 1998). All lines are smoothed.

[51] For this purpose, the total number of students was computed from the Mitchell (1980, 1993, 1998) figures on primary, second, and tertiary students. Population figures by Maddison (1995) were exploited if possible. Missing cases were filled in using Populstat and OxLAD data (see http://www.populstat.info/, and http://oxlad.qeh.ox.ac.uk/search.php, downloaded in May, 2006).

democratization effect works through the student fraction in the population. Hence, in order to extract the direct impact of democracy on educational spending, the latter needs to be controlled for in the regression analysis. Holding the number of students constant, a positive coefficient of the democracy variable would imply a positive marginal effect of democracy on per-student spending. Hence, in a way the analysis answers the question whether democracy leads to educational intensification as opposed to an extension.[52]

Additionally, the regressions should incorporate educational history. After all, a country might spend much on education just because it has a long tradition of doing so. A time-invariant covariate controls for *primary enrollment rates before the First World War*. A priori, it is suspected that countries with high educational achievement before WW I also exhibit high spending on education during the interwar period. That way some of the unobserved country effects are expected to be captured.[53]

Moreover, the equations control for *ethno-linguistic fractionalization* as a measure of diversity in a society. One could also think of it as proxying for social capital. The rationale is that it may be more difficult to obtain majority votes for a public transfer program, if a society is very heterogeneous. Also, the degree of *urbanization* may have an influence on educational spending. On the one hand, it facilitates the constitution of pressure groups and the exertion of pressure. Controlling for this effect, it cannot be picked up by the democracy measure. On the

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[52] Previous studies often use the school-age fraction of the population instead of the actual number of students in the population. There are different motivations for this choice. For instance, Lindert (2004a,b) exploits enrollment rates as a dependent variable. Here, the number of students in the population would be a closely relate measure. Further, Baqir (2002) and Lindert (2004a,b) aim at explaining other types of public social spending with their models. Intuitively, it is clear that the age distribution of the population in this case is a more relevant explanatory factor than the number of students in the population. And finally, Lindert (2004a,b) and Stasavage (2005) aim at explaining the effect of increased voter power on educational spending. Then, of course, it is crucial to consider the age distribution, which is a determinant of the median voter income and preferences. In the present case, however, the intention is to control for the indirect effects of democracy, which work through the number of students. Those are presumed to be a result of the increase in voter's power which is not the focus of the analysis.

[53] The enrollment figures reflect the year 1910. They were borrowed from Lindert (2004a,b) and are available online at http://www.econ.ucdavis.edu/faculty/fzlinder/Lindert%20data%20CUP%20book/App._T._A1__primary_enroll.xls (downloaded: September 20, 2006).

other hand, urbanization is a proxy for the technological state of a country. More highly developed countries may simply have a greater need for education and thus stronger incentives for the government to intervene, even if democratic institutions are non-existent. Both measures are time-invariant.[54]

Eventually, public budgets are path-dependent. It is hard to believe that expenditures for educational purposes are planned from scratch every other year. Instead, budget positions are likely to be negotiated based on last year's scope of the respective position. That is, if anything, one should expect the increments or decrements rather than the absolute levels, to depend on the described variables. Hence, there is economic reasoning for the inclusion of a lagged dependent variable (LDV) in the models. But there is technical reasoning, too, because the presence of serial correlation suggests that the model is dynamically incomplete. However, the accommodation of an LDV would potentially cover up much of the cross-sectional influence on educational spending levels. This concerns, for instance, the time-invariant variable *dstock*. By construction, it does not influence the incremental yearly changes in education expenditures. But for this study, it is really of interest, which factors are decisive for the long-run path an economy follows irreversibly. Hence, two sets of regression analyses are performed, one excluding the LDV and one including it. The next section considers the entailed issues regarding estimation techniques more carefully.

Finally, two dummy variables for the time periods 1925-1929 and 1935-1938 are accommodated in order to capture potential time-dependent behavior of the explained

[54] Urbanization was extracted from Taylor and Hudson (1972). It is measured as the percentage of population living in cities > 100,000 inhabitants. Ethno-linguistic fractionalization was taken from Roeder (2001). Both sources only contain post-WW-II figures around 1960. They do not cover the interwar period. But since both indicators can be assumed to be rather constant over time, the use of the available figures does not seem to pose a problem.

variables.[55] The reference period is 1929-1934. It contains the years of the Great Depression. According to Figure 3.3, one would expect negative signs for the period dummies.

3.3.2 Estimation strategy[56]

Unfortunately, none of the available estimators can be claimed to deliver one hundred percent waterproof estimates of the described specifications. Each one has its shortcomings, and the selection of an allegedly least deficient estimator seems at best arbitrary. There is no reliable way to estimate the coefficients with the data at hand. But leaving the new data lie idle for this reason would be even more inappropriate. Hence, to make best use of what has become newly available, it appears most reasonable to rely on a comparative approach contrasting a whole arsenal of estimation techniques with each other. Such a comprehensive overview of results promises more reliable insights than the selection of a specific method.

The estimation approach starts with ordinary least squares estimation (OLS). In order to account for unobserved heterogeneity across countries, which is potentially correlated with one or more of the explanatory variables, fixed effect estimation (FE) or first differencing (FD) are the standard approaches. The latter offers the additional benefit of eliminating unit roots, which cannot be unambiguously rejected for the dependent variables. FE and FD, however, do not permit the estimation of time-invariant variables, such as the stock of democracy. Those would cause perfect multicollinearity with the fixed country effects. For this reason, random effect estimation (RE) is employed. It utilizes some of the cross-sectional information and allows for time-invariant variables to be included. The Hausman test for

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[55] It is common practice to include a full set of time dummies in a panel analysis. In the present case, however, the number of observations is reduced already due to the restricted availability of some control variables. In order to not further restrain the degrees of freedom, the time dummy set has been reduced to period dummies.

[56] All of the described estimators and tests have become state-of-the-art panel techniques. They are compiled in the textbook by Baltagi (2005).

substantial differences between FE and RE results yields a negative statistic in many cases. Anyway, there is no need to decide which estimates are most reliable, because the purpose of this analysis is to provide a comparative overview over the results from different estimation techniques. Alternatively, as a compromise between FE and RE, the Hausman-Taylor estimator (HT) permits the incorporation of time-invariant variables, too, maintaining the assumption of exogeneity for a defined set of variables. More specifically, HT estimation requires four groups of variables to be present in the model: time-invariant exogenous as well as endogenous variables, and time-varying exogenous as well as endogenous variables. If one group is not represented, the estimation cannot be performed. When declaring *dstock* as an endogenous variable, this requirement is fulfilled, only if the full set of control variables is included in the regression. Now, all of the estimates still suffer from considerable serial correlation, which results in overly optimistic significance levels. Most empirical studies try to dodge this problem by collapsing the yearly information to 5-year cohorts and performing pooled OLS and FE estimation. This way much of the available information is neglected and the already restricted sample sizes are further reduced. Instead of hollowing out the actual advantage of having panel data at hand, two different approaches offer themselves to deal with the presence of serial correlation. First, within group and random effects estimations can be performed on the data after they have been transformed to remove the AR(1) component (FEAR and REAR). Both estimators evade the loss in efficiency associated with the presence of serial correlation.

Reasoning that serial correlation can be interpreted as a sign of a dynamically incomplete model specification, however, it may be more self-evident to add a lagged dependent variable to each of the four models as a second way to solve the problem. This decision is encouraged by the fact that there is an economic rationale behind the accommodation of a LDV. To deal with the so-called Nickell bias, which is entailed when standard panel estimation techniques are used on a dynamic specification, more advanced methods are now required. The Arellano-Bond estimator (AB) is the standard approach for dynamic panels. It is based on the first-differenced regression equation, which eliminates the unobserved effects, and makes use of lagged levels of the dependent variable to instrument for the first differences of the lagged dependent variable. A GMM procedure minimizes the sum of the orthogonality restrictions, which arise from the postulate that the instruments be uncorrelated with the error term. At the same time, this estimator offers the possibility to instrument for the democracy variable, which may well be under suspicion in terms of endogeneity. Again, however, it is impossible to estimate time-invariant variables. The Blundell-Bond system estimator for dynamic panels (BB) can do that. It exploits both the regression equation in first differences as well as in levels and uses lagged differences as instruments in the second equation. Not only is the estimation of time-invariant variables possible with BB; if the dependent variable exhibits unit-root-like behavior, it has even better properties than the AB estimator. After all, both AB and BB estimators are most appropriate for micro-panels, because they rely on large N asymptotics. In smaller samples, like the one in this study, the Sargan test for overidentification frequently rejects the hypothesis of exogenous instruments. Hence, the estimates need to be considered with care. One solution is to restrict the number of instruments. Various restrictions will be tested to illustrate how the estimation results depend on this choice. Five different lag structures will be considered for the instruments in AB estimation, and four in BB estimation.

Finally, it makes sense to follow Beck and Katz (2005), and perform OLS with panel-corrected standard errors (PCSE) on the original specifications including a lagged dependent variable. In doing so, one ignores the Nickell bias, which may be substantial when T is small. Depending on whether individual effects are included, the technique is analogous to OLS or

FE estimation. But contrary to those, the PCSE technique accounts for potential cross-sectional correlation.

3.4 Results

Table 3.2 lists the estimated coefficients for the variables *dem* and *dstock* according to (3.1). Each line represents a different estimator.[57] The variable *dstock* is dropped from all regression models that do not allow the estimation of time-invariant variables. First, consider the estimates excluding the full set of control variables. Only the two period dummies and the indicator of proposed vs. actual budget figures are accommodated.

OLS estimation yields highly significant coefficients for the variables of interest. While the contemporaneous polity index has a positive coefficient, the index averaged since 1875 receives a negative one. This outcome points to an opposing relationship between the short-term and long-term impact of democracy. When controlling for fixed individual effects (FE), the coefficient of *dem* is no longer significant and turns negative. Possibly, the rather short

[57] The following Stata 10 estimation commands were used for the analyses: -xtreg- (OLS), -xtreg, fe- (FE), -xtreg, re- (RE), -xtreg- (FD), -xthtaylor- (HT), -xtregar, fe- (FEAR), -xtregar, re- (RE), -xtabond- (AB), -xtdpdsys- (BB), -xtpcse- (PCSE). AB1 uses all available lags in levels, starting in t-3, as instruments for the differenced lagged dependent variable $\Delta(cee/y)_{t-1}$, and the differenced variable Δdem. AB2 constrains the number of lags on each variable to two. AB3 instruments only for the lagged dependent variable (2 lags). Even more restricted, AB4 includes only one lagged level to instrument for $\Delta(cee/y)_{t-1}$. Finally AB5 allows one lagged level for both the differenced lagged dependent variable and the differenced democracy indicator. All estimates are based on the one-step version of AB. The significance levels change slightly when the one-step estimator is based on robust standard errors. So do the coefficients when the two-step procedure is employed. Nevertheless that does not affect the conclusions drawn from the analysis. BB1 uses all available lags in levels for the dependent variable in the first differenced equation and all available lags in first differences for the level equation. BB2 is restricted to just two lags. BB3 is analogous to BB1 except that it additionally instruments for the variable *dem* using all available lags. BB4 then is restricted to two lags for each instrumented variable. PCSE1 is OLS with panel corrected standard errors. PCSE2 additionally allows for first order autocorrelation in the disturbances. PCSE3 accomodates country dummies in order to capture unobserved individual effects. It is comparable to the FE estimate. PSCE4 is analogous to PCSE2. When the lagged dependent variable is dropped from the PCSE estimates, the estimated coefficients of PCSE1 (PCSE3) equal the OLS (FE) estimate. Similarly, when allowing the disturbances to be AR(1) processes (PCSE2 and PCSE4), the estimated coefficients resemble the FEAR and REAR estimates.

Table 3.2 - Coefficient estimates based on (3.1)

Dependent Variable: Total public educational spending / Total public spending, 1925-1938						
	excluding control variables			including control variables		
	dem	*dstock*	N	*dem*	*dstock*	N
OLS	0.00245 *(0.004)*	-0.00562 *(0.000)*	320	0.00314 *(0.001)*	-0.00618 *(0.000)*	226
FE	-0.00068 *(0.143)*		459	0.00083 *(0.221)*		310
FD	0.00046 *(0.113)*		408	0.00063 *(0.124)*		267
HT				0.00115 *(0.161)*	-0.00371 *(0.378)*	226
RE	-0.00107 *(0.066)*	-0.00141 *(0.301)*	320	0.00137 *(0.090)*	-0.00512 *(0.012)*	226
FEAR	-0.00032 *(0.615)*		414	-0.00019 *(0.838)*		278
REAR	-0.00016 *(0.805)*	-0.00224 *(0.101)*	320	0.00130 *(0.118)*	-0.00529 *(0.010)*	226
Incl. LDV						
AB1	-0.00034 *(0.662)*		367	-0.00099 *(0.325)*		243
AB2	-0.00122 *(0.450)*		367	-0.00286 *(0.083)*		243
AB3	0.00128 *(0.131)*		367	0.00075 *(0.497)*		243
AB4	0.00114 *(0.201)*		367	0.00057 *(0.605)*		243
AB5	-0.00388 *(0.095)*		367	-0.00271 *(0.152)*		243
BB1	0.00059 *(0.452)*	-0.00153 *(0.178)*	284	0.00118 *(0.284)*	-0.00272 *(0.046)*	204
BB2	0.00109 *(0.314)*	-0.00249 *(0.129)*	284	0.00199 *(0.153)*	-0.00416 *(0.026)*	204
BB3	0.00000 *(0.998)*	-0.00087 *(0.378)*	284	0.00120 *(0.255)*	-0.00244 *(0.070)*	204
BB4	0.00046 *(0.724)*	-0.00161 *(0.315)*	284	0.00247 *(0.111)*	-0.00393 *(0.041)*	204
PCSE1	0.00008 *(0.869)*	-0.00059 *(0.344)*	284	0.00084 *(0.259)*	-0.00194 *(0.026)*	204
PCSE2	0.00016 *(0.745)*	-0.00075 *(0.263)*	284	0.00138 *(0.117)*	-0.00303 *(0.006)*	204
PCSE3	-0.00081 *(0.099)*		410	0.00004 *(0.927)*		282
PCSE4	-0.00065 *(0.235)*		410	0.00005 *(0.907)*		282

Notes: p-values in parentheses.

observation period does not contain enough time variability in the democracy indicator for the effect to surface in an estimation that takes into account purely time variance. The FD estimator differs in that the coefficient is positive, but still non-significant. Anyway, the size of the coefficient is economically hardly relevant in both cases. The RE estimates confirm the direction of the long-run effect, even though the coefficient is non-significant. The short-run effect remains negative, too. The FEAR and REAR estimates do not change these insights. Also, the picture persists in dynamic regression models. No statement can be made in terms of the short-run effect; the coefficient of *dem* is positive in 8 and negative in 5 estimates. Conventional significance levels are at best grazed. But the long-run measure *dstock* exhibits a negative (but non-significant) sign in all cases. Most notably, the sign is robust to the inclusion of the full set of control variables. Here, the negative long-run effect of democracy turns significant at conventional levels in all models but RE, whereas the short-run coefficient remains non-significant in most models. Anyhow, the latter now has a positive sign in all but four estimates.

Table 3.3 - Coefficient estimates based on (3.2)

Dependent Variable: Central state educational spending / Total central state spending, 1925-1938						
	excluding control variables			including control variables		
	dem	*dstock*	N	*dem*	*dstock*	N
OLS	0.00405 *(0.000)*	-0.00714 *(0.000)*	314	0.00637 *(0.000)*	-0.00572 *(0.000)*	169
FE	0.00003 *(0.910)*		451	0.00062 *(0.236)*		243
FD	0.00021 *(0.235)*		400	0.00028 *(0.383)*		200
HT				0.00382 *(0.023)*	0.00009 *(0.987)*	169
RE	0.00037 *(0.286)*	-0.00253 *(0.089)*	314	0.00393 *(0.010)*	-0.00282 *(0.568)*	169
FEAR	0.00010 *(0.756)*		406	-0.00066 *(0.320)*		216
REAR	0.00045 *(0.262)*	-0.00255 *(0.064)*	314	0.00502 *(0.000)*	-0.00403 *(0.223)*	169
Incl. LDV						
AB1	-0.00006 *(0.855)*		359	-0.00014 *(0.785)*		183
AB2	0.00065 *(0.248)*		359	-0.00002 *(0.984)*		183
AB3	0.00021 *(0.543)*		359	0.00008 *(0.892)*		183
AB4	0.00013 *(0.741)*		359	0.00054 *(0.419)*		183
AB5	-0.00050 *(0.561)*		359	0.00041 *(0.684)*		183
BB1	0.00040 *(0.173)*	-0.00067 *(0.049)*	277	0.00243 *(0.051)*	-0.00108 *(0.397)*	155
BB2	0.00034 *(0.225)*	-0.00060 *(0.054)*	277	0.00312 *(0.015)*	-0.00168 *(0.178)*	155
BB3	0.00025 *(0.327)*	-0.00042 *(0.154)*	277	0.00173 *(0.083)*	-0.00025 *(0.753)*	155
BB4	0.00077 *(0.013)*	-0.00103 *(0.005)*	277	0.00475 *(0.001)*	-0.00255 *(0.034)*	155
PCSE1	0.00003 *(0.923)*	-0.00014 *(0.718)*	277	0.00134 *(0.044)*	0.00008 *(0.929)*	155
PCSE2	0.00006 *(0.848)*	-0.00019 *(0.649)*	277	0.00181 *(0.026)*	-0.00002 *(0.983)*	155
PCSE3	-0.00007 *(0.735)*		400	0.00010 *(0.854)*		222
PCSE4	-0.00007 *(0.768)*		400	0.00010 *(0.866)*		222

Notes: *p*-values in parentheses.

Estimating equation (3.2) yields overall similar results. Observe from Table 3.3 that all but three estimates deliver a positive short-run effect, and in all but two cases, the long-run effect is negative, provided that the control variables are included. Excluding them, all but four models yield a positive short-run effect and all models a negative long-run effect. In many estimates, the negative long-run effect is significantly different from zero at conventional levels.

Table 3.4 - Coefficient estimates based on (3.3)

Dependent Variable: Total public educational spending / GDP, 1925-1938						
	excluding control variables			including control variables		
	dem	*dstock*	N	*dem*	*dstock*	N
OLS	0.00017 *(0.182)*	-0.00125 *(0.000)*	260	0.00038 *(0.000)*	-0.00080 *(0.000)*	201
FE	-0.00011 *(0.346)*		321	-0.00004 *(0.702)*		243
FD	0.00014 *(0.027)*		279	0.00007 *(0.338)*		200
HT				0.00004 *(0.690)*	-0.00042 *(0.419)*	201
RE	-0.00007 *(0.562)*	-0.00085 *(0.021)*	260	0.00006 *(0.518)*	-0.00035 *(0.306)*	201
FEAR	0.00005 *(0.749)*		290	-0.00001 *(0.905)*		216
REAR	0.00002 *(0.876)*	-0.00091 *(0.006)*	260	0.00011 *(0.276)*	-0.00039 *(0.158)*	201
Incl. LDV						
AB1	-0.00001 *(0.941)*		249	-0.00002 *(0.842)*		178
AB2	0.00009 *(0.791)*		249	-0.00010 *(0.611)*		178
AB3	0.00016 *(0.410)*		249	0.00009 *(0.487)*		178
AB4	0.00019 *(0.349)*		249	0.00014 *(0.290)*		178
AB5	-0.00006 *(0.903)*		249	-0.00008 *(0.730)*		178
BB1	0.00002 *(0.909)*	-0.00061 *(0.015)*	230	0.00028 *(0.113)*	-0.00059 *(0.036)*	177
BB2	0.00003 *(0.802)*	-0.00060 *(0.020)*	230	0.00032 *(0.079)*	-0.00062 *(0.036)*	177
BB3	0.00000 *(0.996)*	-0.00051 *(0.031)*	230	0.00026 *(0.110)*	-0.00054 *(0.029)*	177
BB4	-0.00017 *(0.446)*	-0.00040 *(0.070)*	230	0.00052 *(0.001)*	-0.00078 *(0.022)*	177
PCSE1	-0.00001 *(0.909)*	-0.00049 *(0.001)*	230	0.00025 *(0.004)*	-0.00053 *(0.000)*	177
PCSE2	0.00004 *(0.636)*	-0.00069 *(0.000)*	230	0.00032 *(0.001)*	-0.00062 *(0.000)*	177
PCSE3	-0.00009 *(0.274)*		281	-0.00008 *(0.283)*		212
PCSE4	-0.00005 *(0.530)*		281	-0.00007 *(0.385)*		212

Notes: *p*-values in parentheses.

Not much changes in the regression analyses for (3.3) and (3.4) (Table 3.4 and Table 3.5). Remember that both are analogous to the first two regression equations except for the change in the reference category, which is now GDP. They contain the scope of government as a fraction of GDP on the right-hand side. The latter is included in the regressions that excluded the control variables, too. Table 3.4, again, reveals no unambiguous evidence for a short-run effect of democracy, whereas the finding of a negative long-run effect receives strong support at conventional significance levels.[58] This result is strengthened by Table 3.5. The difference here is that the contemporaneous effect of democracy turns out positive in all models and significant in many of them.

Table 3.5 - Coefficient estimates based on (3.4)

Dependent Variable: Central state educational spending / GDP, 1925-1938						
	excluding control variables			including control variables		
	dem	*dstock*	N	*dem*	*dstock*	N
OLS	0.00047 *(0.000)*	-0.00086 *(0.000)*	254	0.00049 *(0.000)*	-0.00093 *(0.000)*	169
FE	0.00006 *(0.255)*		313	0.00006 *(0.365)*		243
FD	0.00008 *(0.031)*		271	0.00006 *(0.148)*		200
HT				0.00001 *(0.952)*	-0.00033 *(0.734)*	169
RE	0.00006 *(0.219)*	-0.00035 *(0.114)*	254	0.00007 *(0.705)*	-0.00031 *(0.665)*	169
FEAR	0.00012 *(0.069)*		282	0.00007 *(0.421)*		216
REAR	0.00008 *(0.137)*	-0.00040 *(0.038)*	254	0.00045 *(0.005)*	-0.00069 *(0.099)*	169
Incl. LDV						
AB1	0.00013 *(0.002)*		178	0.00013 *(0.056)*		178
AB2	0.00030 *(0.001)*		178	0.00005 *(0.648)*		178
AB3	0.00000 *(0.937)*		178	0.00007 *(0.408)*		178
AB4	0.00007 *(0.249)*		178	0.00020 *(0.052)*		178
AB5	0.00018 *(0.124)*		178	0.00006 *(0.664)*		178
BB1	0.00015 *(0.012)*	-0.00029 *(0.001)*	223	0.00009 *(0.197)*	-0.00011 *(0.268)*	151
BB2	0.00016 *(0.015)*	-0.00031 *(0.002)*	223	0.00024 *(0.089)*	-0.00033 *(0.045)*	151
BB3	0.00008 *(0.010)*	-0.00015 *(0.002)*	223	0.00008 *(0.211)*	-0.00009 *(0.305)*	151
BB4	0.00011 *(0.043)*	-0.00026 *(0.004)*	223	0.00031 *(0.013)*	-0.00033 *(0.052)*	151
PCSE1	0.00006 *(0.088)*	-0.00012 *(0.033)*	223	0.00007 *(0.170)*	-0.00008 *(0.243)*	151
PCSE2	0.00010 *(0.021)*	-0.00018 *(0.011)*	223	0.00010 *(0.082)*	-0.00012 *(0.152)*	151
PCSE3	0.00008 *(0.058)*		272	0.00010 *(0.122)*		212
PCSE4	0.00008 *(0.148)*		272	0.00009 *(0.191)*		212

Notes: *p*-values in parentheses.

In light of the tremendous variation in the estimated coefficient sizes, as well as the imperfections of each single estimator, it does not seem legitimate to give a concrete figure for the marginal effects. Hence, just for orientation, consider that OLS was the preferred method and (3.1) the preferred model. Then, a state with an average democracy score over the

[58] Note that the p-values of *dstock* in (3.2) and (3.4) deteriorate when the control set is included whereas this is not the case in (3.1) and (3.3). This is probably due to the control variable *loc* being time-invariant in (3.2) and (3.4) and thus having a higher degree of collinearity with *dstock* in those specifications.

last 50 years of 10 points would be expected to assign roughly 13 percentage points less of public resources to educational purposes than a state with a completely authoritarian history. Short-term, however, running the democracy scale would win roughly 6 percentage points. This is after controlling for any other influence. Given that the average scope of the educational budget in total spending is roughly 9% in the sample, this is an immense impact.

3.5 Discussion

Apart from the already discussed data limitations, a few more issues deserve brief reflection. Attention will be drawn to a couple of technicalities, which represent the most prevalent criticism against regression analyses. Many of them can be mitigated, based on the diverse set of employed estimation techniques.

One of the major caveats is the loss of observations, which is partly due to the limited availability of control variables and GDP data, and partly due to the nature of the estimation techniques (e.g. first differencing). Many estimates utilize less than half of the potential maximum number of 468 observations. A sample selection problem may well be an implication of this matter. Employing multiple estimation techniques, however, guarantees that some estimates use almost the entire sample. The largest samples sizes are obtained via methods, which exclude the control set as well as any time-invariant variables, and which do not use GDP on the left-hand side. Admittedly, the estimates with the largest number of observations provide the weakest support for a positive short-term effect of democracy. After all, however, little can be done to remedy this problem, apart from highlighting it.

Next, important factors may have been omitted from the analysis. The most obvious is probably the extent of private education expenditures, which can be expected to be negatively related to public spending. The estimates, which do not control for unobserved heterogeneity might be biased downwards, because the democracy variables may pick up this omission. In fact, it may be suspected that the long-term effect of democracy turns out negative in the estimates, just because countries with a long democratic history are likely to have a more highly developed private education system.

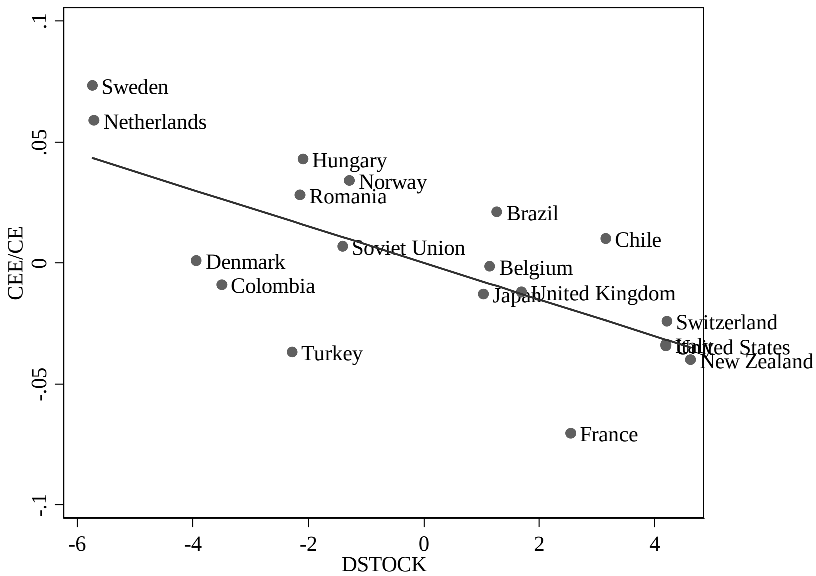

Figure 3.4. Added variable plot for *dstock*[59]

Figure 3.4 supports this view. It shows that in 1937, states like the United States, New Zealand, and Switzerland, which are well-known for their relatively large private contribution to education finance, had low public spending and a high average degree of democratization.[60] Conversely, Northern European countries like the Netherlands, Sweden, Norway and Denmark, which have been monarchies for a long time, are found to be the ones most

[59] The chart is based on a simple cross-sectional OLS estimation of *cee/ce* on *dstock*, controlling only for *dem* and *loc*. The regression contains 18 observations for the year 1937. The slope of the line can be interpreted as the influence of *dstock*, after the other two variables have been controlled for.

[60] Also, Canada belongs in this list. It is missing in Figure 4, because no information was available for this specific year. If the chart was created for 1936, Canada would appear in the lower right corner.

committed to public education. These countries are also known for slender private participation in education finance, even until today.

Further, the control variables are in part strongly correlated with each other, as the correlation matrix in Appendix A.2 indicates. Nevertheless the variance inflation factors do not indicate a multicollinearity problem. Anyway, the standard errors are expected to improve given a reduction in the degree of multicollinearity. If anything, this would improve the p-values. As a test, equation (3.1) which implies the highest case number, has been estimated without the variables measuring ethno-linguistic fractionalization, urbanization, welfare spending, military spending, and the educational history. The coefficients on *dem* and *dstock* did indeed come with better p-values in almost all estimates. Nevertheless, it ought to be emphasized that the purpose of this paper is to determine whether democracy directly affects educational commitment, even after controlling for all kinds of channels democracy might work through. For the sake of clarity and conciseness, the findings regarding the control variables shall not be scrutinized. Nevertheless, Appendix A.1 contains the complete regression tables employing OLS, PCSE2 and BB4 estimators. A noteworthy side result is that government spending as a share of GDP turns out highly significant. Apparently, educational spending rises along with total government spending. For instance, the regression analysis of (3.3) indicates that, when the share of total public consumption in GDP increases by one percentage point, education expenditures go up by roughly 0.06 percentage points. Given the average share of educational spending in the total central state budget of roughly 9% in the estimated sample, this is just a little bit less than what would be expected if educational budgets moved exactly in line with the total budget figures. Further, there may be a trade-off between defense and educational spending (see results of equation (3.2)). But since other studies have not found the same result, it is conceivable that this phenomenon is limited to the interwar period. Also, it stands out that GDP per capita is negatively related to the share of education expenditures in the total budget. The straightforward interpretation is that educational spending is less sensitive to economic shocks than other budget positions. Because the turbulences during the interwar period were unanticipated, the educational budgets showed little reaction.[61] Eventually, pre-WW I enrollment rates seem to be negatively related to public educational spending in the interwar period. It is conceivable that states with previously high enrollment rates had lower incentives to spend public money on education in the interwar period. On the other hand, those states might have just been the ones with a long democratic history and have already had relatively well developed private education systems in 1910. Other control variables do not exhibit notable patterns.

Another popular criticism is that of potential endogeneity. One may simply question the causal relationship between democracy and education expenditures. The approach chosen in this paper, however, is armed to convincingly refute this concern. First of all, the Arellano-Bond and Blundell-Bond estimation techniques provide a way to conveniently instrument for the potentially endogenous variable *dem* along with the lagged dependent variable. This has been put into action in the procedures AB2, AB5, BB3, and BB4, which do not deviate strongly from the remaining AB and BB estimates. But an even more powerful argument is inherent in the model specification. Key is the inclusion of the variable *dstock*. Most researchers would probably agree to accept it as exogenous. The estimates suggest a fairly robust negative effect of a long democratic history on public educational spending. If the positive sign on the short-run variable *dem* was due to reversed causality, then the negative

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[61] This is supported by the finding of a robust negative and significant sign of the first period dummy in AB and FD estimates. The fact that this outcome cannot be observed in the estimates documented in the appendix, is probably owed to the peculiar nature of the period dummy. In the first-differenced specification the dummy is always zero except in the period that contains the difference between the years 1929 and 1930, when the 1925-1929 time dummy jumps from 0 to 1. Since this is the period when the great depression started, the negative sign implies that educational spending as a share of GDP went up when the economic decline started. Apparently, education expenditures are relatively inelastic to macroeconomic shocks. Thinking about the inflexible nature of the components of the cost of education such as teachers who have life-time contracts, this does not seem implausible.

long run effect would be entirely implausible. It would mean that, in the long run, democracy causes lower schooling spending which in turn reduces democracy in the short run. In other words, a long history of democracy would necessarily cause a swing towards less democracy due to its effects on schooling spending. This is hardly compatible with common sense. Hence, the inclusion of the variable *dstock* offers an elegant way to ensure that the contemporaneous effect is not a consequence of reversed causality.

Next, normality of residuals is not given in all of the estimates.[62] Graphical analysis, however, suggests that in most cases the residual distribution has comparable or less probability mass in the tails than the respective normal distribution. This implies that, if worse comes to worst, the significance levels, which are calculated based on an assumed normal distribution with the estimated standard deviation of the residuals, are likely to be too pessimistic rather than too optimistic. Moreover, Hamiltons IQR test does not reveal severe outliers in the majority of the estimates.[63] Hence, overall, it is concluded that hypothesis testing is sufficiently reliable.

Heteroskedasticity has been dealt with in the OLS, AB, BB and PCSE estimates. In those cases the reported significance levels are based on robust standard errors. Only FE, RE, FEAR, and REAR do not make this correction.

Another problem arises, because the observed time period is rather short. The democracy indicator is quite stable over time in general. Hence, there is little variability in *dem*, even though the interwar period is already one of the richest in terms of changes in political regime characteristics. An extension of the observation period to encompass years subsequent to 1938 is omitted because of distortions that may have been imposed on the

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[62] This has been tested using the skewness and curtosis test for normality (-sktest- in Stata 10).

[63] IQR stands for interquartile range (-iqr- in Stata) and can be downloaded as a Stata ado-file (see also Hamilton, L.C., 1991: Resistant normality check and outlier identification, *Stata Technical Bulletin* 9/91, 15-18).

public by budgets for WW II. Data for years preceding 1925 are simply not available. A promising alternative is the comparison of educational spending in the interwar period and after WW II, say in 1960, for a cross-section of countries.

Potential problems would also be created, if the dependent variables were non-stationary. Because the panel is unbalanced, it is not trivial to apply well-established panel unit roots tests. As a solution, Dickey-Fuller (ADF) tests are applied separately to each series with at least 12 successive observations for the dependent variables in both, M1 and M2. Only in a few cases the null of non-stationarity can be rejected. Additionally, the Levin-Lin-Chu panel unit root test is deployed on the greatest possible balanced panel extractable from the whole dataset.[64] Varying numbers of lags are included to eliminate serial correlation. Regardless of the quantity of lags, non-stationarity is rejected for both dependent variables. Yet, in light of the DF tests, no all-clear can be given in terms of the stationarity requirement. Nevertheless, some of the estimation techniques perform quite well if the dependent variable is close to a unit root, e.g. BB and FD. The latter would even eliminate it completely. After all, the issue of a unit root loses importance when N is large. In the present case it is roughly twice the size of T. And, last but not least, the main finding of this paper, the negative long-run effect of democracy, is a cross-sectional phenomenon and would remain unaffected by the presence of a unit root anyway.

Summarizing the results of four models, twenty different estimators and two modifications (inclusion and exclusion of control variables), the most convincing finding is probably the negative long-run effect of democracy.[65] It is hard to argue against the fact that

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[64] The Stata commands employed are -dfuller- for the augemented Dickey-Fuller test, and -levinlin- for the Levin-Lin-Chu test. The latter is available as an ado-file from http://fmwww.bc.edu/repec/bocode/l/-levinlin.ado.

[65] This result persists even when the average democracy score is computed back through 1825 instead of 1875. For reporting purposes the latter option is preferred, however, because the democracy indicator is not available back through 1825 for all countries. This leads to a reduction in sample size.

the coefficient sign was widely robust across estimation techniques, in many cases significant or close to being significant. More specifically, it was positive in only 2 out of 76 estimates, which included the time-invariant variable *dstock*. This effect is a purely cross-sectional phenomenon. In turn, no robust statement can be made in terms of the contemporaneous effect. Overall, the evidence is too weak to speak of a robust short-term influence. Nevertheless, it stands out that a negative sign emerges almost exclusively in those estimates that exclusively employ the time variability. Hence, it may be a corollary of the short observation period. On the other hand, it might simply pick up the negative long-run effect. When cross-sectional variation is utilized, the sign is mostly positive. The strongest support is given by OLS, BB4 and PCSE2. Hence, there may well be antagonistic influences of democratization. While this cannot be taken as a strong form of evidence, the notion persists when controlling for a whole set of other public educational spending determinants. In fact, the coefficients of both variables are not attenuated notably upon incorporation of the control variables. In many instances they increase in absolute value. Hence, the estimated effects are likely to work immediately and not through other factors.[66]

Whereas the mechanisms at work remain unidentified - and speculating about them is not the main purpose of this article - a few possible interpretations of the finding are appropriate. On the one hand, countries with a strong democratic history may be more likely to develop a comprehensive private education system with considerable private funding. The latter is an omitted variable in the analysis. On the other hand, it seems plausible that a democratic history abets the development of a liberal ideology, according to which private returns to education are considered to provide sufficient incentives for private investors in education. Consequently, the priority of public education finance may be relatively low in

[66] Equation (3.1) has been estimated for a high-quality sub-sample utilizing only those observations which had more or less complete local information ($AV > 2$). The results provide very good support of the findings. But because the sample sizes are very small in those estimates, they are not reported.

those states. Furthermore, authoritarian systems can be expected to have a stronger tendency to publicly control education in order to ensure children being raised according to the prevailing ideology. Especially, as Easterlin (1981, p.12) states, "communist governments have vigorously promoted mass education as an instrument of political socialization." And finally, it is conceivable that the negative long-term effect is the result of a spurious regression. Some countries with a long democratic history and low educational spending in the interwar period (Switzerland, United States, Australia, Canada) have a strong Calvinistic background. After all, the protestant ethics in those countries may have been driving both, an early democratic development and lower responsibility of the state in terms of public education provision.

3.6 Conclusions

The presented project has been motivated by the empirical ambiguity regarding the existence of education externalities. If neither the need for market correction nor any other of Musgrave's (1959) reasons justify public financial intervention: what, then, drives public education finance strategies? Public choice theory has long been modeling the process of political decision making and its impact on the scope of government spending. It provides the theoretical foundation of many empirical studies on the relationship between democracy and public education expenditures. For once, it argues that increases in public service provision, and thus education spending, may be caused by widening the electorate. This has been empirically confirmed by Lindert (2004) and Stasavage (2005). On the other hand, it argues that other potentially democracy-related factors, such as bureaucracy, administrative efficiency or politicians' agenda control are important determinants of the size of government. Baqir (2002) and Brown and Hunter (2004) empirically capture those mechanisms by employing a more general measure of institutionalized democracy.

This paper has been framed differently, placing emphasis on yet another aspect of democracy. For this purpose, following Baqir (2002) a broad measure of political regime characteristics was applied. Additionally, the empirical specification was designed to control for social spending, which arguably captures the prominent impact of an extension of voters' influence, as well as the other discussed democracy-related effects. Therefore, it was maintained that a potential effect due to the democracy variables must reflect the implications of a change in ideology. Moreover, a long-run effect of democracy has been accommodated in the specification of the empirical model in addition to the short-term effect.

Most interestingly, the long-run effect turned out negative in most estimates. One way of explaining this is that democracies are ideologically less in favor of public financial support for education. Alternatively, one may think that authoritarian regimes use the education system to impose their philosophy on the youth. Yet another interpretation is that early democracies have more advanced private systems of education, which might crowd out public support in the long run.

Regarding the short-term impact, generalizations for the set of countries in the observed sample are hardly possible. Given that countries with a long democratic history have adopted the path to lower public education expenditures long ago, it is hard to argue - based on the estimation results - that in the short run they still have a stronger preference for public educational spending in the short run than less democratic countries with a comparable history. Hence, the ideological argument for a short-term effect of democracy drops out. The most striking counterexample in this regard is certainly the Soviet Union where public spending on education was rather generous during the interwar period in spite of the authoritarian character of the regime.

An arsenal of estimation techniques was employed to guard against the most prevalent technical criticism typically put forward against this type of quantitative analysis.

Nevertheless, keeping in mind the serious limitations of the database, the results of this article should not be taken as the ultimate truth, but rather as an impulse for discussion and further analyses.

In general it seems that path-dependency is the factor that dominates all other explanations of educational spending. Apart from the possibility that early democratic regimes may more likely develop institutions which foster private education, educational spending may follow something close to a random walk. A unit root could not clearly be rejected, and the lagged dependent variable in the estimates accounted for most of the explanatory power in the dynamic regression models. Also, common sense suggests that budget decisions are made primarily based on previous year's budget. The year-by-year surcharges and deductions depend only weakly on changes in the political regime characteristics. This is not to say that there can be no countries where political transitions or the ideology of political leaders do have an immediate impact. But making a general statement for a broad sample of countries is not safe. There may just be a very important traditional factor in educational spending levels.

So, if democracy is not clearly the regime type that leads to more public input for education, it would next be natural to investigate in the future whether it causes higher output. If this was the case, democracies could at least be argued to have the more efficient education systems.

Appendix A

A.1 Complete regression table based on (3.1) and (3.2)

	(3.1)						(3.2)					
	OLS		BB4		PCSE2		OLS		BB4		PCSE2	
LDV			0.46246	***	0.46931	***			0.62969	***	0.75638	***
			(0.002)		*(0.000)*				*(0.000)*		*(0.000)*	
dem	0.00314	***	0.00247		0.00138		0.00637	***	0.00475	***	0.00181	**
	(0.001)		*(0.111)*		*(0.117)*		*(0.000)*		*(0.001)*		*(0.026)*	
dstock	-0.00618	***	-0.00393	**	-0.00303	***	-0.00572	***	-0.00255	**	-0.00002	
	(0.000)		*(0.041)*		*(0.006)*		*(0.000)*		*(0.034)*		*(0.983)*	
loc	0.03156	*	0.05837	**	0.04438	***	-0.10334	***	-0.05270	**	-0.04239	***
	(0.078)		*(0.011)*		*(0.001)*		*(0.000)*		*(0.027)*		*(0.002)*	
av	0.00466		-0.00305		-0.00046							
	(0.134)		*(0.348)*		*(0.822)*							
Welf. exp	0.19773	*	0.19290		0.22241	***	0.46917		-0.36609		0.06346	
	(0.053)		*(0.205)*		*(0.000)*		*(0.291)*		*(0.281)*		*(0.807)*	
Milit. exp.	0.09218	*	0.11629		0.09650	**	-0.49790	**	-0.21103		-0.42229	***
	(0.074)		*(0.229)*		*(0.012)*		*(0.046)*		*(0.308)*		*(0.003)*	
log(y/pop.)	0.00263		-0.00920		-0.00775		-0.02814	**	-0.03013	**	-0.02343	***
	(0.816)		*(0.487)*		*(0.417)*		*(0.013)*		*(0.019)*		*(0.002)*	
Student fract.	0.17572	*	0.12929		0.15571		0.29931	***	0.09607		0.08428	
	(0.088)		*(0.365)*		*(0.139)*		*(0.001)*		*(0.217)*		*(0.192)*	
Ethn-ling. fract.	-0.04469	***	0.00308		0.00156		-0.06874	***	-0.01562		-0.01929	
	(0.008)		*(0.901)*		*(0.909)*		*(0.000)*		*(0.188)*		*(0.147)*	
urbanization	-0.00042	**	-0.00026		-0.00026		-0.00022		0.00022		0.00013	
	(0.041)		*(0.380)*		*(0.117)*		*(0.370)*		*(0.280)*		*(0.352)*	
Educ. history	-0.10085		-0.06111	**	-0.05774	**	-0.09574	***	-0.04779		-0.02826	
	(0.000)		*(0.032)*		*(0.020)*		*(0.000)*		*(0.104)*		*(0.190)*	
Time dummy	0.00284		0.01233	*	0.01209	**	-0.00041		-0.00166		0.00028	
1925-1929	*(0.703)*		*(0.099)*		*(0.036)*		*(0.947)*		*(0.650)*		*(0.931)*	
Time dummy	-0.00491		-0.00532		-0.00717		-0.00616		-0.00635	**	-0.00496	*
1935-1938	*(0.527)*		*(0.390)*		*(0.317)*		*(0.313)*		*(0.034)*		*(0.083)*	
Budget type	-0.00366		0.00857		0.00781		0.00341		0.01584	***	0.01287	**
	(0.715)		*(0.367)*		*(0.382)*		*(0.709)*		*(0.005)*		*(0.021)*	
R^2	0.58		0.87		0.65		0.79		0,97		0.91	
F-statistic	27.79		1428.49		346.53		94.84		30895.06		111045.56	
N	226		204		204		169		155		155	

Notes: p-values in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$. Constant not reported. In the BB4 estimate, the reported R^2 is the simple correlation between the predicted and observed values of the dependent variable, and the F-statistic is replaced by the Chi-squared statistic.

A.2 Complete regression table based on (3.3) and (3.4)

	(3.3)			(3.4)		
	OLS	BB4	PCSE2	OLS	BB4	PCSE2
LDV		0.20084 ***	0.17797 ***		0.68330 ***	0.84547 ***
		(0.000)	*(0.000)*		*(0.000)*	*(0.000)*
dem	0.00038 ***	0.00052 ***	0.00032 ***	0.00049 ***	0.00031 **	0.00010 *
	(0.000)	*(0.001)*	*(0.001)*	*(0.000)*	*(0.013)*	*(0.082)*
dstock	-0.00080 ***	-0.00078 **	-0.00062 ***	-0.00093 ***	-0.00033 *	-0.00012
	(0.000)	*(0.022)*	*(0.000)*	*(0.000)*	*(0.052)*	*(0.152)*
te/y	0.05967 ***	0.05542 ***	0.05464 ***	0.04939 ***	0.02591 **	0.01559 ***
(c*e/y* in Eq. 2.4)	*(0.000)*	*(0.004)*	*(0.000)*	*(0.000)*	*(0.032)*	*(0.007)*
loc	0.00705 ***	0.00945 ***	0.00876 ***	-0.00993 ***	-0.00287 *	-0.00107
	(0.000)	*(0.000)*	*(0.000)*	*(0.000)*	*(0.086)*	*(0.194)*
av	0.00201 ***	0.00154 **	0.00163 ***			
	(0.001)	*(0.037)*	*(0.000)*			
Welf. exp	0.07599	0.03246	0.05553	0.18876 ***	0.00513	0.01169
	(0.112)	*(0.615)*	*(0.145)*	*(0.004)*	*(0.887)*	*(0.695)*
Milit. exp.	0.06346	0.04257	0.03224	0.04365	0.00243	-0.00573
	(0.131)	*(0.558)*	*(0.447)*	*(0.158)*	*(0.933)*	*(0.687)*
log(y/pop.)	0.00537 ***	0.00290	0.00364 ***	0.00298 **	-0.00007	0.00017
	(0.000)	*(0.137)*	*(0.000)*	*(0.014)*	*(0.933)*	*(0.846)*
Student fract.	0.03158 ***	0.02452 *	0.01855	0.05540 ***	0.01338	0.00573
	(0.001)	*(0.097)*	*(0.185)*	*(0.000)*	*(0.204)*	*(0.374)*
Ethn-ling. fract.	-0.00674 ***	-0.00359	-0.00518 **	-0.00214	-0.00078	-0.00087
	(0.002)	*(0.395)*	*(0.034)*	*(0.180)*	*(0.528)*	*(0.289)*
urbanization	-0.00005	-0.00004	-0.00004 **	-0.00008 ***	-0.00002	-0.00002
	(0.101)	*(0.481)*	*(0.050)*	*(0.002)*	*(0.345)*	*(0.152)*
Educ. history	-0.01835 ***	-0.01603 ***	-0.01432 ***	-0.01529 ***	-0.00521 *	-0.00205
	(0.000)	*(0.002)*	*(0.000)*	*(0.000)*	*(0.097)*	*(0.313)*
Time dummy	-0.00036	0.00010	0.00012	0.00059	-0.00013	-0.00004
1925-1929	*(0.690)*	*(0.885)*	*(0.839)*	*(0.423)*	*(0.577)*	*(0.932)*
Time dummy	-0.00050	-0.00095	-0.00095 *	-0.00079	-0.00055	-0.00039
1935-1938	*(0.628)*	*(0.269)*	*(0.091)*	*(0.329)*	*(0.149)*	*(0.341)*
Budget type	-0.00220 *	-0.00076	-0.00047	-0.00231 *	0.00031	0.00030
	(0.074)	*(0.470)*	*(0.643)*	*(0.056)*	*(0.569)*	*(0.505)*
R^2	0.85	0.95	0.87	0.84	0.99	0.96
F-statistic	101.37	7516.52	5631.79	72.26	14014.44	10801.35
N	201	177	177	169	151	151

Notes: p-values in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Constant not reported. In the BB4 estimate, the reported R^2 is the simple correlation between the predicted and observed values of the dependent variable, and the F-statistic is replaced by the Chi-squared statistic.

A.3 Correlation matrix for equations (3.2) and (3.4)

	cee/y	cee/ce	Welf. Exp/ce	Milit. exp./ce	ce/y	Welf. Exp/y	Milit. exp./y	dem
cee/y	1.00							
cee/ce	0.74	1.00						
Welf. Exp/ce	0.09	0.12	1.00					
Milit. exp./ce	-0.16	-0.05	-0.46	1.00				
ce/y	0.69	0.11	-0.04	-0.16	1.00			
Welf. Exp/y	0.37	0.21	0.86	-0.38	0.28	1.00		
Milit. exp./y	0.41	0.05	-0.25	0.40	0.66	-0.02	1.00	
dem	-0.16	-0.10	0.55	-0.46	-0.26	0.42	-0.35	1.00
dstock	-0.43	-0.35	0.27	-0.26	-0.27	0.11	-0.22	0.74
Educ. history	-0.33	-0.11	0.45	-0.45	-0.27	0.24	-0.32	0.68
urbanization	-0.21	-0.26	0.42	-0.42	0.00	0.37	-0.16	0.53
Ethn-ling. fract.	-0.38	-0.51	-0.26	0.10	-0.05	-0.29	-0.07	-0.05
loc	-0.66	-0.74	0.08	0.01	-0.33	-0.19	-0.25	0.28
Log(y/pop)	-0.03	-0.07	0.57	-0.63	-0.04	0.42	-0.24	0.70
Student fract.	0.19	0.18	0.26	-0.44	0.28	0.21	0.05	0.46

	dstock	Educ. history	urbanization	Ethn-ling. fract.	loc	Log(y/pop)	Student fract.
cee/y							
cee/ce							
Welf. Exp/ce							
Milit. exp./ce							
ce/y							
Welf. Exp/y							
Milit. exp./y							
dem							
dstock	1.00						
Educ. history	0.73	1.00					
urbanization	0.57	0.72	1.00				
Ethn-ling. fract.	0.09	-0.33	-0.17	1.00			
Loc	0.19	0.12	0.39	0.33	1.00		
Log(y/pop)	0.71	0.81	0.75	-0.23	0.17	1.00	
Student fract.	0.58	0.72	0.48	-0.32	-0.03	0.60	1.00

4 Innovation and Growth on a Macro Level, 1500-1990[67]

This chapter employs a new literature-based innovation indicator to study the long-run relationship between innovation and growth as well as the nature of the innovation process on a country level. In the first step, it is revealed that homemade knowledge growth has not been a crucial determinant of national economic growth when looking at the period 1500-1990. Even in pre-industrial Europe, technological progress was generated collectively. In a second step, count data regression models are used to test the innovation production function typically proclaimed by innovation-driven growth theory. At the same time, the debates regarding frequently presumed determinants of innovation - scale, institutions, human capital, and geography - are revisited. Leaving potential data problems aside, the results suggest that, during 1500-1990, the idea generation process exhibited roughly constant returns to scale on a country level. Because of the first-step result, however, those did not precipitate in national economic growth rates. Further, the creation of new ideas seems to have become more difficult at higher levels of knowledge. If this is true in general, even on the world level a scale effect in economic growth rates can exist only if ideas increase in absolute effectiveness. Finally, institutions are found to have been of great importance for countries' innovativeness during the entire observation period. No evidence, however, could be found in support of schooling and geography as drivers of innovativeness.

[67] This paper has been conceptualized as a dissertation chapter in the first place. It has not yet been presented at conferences or submitted to journals.

4.1 Introduction

Generally, two types of economic growth have to be distinguished, the growth of leader countries, and the growth of follower countries. Follower growth results primarily from technology adoption, which is, in turn, determined by human capital availability (e.g. Easterlin, 1981; Lucas, 1988) and the institutional setting (North, 1981/1990).[68] The *ultimate* driver of growth, however, is technological progress (Helpman, 2004; Clark, 2007). It defines the growth rate of technological leaders as well as the growth potential of followers. Hence, studying the sources of growth boils down to exploring the drivers of technology in the end. Exogeneity of the latter in Solow's (1956) model was criticized many times. However, little progress has been made in terms of actually explaining the forces behind its development. Even the most recent advancements of growth theory - unified growth models -, which reconcile empirical facts of the Malthusian growth regime, the modern growth regime, and the demographic transition, frequently rely on exogenous technology parameters (e.g. Lucas, 2002; Boucekkine and de la Croix, 2007). Admittedly, technological progress may in fact be a self-sustained and exogenous process to a considerable extent, and thus be partly inevitable; innovations may happen irregularly and not at a constant predictable rate. For instance, Hansen and Prescott (2002) suggest that previously generated ideas may be more important determinants of subsequent innovations than anything else, and Galor and Moav (2001, 2002) even draw parallels to the evolutionary processes known in biology. Nevertheless, the proposition of humans being unable to influence the speed of technological advancement has been a source of discontent among economists.

Empirical studies so far investigate on the micro level the relationship between R&D expenditures and innovation success (Hausman, Hall and Griliches, 1984; Crépon and

[68] In this chapter, the term 'human capital' is preferred over the term 'education', because the former is primarily used by the macroeconomic growth literature.

Duguet, 1997; Blundell, Griffith and Windmeijer, 2002), respectively market share and innovation success (Blundell, Griffith, van Reenen, 1999). Using count data models, they aim at explaining the number of patents generated by firms. This paper is bedded differently. It ties to innovation-driven growth theory induced by Romer (1990) and Grossman and Helpman (1991), which explores the nature of the innovation process as well as its implications for economic growth on the macro level. The goal is to empirically test the features of the macroeconomic innovation production function commonly assumed by innovation-driven growth theory, and revisit the most prevalent debates regarding the nature and determinants of the innovation process. In doing so, it benefits from a newly available database (Metz, 2003). The latter contains a citation-based selection of important innovation events starting with the discovery of fire as early as 400.000 BC and may be argued to be a good reflection of human technological advancements throughout history. Providing information way beyond periods that are typically covered by patent collections, the database permits a quantification of countries' innovation success over a long period of time. Thereby, it offers a unique opportunity of retesting in count data models some hypotheses regarding the drivers of technological progress. The objective is to focus on aspects of the innovation process which can be generalized for a large set of countries and a long period of time, here 1500-1990.

The paper is structured as follows: Section 4.2 briefly summarizes the literature that deals with the determinants of innovation on the macro level. It provides the theoretical basis of the following empirical analyses. Section 4.3 lays out the content and structure of the database, as well as the work that was done to make the information applicable for the analysis. Section 4.4 asks what is more important for economic growth: homemade innovations or advances in the international stock of knowledge. Section 4.5 contains empirical tests of the hypotheses sketched in section 4.2 and discusses some technical issues.

Section 4.6 gives an interpretation of the results and demonstrates how they may serve to substantiate the theoretical models of innovation and growth. Section 4.7 concludes.

4.2 Literature and theoretical framework

Following the lead of Nordhaus (1969), who was among the pioneers attempting a formal economic theory of technological change, three major candidates have been explored in the literature as drivers of technological progress[69]: population, human capital (or better: education), and institutions.

In Grossman and Helpman (1991), who first merged innovation and growth theory, population size matters for innovativeness and constitutes the so-called scale effect. Jones (1995), however, presented evidence contradicting this hypothesis convincingly. The "Jones critique" was followed by semi-endogenous growth models, which imply that the growth rate of population rather than its level drives the economic growth rate. This is based on the assumptions of either increasing difficulty of innovations (Kortum, 1997; Segerstrom, 1998) or dispersing research effort (Dinopoulos and Thompson, 1998; Young, 1998; Peretto, 1998). Unfortunately, these models still imply a level effect, which raises concerns very similar to the Jones critique (Jones 1999). Nevertheless, both the scale and the level effect are not yet off the table. Kremer (1993) has argued that the former may exist for large regions in the long run, whereas Jones (2001) simulates a model with a population growth effect and produces results that are compatible with the actual long-run development of world economic growth. In fact, some unified growth theories, which model the demographic transition and the take-off from Malthusian stagnation to modern economic growth, rely on a scale effect to explain the gradually rising rate of technological progress before the outbreak of the Industrial

[69] I use the terms knowledge, technology, and technological knowledge interchangeably throughout this paper. Incremental changes in the stock of knowledge will be called ideas.

Revolution (Galor and Weil, 2000; Galor, 2005). Given this discrepancy between modern endogenous growth theory and the more historically oriented and holistic growth theory, it makes sense to further investigate the role of population in the innovation process.

Frequently, human capital is thought to drive technology.[70] As in Romer (1990), who was the first to model this idea, its effect is not always clearly distinguished from the effect of population. The term 'scale effect' may refer to the size of population or to the size of the human capital stock. In unified growth models, the level of human capital acts as a catalyst in that it accelerates the speed of technological progress during the demographic transition (Galor and Weil, 2000; Galor and Moav, 2001). The Jones critique, however, applies. Consequently, in endogenous growth theory, exogenous population growth was replaced by endogenous human capital accumulation, making the rate of progress depend on the rate of HC growth (Blackburn, Hung and Pozzolo, 2000; Arnold, 1998; Stadler, 2006). Contrary to the theoretical efforts, surprisingly little empirical work exists on the relationship between human capital and the outcomes of the innovation process, especially for the long run.[71] Given the relatively good availability of human capital measures for historical periods, such as numeracy (e.g. Crayen and Baten, 2008) and literacy, the only apparent reason for this is the lack of long-run innovation data. A gap which may be filled by this study!

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[70] Note that human capital may have a twofold effect (e.g. Temple 2001). On the one hand, it works as a production factor according to Lucas (1988). The speed of accumulation depends on the return to education which is set by the state of technology (Nelson and Phelps, 1966). On the other hand it may drive knowledge creation, i.e. technological progress. Those functions have also been referred to as *level effect* and *growth effect* of human capital, see chapter 2 of this work.

[71] Labuske and Baten (2007) examine the influence of schooling on patenting around the turn of the 20th century and find a significant positive effect. Khan and Sokoloff (2004) look at the biographies of US inventors and conclude that institutional factors were more decisive in stimulating their innovation activities than human capital. Of course, there is a bulk of empirical literature on the impact of human capital on economic growth (e.g. Barro 2001) but those studies make it difficult to judge whether the effect works through technology adoption or technology creation.

Formally, Schumpeterian models of innovation-driven economic growth dating back to Romer (1990) as well as Grossman and Helpman (1991) can be summarized a follows. Typically, they rely on an aggregate production function similar to

$$Y = AK^{\alpha} L^{1-\alpha}, \tag{4.1}$$

with $0 < \alpha < 1$.[72] K is the physical capital stock, and L represents the size of the productive labor force. The productivity parameter A is commonly interpreted as the stock of non-rival technological knowledge. Growth of this parameter is what causes sustained economic growth in the long run. Usually, the change in A, $\dot{A}$, is determined by an innovation production function of the type

$$\dot{A} = \delta A^{\phi} S, \tag{4.2}$$

where S is a scale factor, be it the size of the labor force or the stock of human capital. $\phi > 0$ implies that past discoveries make it easier to generate new ideas, whereas $\phi < 0$ means that they make it more difficult (see Jones, 1999). For this type of model to work on a country level, economic growth must strongly depend on homemade knowledge. If this was not the case, and A reflected the international technological frontier, which is the same for all countries, this formulation would not be capable of explaining why some countries lag so far behind the others.

Models of endogenous growth dating back to Lucas (1988) and Uzawa (1965) generate sustained economic growth by incorporating human capital in the production function:

$$Y = K^{\beta} (uH)^{1-\beta}, \tag{4.3}$$

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[72] Time and country indices are skipped.

with $0 < \beta, u < 1$. They crucially depend on the prerequisite of human capital, *H*, being able to grow without bound. Its growth rate depends on the fraction of time, 1-*u*, devoted by workers to its accumulation, or formally,

$$\dot{H} = B(1-u)H\ , \tag{4.4}$$

where *B* specifies the productivity of the education sector. Because the quantity of education cannot exceed an upper limit, this approach requires the subsumption of knowledge under the concept of human capital. Hence, it is conceptually not much different from the Schumpeterian approach and does not permit to separate the effects of knowledge growth on the one hand and improvements in education on the other hand. Nevertheless, it works better to explain cross-sectional differences in per capita income and emphasizes that follower countries may grow by accumulating human capital, because it enables them to adopt foreign knowledge.

Thanks to North (1981, 1990) the institutional setting has received increased attention as a crucial facilitator of economic development. Mokyr (1990) has emphasized its relevance for historical technological progress.[73] In particular, the protection and enforcement of property rights are regarded in this context.[74] It guarantees the appropriation of rents from inventive activity and generates an incentive to innovate. Empirical evidence on this issue, however, is ambiguous. Jones (2001) suggests that institutional changes were important in the timing of the Industrial Revolution. Khan and Sokoloff (2004) maintain that the US patent system was the decisive element in allowing the US to take over technological leadership in

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[73] Again, this effect should be distinguished from the role of institutions for technology adoption, which is what Acemoglu (2001), Hall and Jones (1999), and other authors have in mind when writing about the importance of institutions for economic growth.

[74] A whole literature has evolved around the concept of *national innovations systems*; see especially Freeman (1992, 1995) and Lundvall (1992, 2007). It encompasses a subset of institutions that is relevant for innovation, especially those that facilitate information flow and interactive learning, as well as educational and geographical aspects.

the 19th century. Based on countries' contributions to international technology exhibitions, Moser (2005) finds that the existence of patent laws determines the direction of technological innovations. Jaffe (2000) provides a meta-survey of studies focusing on the transition of the U.S. patent system. He questions the robustness of conclusions regarding the consequences of patent policy changes on technological innovation. In fact, Sakakibara and Branstetter (2001) provide evidence from a Japanese patent law reform in favor of reversed causality between patent protection laws and innovation input or output. In light of this contradictory evidence it seems worthwhile to also retest the effect of institutions on countries' innovativeness.

Finally, following Marshall (1890) who first mentioned externalities from industry concentration, the literature on innovation clustering and knowledge spillovers (e.g. Feldman, 1994; Audretsch and Feldman, 1994; Jaffe, Trajtenberg and Henderson, 1993) has emphasized many times that geographical proximity is an important determinant of innovative success, because it is likely to affect the speed of knowledge diffusion. In particular, this regards tacit knowledge (Gertler, 2007). Even though this argument typically alludes to an intra-national context, it can be presumed to be valid for larger geographical regions as well. That is, economies should be able to benefit more from new knowledge that was generated in close-by countries.[75]

No study could ever test those theoretical considerations for the very long run and a considerable number of countries. The availability of a new database offers the unique opportunity to make up for this lapse. The next section describes the respective data.

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[75] Note that this is different from the effect, which has - among others - been highlighted by Diamond (1998) and Sachs (1997). The latter refers to the geographical opportunity of implementing or developing specific production technologies that cannot be copied easily by other countries due to differences in the geographical environment.

4.3 The IAB innovation database

In light of the weaknesses of patents as innovation indicators (Griliches, 1990), the use of literature-based innovation indicators has been postulated for quite some time (see Kleinknecht and Reijnen, 1993; Link, 1995). Nevertheless, only few are available to date. Examples include the Science Policy Research Unit (SPRU) innovation database containing major innovations in the UK since 1945 (cited in Ratanawaraha and Polenske, 2007), the US Small Business Administration (SBA) survey for 1982 (Edwards and Gordon, 1984), or the database by Coombs, Narandren and Richards (1995) on British innovations. All of those, however, are either restricted to specific countries or periods. Recently, Metz (2003) has made a new database available that is a lot more promising than the previously mentioned alternatives. It contains innovation events throughout human history.[76] Each observation identifies an event that was mentioned in at least one of more than 1,300 references, primarily from the field of history of technology. Close to 15,000 such instances have entered the list (13,764 for the period 1500-1990). Assuming that citation of an event in the literature qualifies for being viewed as a significant contribution to technological advancement, the database may be argued to mirror the entire history of human technological progress. Details available for each event include - among other things - the name of the person or institutions who was accorded responsibility for the occurrence of the event, his/her place of birth or the location of the respective institution (place and country), year and location of the event (place and country), as well as the type and a description of the event. Table 4.1 provides an excerpt from the database. It lists all events reported for the year 1769. The most well-known are probably the grant of the patent for the steam engine and the construction of Cugnot’s steam car.

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[76] Originally, the database was assembled by the *Institut für Arbeitsmarkt- und Berufsforschung* (IAB) in Nürnberg. It is now stored at *Zentralarchiv für empirische Sozialforschung*, Cologne.

An important strength of the database is the broad notion of an innovation event. Note that usually an innovation is understood as a new product or specific method that is ready for market. Here, however, single incidences have been chosen to document the innovation process. In addition to actual inventions or discoveries, a whole range of other types of events have been considered as crucial occurrences in the innovation process, such as the first idea, an early draft, a publication or a successful trial run. That is, there may be two, three, or even more entries related to a specific innovation. The steam car, for instance, is represented in the database by three entries: the construction and the presentation of the car, as well as the first ride with it. In this case, the events occurred in the same year, but in other cases they are dispersed over many years. I maintain that the likelihood for manifold occurrences being documented with respect to just one innovation is higher the more attention an innovation received by society. This, in turn, is probably closely related to its significance in terms of economic growth. Hence, the database provides a promising alternative to traditional innovation measures, such as patents, which must be weighted in terms of their importance for economic growth.[77] The respective procedures, however, may entail arbitrariness.[78] Table 4.1 reveals that institutional innovations are also considered as a part of the list, if they are connected with technological development. Among others, those include laws (e.g. regulating the protection and organization of labor and intellectual property rights) and foundations (e.g. academic societies, universities). Robustness checks of the empirical results should therefore test subsamples, which exclude those types of innovation events.

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[77] Actually, in some cases the exact same incidence is listed twice. Table 4.1 encloses two of those cases: the patent grant for the steam engine, and the installation of the first arrester in Germany. Probably being a coding error, it seems plausible to assume that such a mistake is more likely to occur, the more often an event is cited in the literature, hence the more important it is. So, the overall innovation frequencies series still reflect the technological advancement generated in every period. This view is supported by Metz and Watteler (2002).

[78] In fact, some studies have used patent citations to identify important patents (see Hall, Jaffe, and Trajtenberg, 2000).

Table 4.1 - Documented innovation events in the year 1769

No.	Person associa-ted with event	Place of birth	Country of birth	Place of event	Country of event	Type of event	Description of event
5428	Arkwright, R.				England[b]	Patent	Spinning machine
5426	Beccaria				Italy[b]	Succesful Trial	Electrical charging of glass and other materials
12039	Beckmann, J.	Hoya	Germany	Göttingen	Germany[b]	Publication	First agricultural schoolbook
5427	Bergman, T.O.		Sweden		Sweden[b]	Hypotheses	Crystals result from chemical reaction in ocean water
5907	Born, I.E. von	Karlsburg		Prag	Czech R. [b]	Foundation	.
5908	Crane, J.	Edmonton				Construction	Mechanical production device[a]
4206	Cugnot, N.J.	Paris			France[b]	Presentation	Steam Car
4207	Cugnot, N.J.	Paris		Paris	France[b]	Construction	Steam Car
8495	Cugnot, N.J.				France[b]	First Ride	Automobile with front drive and steam exhaust
5904	Gahn, J.G.	Voxna	Sweden		Sweden[b]	Discovery	Phosporic acid in bones
5368	Mende, J.F.	Lebusa			Germany[b]	Installation	Ship hoist
5905	Reimarus, J.A.H.			Hamburg	Germany	Installation	First lightning arrester in Germany
14131	Reimarus, J.A.H.			Hamburg	Germany	Installation	First lightning arrester in Germany
5431	Scheele, K.W.	Stralsund	Sweden		Sweden[b]	Discovery	Tartaric acid
12276	Sivrac, Graf de			Paris	France	Invention	Celerifere/Velocifere: precursor to the bicycle.
4063	Smeaton, J.				England[b]	Construction	Early drilling machine
4208	Vevers, J.				England	Construction	Mechanical carriage with treadles
4062	Watt, J.				Scotland[b]	Patent	Improved steam engine
12722	Watt, J.				Scotland[b]	Delivery	First steam engines delivered
14460	Watt, J.				Scotland[b]	Patent Grant	Steam engine
12831	Watt; Boulton, M.				England[b]	Patent	Self-regulating steam engine, first steam engine plant in Birmingham.
5909	Wise, S.				England[b]	Patent	Mechanical production device[a]
3599	.				England	Law	Law to prevent demoliton of machines and factory buildings
5430	.				USA	Foundation	American Philosophical Society of Philadelphia
5906	.				England	Law	Law to prevent any action against the introduction of machines

Notes: The original data is documented in German language. Hence, for the purpose of presenting an example, the information in this table have been translated into English. The translation, however, does not reflect the information from the original database with 100% accuracy. In some cases the terms may deviate from what would be the correct technical label, in other cases information was omitted from the description to keep it concise.

[a] The exact term could not be translated.

[b] Information completed as described by appendix B.1.

Unfortunately, the country is specified for only 34% of the cases in the original database. In order to extract series of innovation frequencies for a large set of countries, some effort had to be expended to recode this variable for as many observations as possible. Using other available details regarding the inventor or the city of an event, country information could be derived for roughly 85% of the events. Partly, internet sources were utilized to obtain this information. In fact, for most cases, it was possible to distinguish between the place of an event and the place where the respective inventor received his/her education. A detailed description of the steps taken to complete this information is provided in Appendix B.1.

Upon this effort, two types of innovation frequency series were derived from the data for each country that was mentioned at least once as the origin of an innovation event. The first is based on the place/s of an event, and the second on the place/s of birth (and allegedly education) of the person/s owning responsibility for the events. The latter would be the natural basis of an analysis, which is mainly concerned with the effect of human capital. Provided a stronger interest in the effect of national institutions on innovation success, for instance, one might choose to base the analysis on the former series. For events associated with more than one country, be it because it occurred simultaneously - but independently - in different states, or because persons from different states collaborated on a project, each involved country was assigned the respective share of the event. That is, for joint events of two countries, each was assigned one half, for joint events of three countries one third, and so forth.[79]

[79] This approach discriminates against countries with many shared events in comparison to those with few shared events. Alternatively, a shared observation could be assigned fully to each of the involved countries. Which approach is chosen should not affect the results of an empirical analysis as long as it takes account of unobserved individual effects.

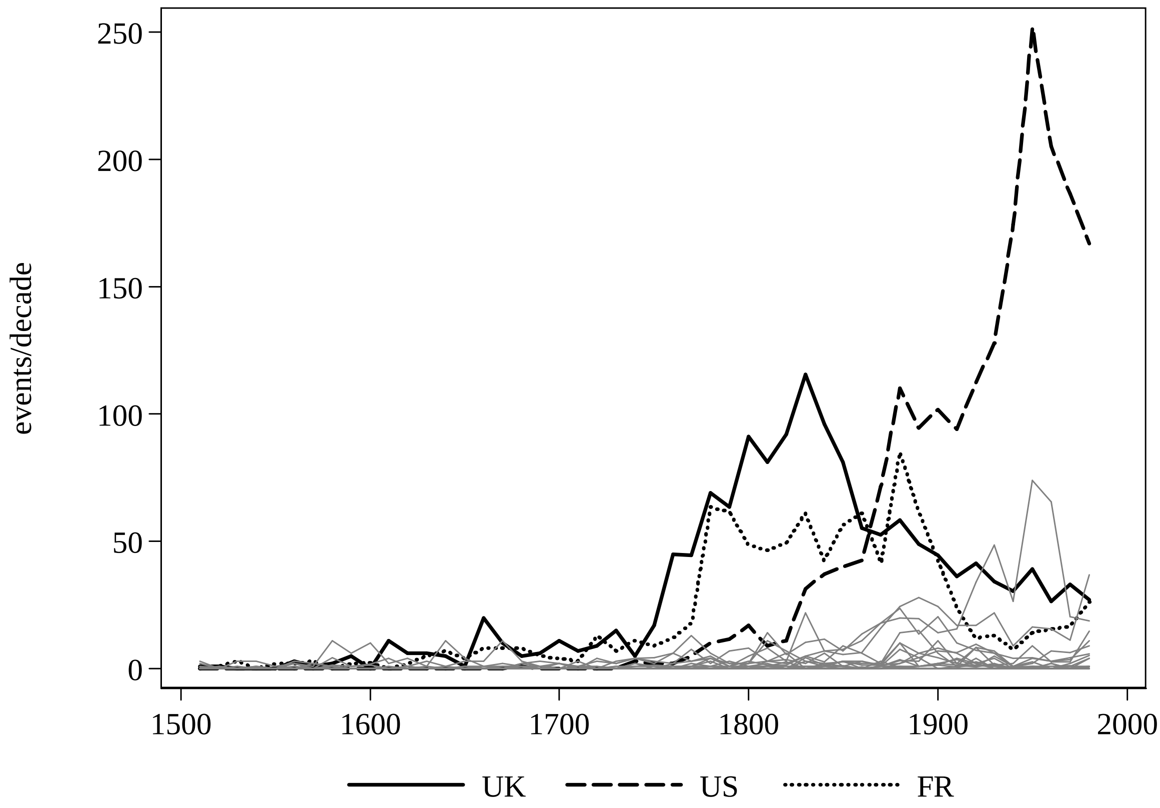

Figure 4.1. Innovation frequencies by countries, 1400-1990[80]

Source: Metz (2003).

Figure 4.1 provides an overview of innovation frequencies by countries between 1400 and 1990. The frequency for a country *j* is given by the number of documented events per decade, $\dot{I}_j$. Only the lines for the UK, the US, and France are highlighted, all other lines are displayed in light grey color. The main message from this chart is that technological progress has been generated by very few countries. Depending on the period, technological leadership changed (e.g. Italy around 1500, UK around 1800, and the US after 1850). But when picking

[80] For the purpose of a neater presentation, not all the countries have been included in the chart. The light grey lines represent Australia, Austria, Belgium, Czech Republic, Switzerland, Denmark, Estonia, Spain, Ireland, Italy, Greece, Hungary, Netherlands, New Zealand, Poland, Portugal, Russia, and Sweden. Germany is excluded from the chart, because it is suspected that the database entails a bias in favor of German innovations given that only German literature was used by the assemblers of the database.

a specific period, essentially a few nations created most of the innovations and hence drove technological advancement while the rest of the world obviously adopted it.[81] Further, the sudden take-off of innovative activity after 1750, as well as the quick reaction of France to the Industrial Revolution in Great Britain, seem hard to explain by the smooth and continuous development of population and human capital. Rather, shocks to the institutional environment, or the occurrence of some crucial technological advances are imposed as plausible explanations.

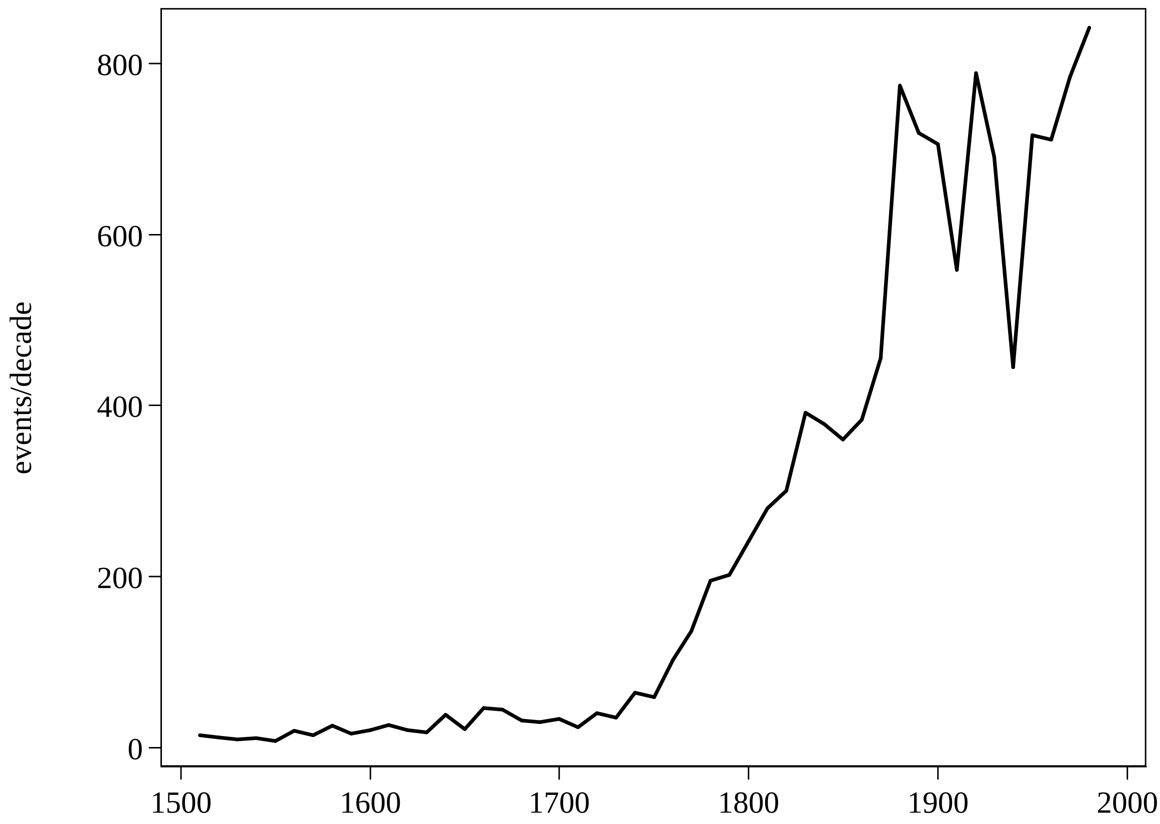

Figure 4.2. Worldwide innovation frequency, 1400-1990

Source: Metz (2003).

[81] It is suspected that the database entails a bias in favor of German innovations, because only German literature was used by the assemblers of the database. That is why Germany is excluded from this chart.

Figure 4.2 depicts the development of aggregate worldwide innovation frequency, $\dot{I}^*$. The pattern implies a declining growth rate $\dot{I}^*/I^*$. However, it does not necessarily imply a decline of actual knowledge growth. The observed pattern may be explainable by a declining probability of an event of being documented in written form and be remembered as an important technological contribution. Consider the following arguments: Two of the most frequently cited references date from the early 20th century (see Metz, 1999). Obviously, those do not include events from the subsequent years, which could create a bias in favor of events that occurred prior to 1900. At the same time, however, possibilities of documentation certainly improved over time along with technological development, such that later publications can contain a larger share of the significant contributions to technological progress. Both effects might compensate each other. Anyhow, subsample estimates for years prior to 1900 are an easy way to control for a potential distortion. Further, one might argue that literature is less likely to reach a consensus about the significance of very recent events. Hence, the documented number of incidences associated with an innovation (e.g. idea, first draft, trial runs etc.) may be smaller for more recent cases. On the other hand, recent documentation may be broader in the sense that a wider range of events appears in the literature, part of which vanishes after a while. Both these effects are not unlikely to cancel each other out, which would make them unproblematic. Finally, assume that, in reality, the stock of knowledge grows boundlessly at an exponential rate. In that case, the number of ideas generated in each period would soon exceed the documentation capacities, requiring that only the most significant events, i.e. the ones that receive most attention, be put on record. Hence, the fraction of events that can actually be documented would have to decline steadily over time. Consequently, the documented events would gain in relative significance. This could explain the revealed pattern even in the presence of constant knowledge growth rates. Because attributed significance or attention is likely to be correlated with the strength of the productivity improvement effect, a database event may reflect greater shifts of the technological frontier in later years than in earlier years. On the other hand, one might argue that recording is not reduced over time at all, and innovations do in fact occur more rarely. This view receives support from the observation that patent statistics, too, reveal a similar stagnating pattern, at least during the last decades (see Kortum, 1997). Also, other - much less comprehensive - long-run innovation counts (e.g. Baker, 1976) are well in line with the IAB data. Metz and Watteler (1999) provide graphical comparisons; nothing in their charts suggests that recent innovations could be unrepresented by the IAB data.

A possible explanation is that increasing complexity might make innovations more and more difficult, causing diminishing returns of existing knowledge in the generation of new ideas. Whichever interpretation is correct, the issue of potential changes in documentation behavior should be kept in mind, because it makes interpretation of the empirical results regarding the returns of existing knowledge less straightforward.

4.4 Innovation and growth in the long run

As explained, the significance of homemade technological knowledge is a prerequisite for the Schumpeterian growth models to work on a country level. This section explores the relationship between knowledge growth as measured by innovation frequencies, and economic growth. The approach is separated into a qualitative as well as a quantitative analysis. Because the main purpose is to distinguish the effects of homemade and adopted know-how, the potential problem of time-inconsistent innovation documentation can be ignored in the quantitative part. It would equally affect knowledge growth on the national and international level. I assume for the qualitative analysis, too, that the stock of innovations indeed reflects the stock of knowledge and postpone further discussion to the end of the chapter.

4.4.1 Qualitative analysis

Figure 4.3 depicts the development of world GDP levels and the worldwide stock of knowledge. Hardly surprising, the explosion of worldwide knowledge preceded the sharp rise of income levels, which started only after 1800.

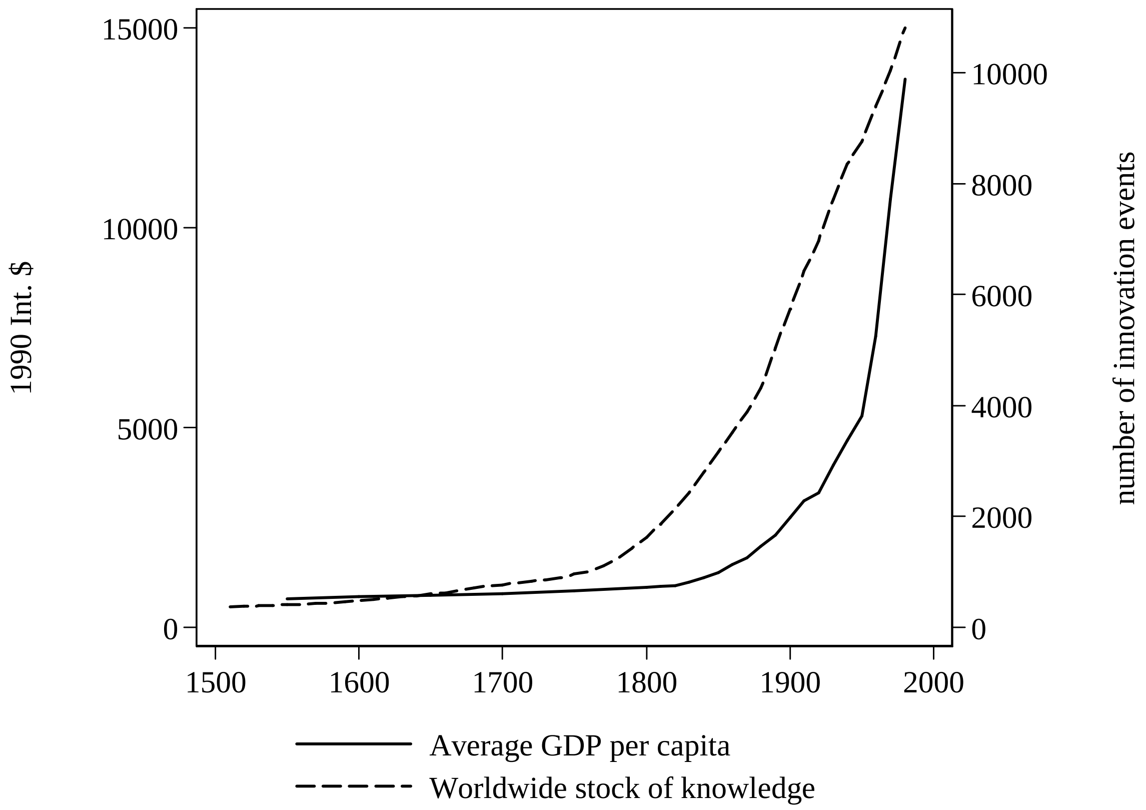

Figure 4.3. Development of worldwide knowledge and per capita income[82]

Sources: Maddison (1995), Metz (2003).

Figure 4.4 shows the respective growth rates on a halfcentury-basis from 1400 through 1950 (chart a.), as well as per decade from 1800 through 1990 (chart b.). Although modest

[82] Both series are based on today's OECD countries with the exception of Turkey, Luxembourg, Iceland, and Ireland. Slovakia and Czech Republic are treated as one country. Otherwise, Maddison's data would not allow computing average GDP for a balanced panel of countries without gaps. Further details on GDP per capita figures are provided by Appendix B.2.

knowledge growth is reported even for earlier halfcenturies, the rate of idea generation accelerated rapidly in the second half of the 18th century, the period known as the time of the Industrial Revolution. After their all-time high in 1850, international knowledge growth rates seem to have declined continuously. The decline of economic growth rates did not set in before the 1970s, neglecting the impact of the two world wars. Overall, the world level of aggregation clearly indicates a causal relationship that runs from innovation to growth. The following discussion demonstrates that such evidence cannot be found on the country level.

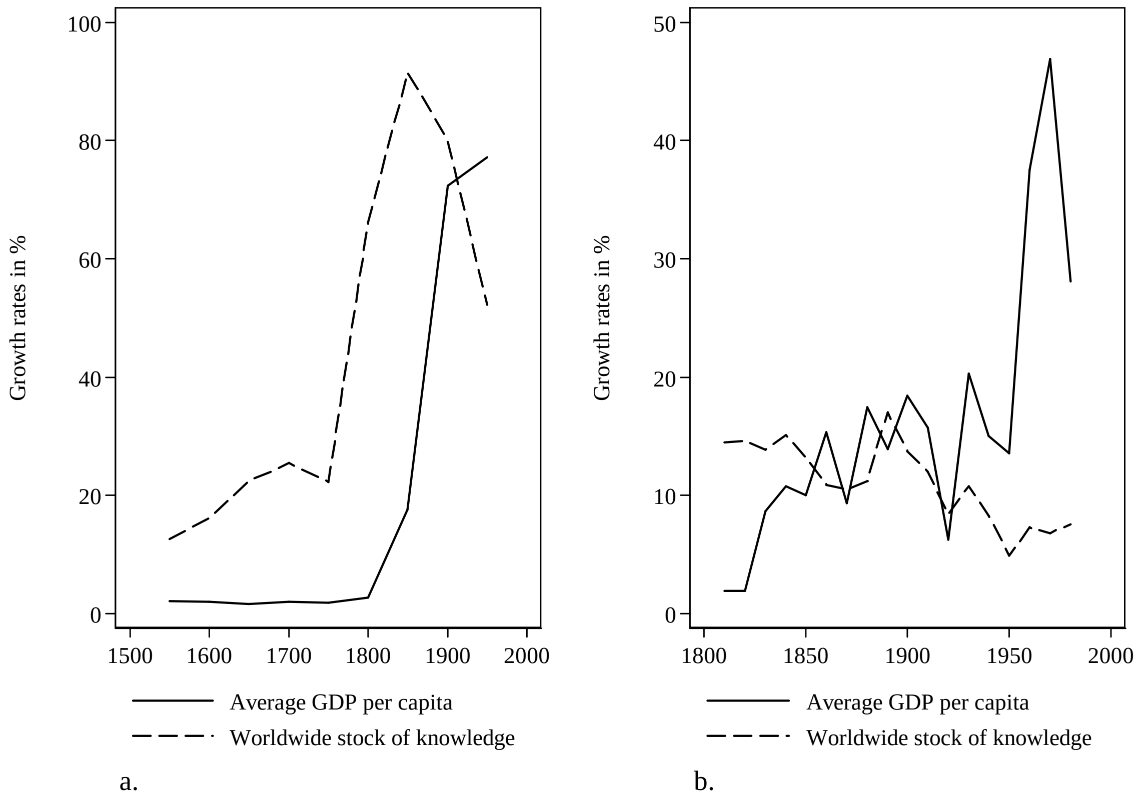

Figure 4.4. Growth rates of worldwide knowledge and per capita income[83]

Sources: Maddison (1995), Metz (2003).

[83] Growth rates reflect averages during the observation period preceding the respective point in time. That is, the data point for 1800 in chart a. reflects average growth rates from 1750 through 1800. To compute decadal growth rates (chart b.), the sample of countries as described in the notes of Figure 4.3 was used. For the halfcentury growth rates (chart a.), Bulgaria, Brazil, China, India, Romania, and Yugoslavia were added to the sample. Interpolations were made as described in the notes of Figure 4.3.

First of all, technological advances were international in character even before the Industrial Revolution. In most cases, national accomplishments were merely small steps in the development of an innovation, which ultimately gave an impulse to the international technological frontier. Quite a few countries produced important contributions even before the actual acceleration of worldwide GDP growth during the first half of the 19th century. Those may be called early technological leaders.[84] Up to 1550, technological progress in those countries was of a rather practical nature. Early post-medieval events include book-printing, which was brought to perfection in Germany, the optical and mechanical inventions of Leonardo da Vinci and others in Italy, the astronomical revolution caused by the Prussian Nicolaus Copernicus, and the advancements in navigation made in Portugal and Spain. It is likely that those developments in different parts of Europe were not entirely independent of each other. For example, optical inventions may have been fueled by the interest in astronomical matters, which in turn might have been inspired by the use of the respective knowledge for navigation.[85] As of 1550, technological progress became more and more scientific in nature. Most of the new ideas were related to the fields of astronomy, mathematics, and physics (more concretely mechanics and optics). This type of progress, which took place between 1550 and 1750, was clearly international. Important contributors to the field of astronomy came from Italy (Galileo Galilei), Denmark (Tycho Brahe), Germany (Johannes Kepler) and England (Edmund Halley). Events in the field of mathematics have

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84 Speaking of "technological leaders" as opposed to "followers", one might refer to countries operating close to the technological frontier, i.e. employing state-of-the-art technology and generating high income per capita in international comparison. It is not necessarily the case, however, that those countries actually produce innovations and contribute to the development of new knowledge. Yet, they typically will. Because countries observed in this section are all more less close to the frontier, I use the term "leaders" for the major producers of innovations. Alternatively, they might be called "contributors" as opposed to "adopters" or "free-riders". Admittedly, this is a little vague, as it is not clear at what point a country turns from a leader into a follower, but there is no need to apply a stricter definition in this work.

85 Less famous innovations of this time include the improvements in medical techniques like Jacob Nufer’s first caesarian section and the work of Paracelsus (both in Switzerland), the street lighting of Paris, and the production of graphite pencils in the UK.

been attributed to individuals from all over Europe, such as Gottlieb Wilhelm Leibniz (Germany), Simon Stevin (Netherlands), John Napier (Scotland), Edmund Gunter (England) or Joost Bürgi, as well as Johann and Jakob Bernoulli (all three Switzerland). Probably the most notable contributions stem from the French Francois Vieta, Rene Descartes, and Blaise Pascal. Eventually, physics was brought forward by William Gilbert and Isaac Newton (UK), Galileo Galilei and Evangelista Torricelli (Italy), Otto von Guericke (Germany), Blaise Pascal (France), and Daniel Bernoulli (Switzerland). The latter four, as well as Robert Boyle (UK), are responsible for crucial steps in thermodynamics that were indispensable for the development of the steam engine. Above all, the latter was not invented by James Watt alone. Denis Papin in France and Thomas Savery in Great Britain made important first attempts, and Thomas Newcomen invented it in 1705, before James Watt in Scotland drastically improved its efficiency in 1769. Other countries like Spain, Sweden, Russia, Austria, Norway and Belgium were not among those early technological leaders, but still provided important early contributions to technological development before the invention of the steam engine. The discussion illustrates the international nature of technological progress. Given these facts, it would be naive to think that the acceleration of economic growth in the leader countries could have been the exclusive result of national innovative success.

Figure 4.5 shows the national GDP and knowledge growth rates of the early technological leaders UK, France, Germany, Netherlands, Italy, and Portugal, based on halfcenturies. In spite of their different history of knowledge growth, economic growth rates of all countries exploded nearly simultaneously at the beginning of the 19th century, implying that the main driving force must have been a common factor. Further, most countries have experienced an early phase of knowledge growth that was not immediately followed by economic growth. In some cases, the lag exceeds 200 years, which seems rather long provided the claim of a direct causal relationship between the growth rates. This sheds doubt on the hypothesis of national innovations having a significant influence on economic growth.

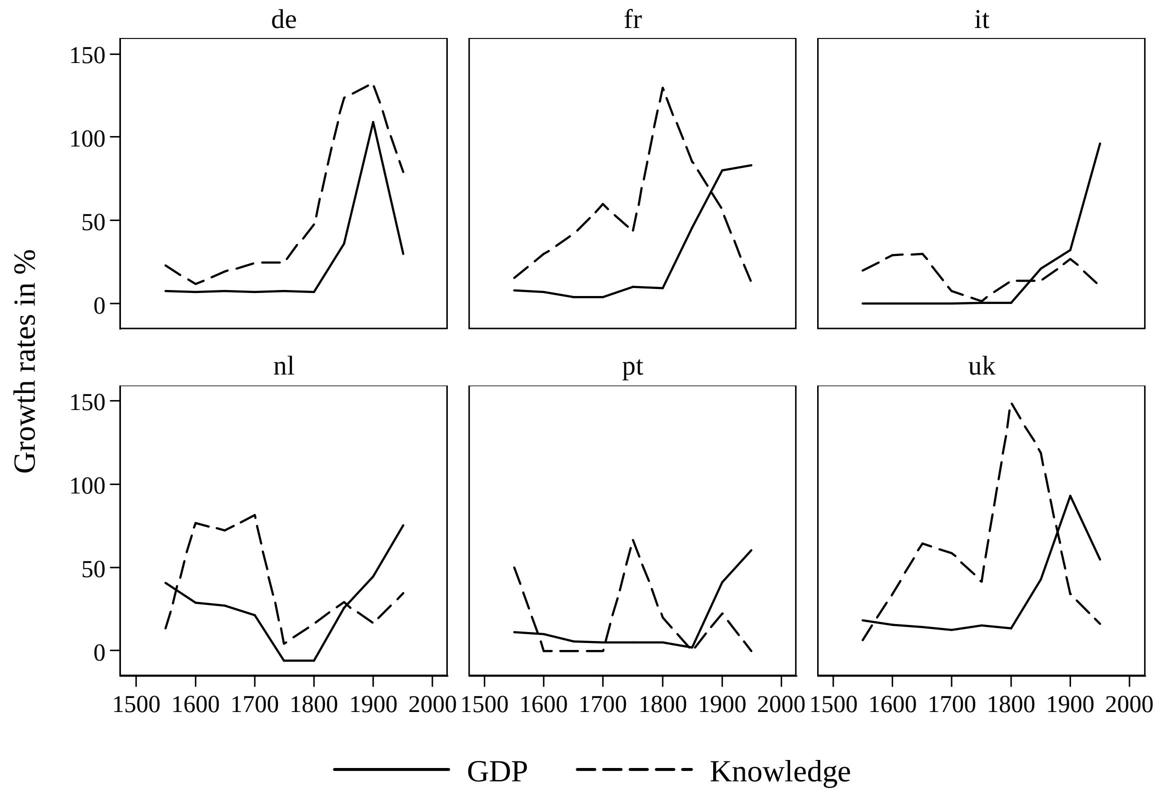

Figure 4.5. Knowledge and GDP growth rates of early technological leaders by halfcentury

Sources: Maddison (1995), Metz (2003). Footnotes 82 and 83 apply.

Especially, consider Italy and Portugal: despite their earlier technological achievements, economic growth in those countries did not speed up any sooner than in the other four countries. Unique growth paths of countries associated with their individual history of knowledge creation do not seem to exist. Looking at the decadal growth rates after 1800 (see Figure 4.6) leads to the same conclusion. The series contain too much noise to make a statement about the causality or the lag length of the relationship. Obviously, however, France and the UK exhibit a declining trend in knowledge growth rates after 1800. GDP growth rates, on the other hand, show an upward trend. In fact, during most of the 20th century economic growth rates exceeded knowledge growth rates considerably.[86] In Figure 4.7, national growth rates are divided by world growth rates to take into account international trends and database shortcomings. Now, both curves show a common downward trend. Nevertheless, GDP growth rates remained on average close to internationally comparable rates. Whatever may be the reasons for the decline of knowledge growth, it has not been followed by an equally radical slow-down in economic growth, casting doubt on a prominent role of national knowledge growth for economic growth. At best, the pattern gives hints on a contemporaneous correlation which would really point at reversed causality.

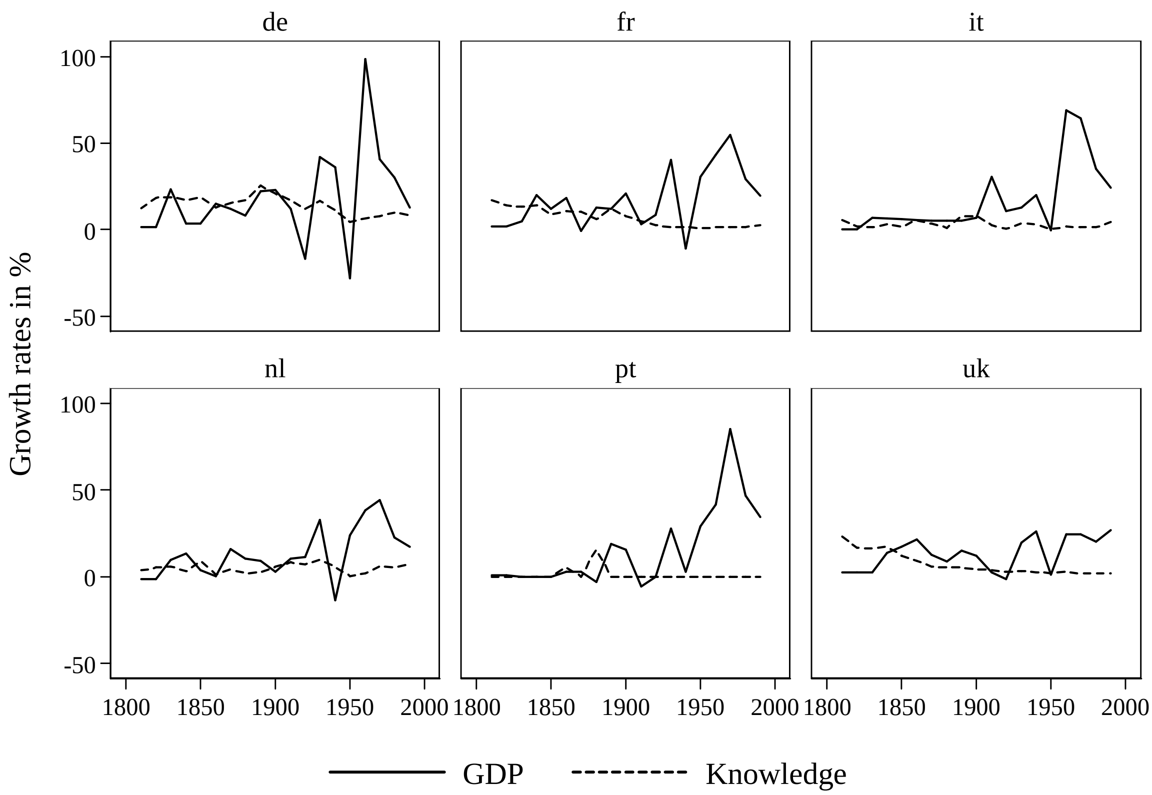

Figure 4.6. Knowledge and GDP growth rates of early technological leaders by decade

Sources: Maddison (1995), Metz (2003). Footnotes 82 and 83 apply.

[86] Italy and Portugal even display an extreme version of this pattern. After their early innovation success, both countries contributed very little to international technological development, but their growth experience was quite similar to the ones of other countries, at least in the 20th century.

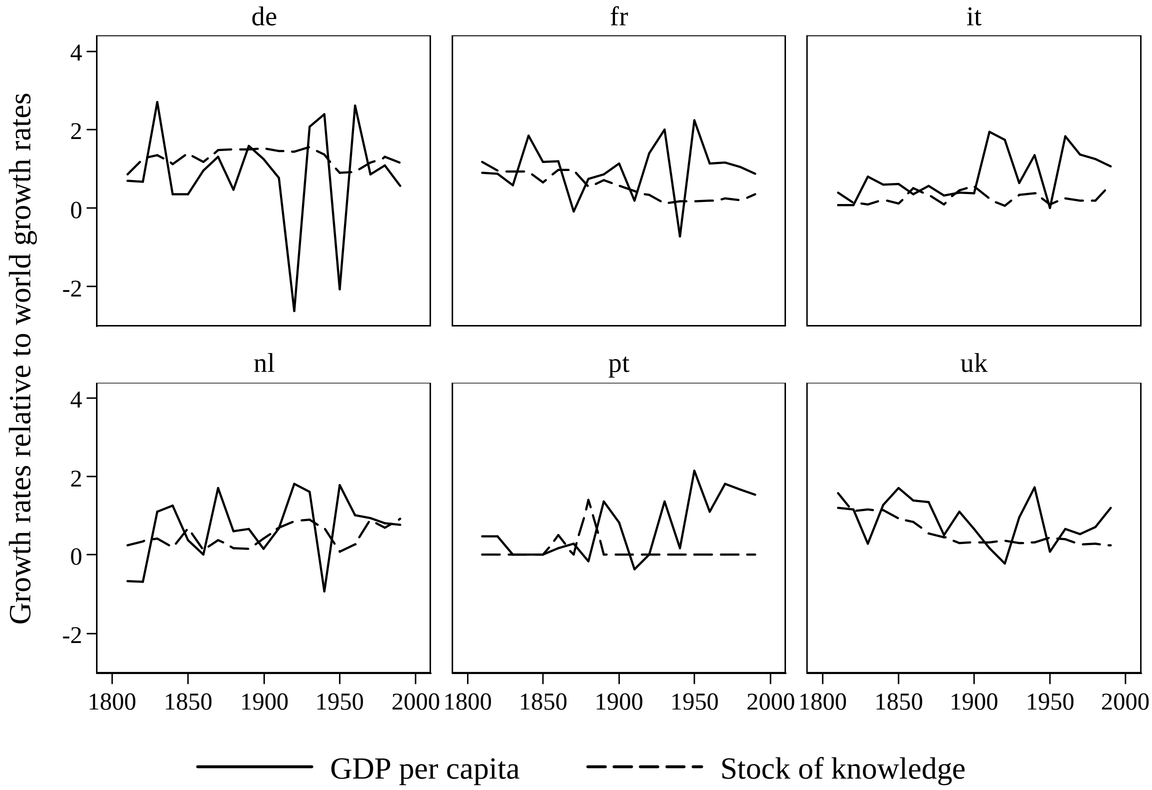

Figure 4.7. Knowledge and GDP growth rates of early technological leaders relative to world growth rates by decade

Sources: Maddison (1995), Metz (2003). Footnotes 82 and 83 apply.

Next, the growth experience of nations that were early technological followers, such as the US and Canada, also puts into perspective the importance of national innovation success. Those countries show above-average GDP growth even before the occurrence of the first homemade innovations (see Figure 4.8). For instance, the first documented innovation event for the US is the production of paper in 1690. Clearly this technique must have been brought into the country by migrants from Europe. The first real contributions to technological development are the inventions of the arrester and the harmonica by Benjamin Franklin in 1752 and 1765. Nevertheless, the US had already experienced 200 years of above-average

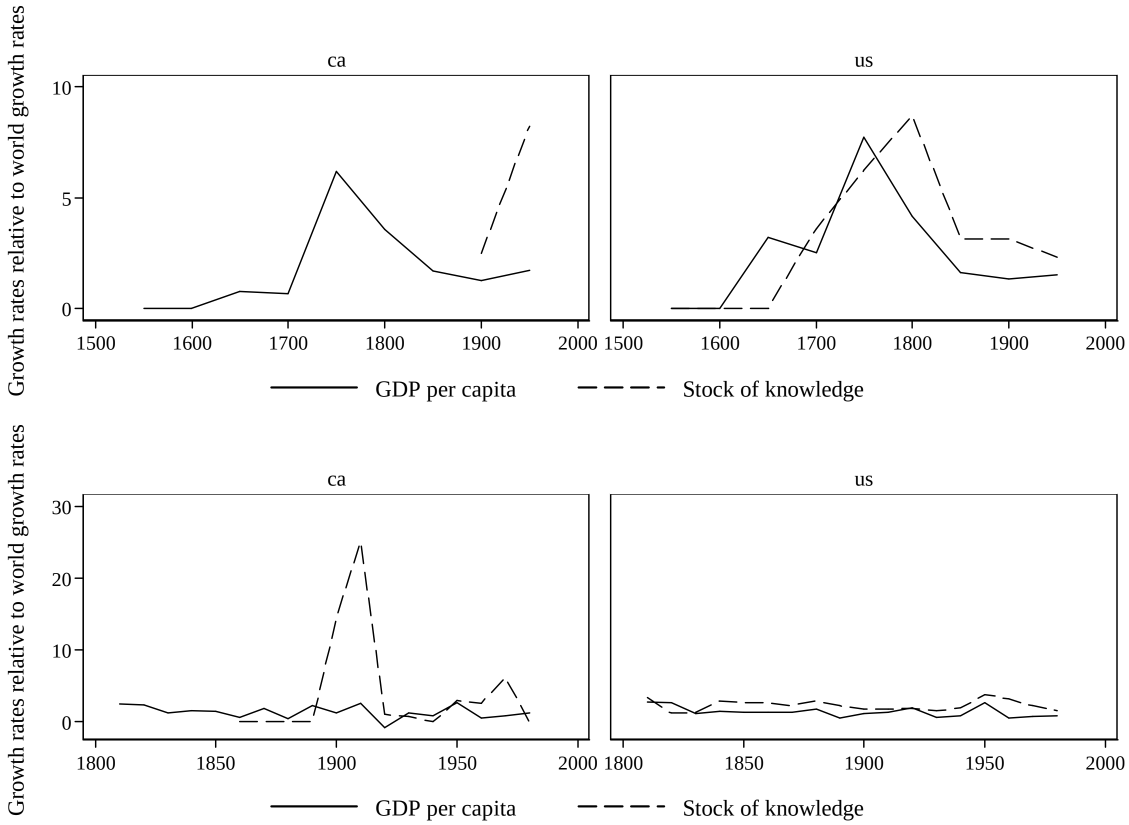

Figure 4.8. Knowledge and GDP growth rates of early technological followers relative to world growth rates by halfcentury and decade

Sources: Maddison (1995), Metz (2003). Footnotes 82 and 83 apply.

economic growth by that time. Similarly, Canada had long been growing at high rates, before the first reported inventor Reginald Aubrey Fessenden made his contributions to radio development. Of course, the experience of above-average economic growth rates before the first innovative contribution reflects the process of catching up with the technological frontier.[87] After catch-up, the US exhibited exceptionally high knowledge growth rates between 1750 and 1900. This is partly owed to the fact that the share in worldwide innovations was still close to zero by 1750. Without doubt, however, the US became a

[87] Hungary in Europe, for instance, which also started generating homemade technology only after 1800, did not exhibit above-average GDP growth before that time. Catch-up was not necessary, because the country did not start from scratch.

technological leader during that time. In the second half of the 19th century, it already generated more innovations than the UK. But still, the boom of national GDP growth does not necessarily have to be a result of this. In fact, a glance at the decadal GDP and knowledge growth rates in Figure 4.8 suggests that the relationship was of a simultaneous character. Changes in the ratio of economic growth rates were accompanied by similar changes in the ratio of knowledge growth rates. However, if national knowledge growth rates were the decisive driver of national economic growth, one would expect the former to precede the latter. Hence, this phenomenon might have to be interpreted as a reverse effect: intuitively, periods of positive economic development may just as well be periods of positive technological development.[88]

Finally there are countries, which have - throughout most of their history - been free-riders on the worldwide innovative efforts and nevertheless belong to the group of industrialized countries today. Examples are Australia, Greece (except for the classical antiquity), Mexico, and Finland. New Zealand is an extreme case; no single innovation event is documented before the Second World War, but GDP had nevertheless reached internationally comparable levels.

In short, these stories document that economic growth is very well possible without homemade knowledge growth. The reverse is true as well. High knowledge growth rates do not necessarily need to be followed by comparably high economic growth rates. In light of this evidence, it makes sense to believe that the cumulated international stock of technological knowledge, i.e. the technological frontier, is more important for economic growth than the number of homemade innovations. Very likely, the collective state of technology is the most relevant determinant of the long-run growth path of any economy capable of adopting it. The

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[88] This clearly applies for the case of Japan, where knowledge growth set in simultaneously with - and not before - the rise in living conditions after 1870.

analysis further suggests that this is, because - even before information and new knowledge could easily be disseminated via telegraphs and railways - technological progress was international in nature. In pre-industrial Europe, the innovative center countries encompassing at a minimum the UK, France, Germany, Italy, the Netherlands, Denmark, and Switzerland, generated progress collectively.[89] This holds true after the Industrial Revolution, even though technological leadership changed. Finally, the relationship between national knowledge growth and economic growth may actually be a reversed one. In the process of catching up with the technological frontier, countries produce more and more innovations themselves. Also, there may be a pattern of rising innovativeness during economic upswings and vice versa.

4.4.2 Quantitative analysis

Two rather simple panel regression analyses serve to substantiate the qualitative discussion. The first ought to shed light on the relative importance of national and international knowledge for economic growth. The empirical model is as follows:

$$\frac{\dot{Y}_{jt}}{Y_{jt}} = \beta_0 + \sum_{k=1}^{4}\left(\beta_1 \frac{\dot{I}_{jt}}{I_{jt}} + \beta_2 \frac{\dot{I}_t^*}{I_t^*}\right) + ww_t + \varepsilon_{jt}\,, \tag{4.5}$$

where

j	=	country index,
k	=	number of lags,
$\dot{I}/I$	=	growth rate of national stock of innovation events,
$\dot{I}^*/I^*$	=	growth rate of worldwide stock of innovation events
ww	=	dummy variable indicating whether period t contains a world war.

[89] Quite a few events are documented for what are today the areas of Austria, Belgium, Hungary, Poland and the Czech Republic. Their influence would be exaggerated, however, if they were mentioned along with the Central European countries.

The dependent variable contains average growth rates during the preceding period, i.e. 50 years. The parameters of interest are the coefficients of national and international knowledge growth rates and their lags. Besides a full set of time dummies and a dummy variable which indicates periods spanning a world war, no other covariates are included in the model.[90] The sample is a balanced panel of 28 countries for the period 1500-1950. Hence, there are nine subsequent observations for each country, making the number of cases N=252.

Table 4.2 - Fixed effect estimates of equation (4.5)

Dependent Variable: GDP growth rates (Maddison, 1995), 1500-1950					
	(1)	(2)	(3)	(4)	(5)
National knowledge growth rate (NGR)	0.0289	0.0190	0.0116	0.0134	0.0202
	(0.026)	(0.023)	(0.026)	(0.029)	(0.033)
World knowledge growth rate (WGR)	0.623***	-0.110	-0.0673	-0.159	0.0107
	(0.079)	(0.11)	(0.14)	(0.19)	(0.16)
NGR , Lag 1		0.00778	0.00432	0.00615	0.0105
		(0.025)	(0.028)	(0.032)	(0.035)
WGR, Lag 1		1.027***	0.800***	0.838***	0.781***
		(0.12)	(0.20)	(0.22)	(0.27)
NGR , Lag 2			-0.0193	-0.0380	-0.0381
			(0.027)	(0.031)	(0.037)
WGR, Lag 2			0.405*	0.385	0.399
			(0.23)	(0.26)	(0.28)
NGR , Lag 3				0.0484	0.0445
				(0.030)	(0.036)
WGR, Lag 3				0.778	-0.0128
				(0.84)	(0.28)
NGR , Lag 4					0.0743**
					(0.037)
WGR, Lag 4					0.0593
					(0.89)
World War in period *t* (Dummy)	56.51***	17.36**	0.299	-38.25	0
	(7.06)	(7.78)	(12.4)	(45.3)	(0)
Constant	-7.472*	-13.44***	-16.95***	-32.17**	-25.76
	(4.21)	(3.76)	(5.46)	(16.0)	(17.8)
Observations	252	252	224	196	168
Number of groups	28	28	28	28	28
R-squared	0.40	0.55	0.55	0.55	0.55
adj R-squared	0.322	0.481	0.470	0.452	0.425

Notes: Standard errors in parentheses. Time/Country dummies not reported. *** p<0.01, ** p<0.05, * p<0.1. Footnotes 82 and 83 apply.

90 Certainly, other variables, such as the growth rate of human capital, or changes in institutions, are drivers of national growth rates. But they work mainly through the adoption of foreign technology. Hence, including them in the model might make international knowledge growth appear less important than it is in relation to national knowledge growth rates.

Table 4.2 displays the results produced via fixed effects estimation. In column (1), solely contemporaneous knowledge growth rates are included in the model. Obviously, an increase in international growth rates of one percentage point implies an increase in national GDP growth rates of more than half the size (β_1= 0.62). Given a period length of 50 years, this effect is of course not necessarily contemporaneous in a strict sense. Increases in national knowledge growth rates, however, do not have a significant effect. When one or more lags of both explanatory variables are used as covariates, the contemporaneous effect vanishes (columns (2-5)). The strongest effect occurs after 50 years, the additional positive effect after 100 years is weaker and not statistically significant. This seems quite plausible given the late impact of the steam engine. Even today, with the first computer being roughly 60 years old, computerization is ongoing and there are many productive areas left to be penetrated by this technique. But more importantly, national innovations are irrelevant for countries' growth experiences after controlling for worldwide knowledge growth. Even when the t-value indicates statistical significance, the coefficient is practically irrelevant. Hence, solely movements of the international technological frontier matter for individual economies' long-run development.

To substantiate the existence of a contemporaneous effect of economic development on national knowledge growth, the following simple model is estimated:

$$\frac{\dot{I}_{jt}}{I_{jt}} = \beta_0 + \beta_1 \frac{\dot{Y}_{jt}}{Y_{jt}} + ww_t + \varepsilon_{jt} \qquad (4.6)$$

where the period length t is now set to 10 years. A balanced panel of 24 countries can be constructed for the period 1820-1990. Table 4.3 lists the results. In a fixed effect regression, the coefficient is significant (column (1)), implying a correlation between economic and knowledge growth rates. A one percentage point higher economic growth rate leads to a 0.15-percentage-point increase in the rate of national knowledge growth. In light of the short observation period, reversed causality is unlikely. One would not expect innovations to precipitate in growth rates within less than ten years. Nevertheless, to rule it out, column (2) shows the result Arellano-Bond estimates of the same equation, where a lagged dependent variable is included and the rate of GDP growth is specified as an endogenous variable. The coefficient is only slightly smaller and still significant at the 10% level. Hence, the economic short-run situation seems to feed back into the innovation process. The evidence is weaker when the national growth rates are related to the average growth rates in the sample of countries (columns (3) and (4)). Now, the coefficients do not turn significant. Altogether, the conclusions from the qualitative analyses withstand the quantitative overhaul.

Table 4.3 - Fixed effect estimates of equation (4.6)

Dependent Variable: Growth rates of the national knowledge stocks (Metz, 2003), 1820-1990				
	Fixed Effect	Arellano-Bond	Fixed Effect	Arellano-Bond
GDP growth rates	0.159**	0.130*		
	(0.068)	(0.078)		
Relative GDP growth rates			0.147	0.135
			(0.10)	(0.11)
World War in period *t* (Dummy)	7.993	-4.334	0.235	0.00167
	(7.61)	(3.81)	(0.78)	(0.32)
Constant	-2.704	5.285**	0.382	0.518**
	(6.00)	(2.15)	(0.57)	(0.23)
Observations	456	432	456	432
Number of groups	24	24	24	24
R-squared	0.06	.	0.04	.
adj R-squared	-0.0377	.	-0.0535	.

Notes: Standard errors in parentheses. Time/Country dummies not reported. *** p<0.01, ** p<0.05, * p<0.1 The notes of Figures 3 and 4 apply.

4.4.3 Implications

In the long run, it does not seem to matter which country produces innovations. They are not a crucial factor for national economic growth. On the country level, a causal relationship could not be identified either in the case of technological leaders or followers; the contemporaneous pattern visible in decadal growth rates for few countries like the United

States and Canada is likely to reflect a reverse effect of national GDP growth rates on innovativeness. Instead, the speed of knowledge diffusion seems to have been sufficiently high even in early times for the international state of technology to determine the growth potential of all world economies. Whether an economy is actually capable of realizing this potential certainly depends on factors like openness, its human capital stock and the institutional conditions. In summary, when exploring the relationship between innovation and growth it does not make much sense to look solely at the country level. Further, technological progress has been generated collectively by many countries even in pre-industrial times, making it international in nature. Consequently, equation (4.2) should be rephrased to identify a country's contribution as

$$\dot{A}_{jt} = \delta A_t^{*\phi} S_{jt}^{\psi}, \tag{4.7}$$

where j is a country index. A^* denotes the international technological frontier, which is determined by the worldwide stock of technological knowledge. Shifts of the international technological frontier are given by the sum of individual contributions, $\dot{A}_t^* = \sum_j \dot{A}_{jt}$.

4.5 The innovation process in the long run

4.5.1 The empirical model

To test the determinants of innovativeness on a country level, the empirical model follows from equation (4.7). Taking the log gives

$$\log \dot{A}_{jt} = \log \delta_{jt} + \phi \log A_t^* + \psi \log S_{jt} . \tag{4.8}$$

If - for a specific country - the number of innovation events per period as given by the IAB data, $\dot{I}_{jt}$, mirrors its actual contribution to the change in knowledge, $\dot{A}_{jt}$, and likewise, the international stock of technological knowledge, A_t^*, may be proxied by the cumulated number of worldwide innovation events, I_t^*, then the mean function of the respective count data regression model can be written as

$$\dot{I}_{jt} = \exp\left(\log C + \psi \log N_{jt} + \phi \log I_t^* + \boldsymbol{\beta Z_{jt}} + u_{jt}\right) \tag{4.9}$$

where u_j are country-specific unobserved effects.[91] The dependent variable gives the number of events within a period, whereas all of the right-hand side variables are measured at the beginning of a period. N_{jt}, the size of the population, is the scale factor in the model. It is constructed as a combination of population figures from McEvedy and Jones (1978) and Maddison (1995).[92] Note that the constant, $\log C$, is different from $\log \delta$. It merely reflects exogenous technological progress, which would take place even if the covariates were all zero, because the right-hand side of the equation controls for unobserved country effects and the vector $\boldsymbol{Z}$. The latter includes a couple of variables, which serve to revisit the debates sketched briefly in section 4.2. They will be discussed subsequently.

First, $inst_{jt}$ is a proxy for the institutional setting. It measures constraints on the executive. It is a combination of the variable used by Acemoglu, Johnson and Robinson (2005), and the respective Polity IV variable by Marshall and Jaggers (2002). Constraints on executives may be crude. But it is the only measure capable of proxying for the institutional environment in a broad sense for a diverse set of countries over a long time period. Most likely, a society that controls the power of executives and representatives also ensures a relatively high degree of liberty. On the one hand, liberal trade regulations etc. enhance access to international knowledge and thereby facilitate its adoption. Also, they may affect the

91 See Cameron and Trivedi (1998) for a comprehensive textbook treatment of count data regression models.

92 Details on the construction of all explanatory variables are provided by Appendix B.2.

perception of potential entrepreneurs regarding whether or not investments in new techniques are worthwhile or not. Beyond that, however, institutions like the protection and enforcement of property rights may affect innovativeness immediately by creating incentives or facilitating the innovation process.

Similarly, geography may have an immediate impact on innovativeness, which goes beyond its role as a facilitator of technology adoption. Even if a country cannot adopt technologies because of a lack of human capital or an unfavorable institutional setting, researchers may be able to get access to the respective knowledge. This seems more likely the closer a country is located to the technological leaders, especially during the pre-railroad and -telegraph era. Geography is modeled by a set of five dummy variables, *geo1* through *geo5,* which reflect the distance of a country to the innovative center of Europe. *geo1*=1 for the UK, France, Germany, Netherlands, or Belgium. Those constitute the center of Europe. *geo5*=1, if the respective country is located outside of Europe. Turkey is classified in this category. *geo2* through *geo4* reflect intermediate states. Distance is measured in terms of the number of borders that need to be crossed in order to reach one of the *geo1* countries. This indicator seems to reflect more accurately than pure distance the potential for technology diffusion.[93]

Eventually, h_{jt} is a measure of human capital. Because the stock of human capital, rather than its flow, is relevant to produce innovations, years of schooling are chosen as its basis. A direct measure of school years exists only during 1960-1990 (Barro and Lee, 2001). For years prior to 1960, literacy rates are available for few countries. Also, numeracy can be measured based on age-heaping data for a variety of countries (Crayen and Baten, 2008). And as of 1830, primary and secondary school enrollment figures do exist (Lindert, 2004). In order to obtain a human capital variable that is consistent over time, those diverse inputs have to be

[93] Apart from geographical proximity, cultural proximity may facilitate knowledge diffusion. It correlates highly with geographical proximity, though.

transformed into years of schooling. From enrollment rates, for instance, a rough measure of school years may be inferred by making a few simplifying assumptions about the average length of primary and secondary schooling. In the case of literacy and numeracy data, regression analyses are needed to estimate the general relationship between literacy - or numeracy respectively - and years of schooling. Then, years of schooling can be predicted. Eventually, common observations may be used to merge the resulting series such that consistent time series without breaks are obtained for each country. Finally, actual years of schooling are related to the potential maximum number of school years. The absolute maximum is assumed to be equal across countries. Reasoning that total primary and secondary education lasts 12 years and tertiary education 5 years, it was set to 17 years.[94]

Eventually, $\boldsymbol{Z}_{jt}$ contains an interaction term, which is the product of logged international knowledge stock and efficiency, eff_{jt}. The latter proxies for the distance of an economy from the technological frontier. It is defined as $eff_{jt} = Y_{jt} / Y_t^{\max}$, where $Y_t^{\max}$ is the maximum income per capita across countries in every period. This measure is based on Maddison (1995); some missing values were filled by interpolation. The intention behind including this term is to control for the potential indirect effect of the other covariates in $\boldsymbol{Z}_{jt}$. Apart from how much knowledge is available in the world, it may also matter for a country's innovativeness, whether researchers in the country actually have access to it. Access may be restricted by the capability of an economy to exploit or adopt the respective techniques and implement them in the economy's production sector. The degree to which a country is able to adopt foreign technology, in turn, may depend primarily on its human capital stock, the institutional framework, as well as its proximity to innovative countries. In other words: if the

94 Changing this fictitious upper bound would not affect the analysis as it translates into the same percentage change for all observations. Its application simply serves to point out that the adopted notion of human capital does not allow boundless growth.

interaction is excluded, the covariates in $\boldsymbol{Z}_{jt}$ may just capture the fact that access to knowledge is enhanced.

4.5.2 Results

The results are based on a fixed effects Poisson regression model. It has been proposed by Hausman, Hall and Griliches (1984) and - together with the fixed effects negative binomial regression model – has today become the standard estimation technique for count dependent variables in the presence of unobserved heterogeneity.[95] The Poisson regression analysis employs a panel of 48 countries and 6 decades from 1500-1800 (these are 1500-1509, 1550-1559, 1600-1609, 1650-1659, 1700-1709, and 1750-1759) plus 20 decades from 1800-1990; i.e. a theoretical maximum number of 1248 observations.[96] Because the explanatory variables are not available throughout, the panel is unbalanced. Country dummies were included to control for unobserved heterogeneity, and time dummies are supposed to filter out potential trends. The model has been estimated with and without the vector of control variables. Table 4.4 presents the results.

When the control variables are excluded from the model, population has a positive effect. It is close to one as would be expected; doubling population size leads to twice the number of ideas. Depending on the specification it varies between 1.4 and 0.8.

The stock of worldwide ideas is important, but the coefficient size of roughly 0.6 implies that a country's contribution to international knowledge growth can be kept constant only in the presence of population growth, because the generation of ideas gets more

95 In Stata, these are implemented in the commands -xtpoisson- and -xtnbreg-.

96 In principle, observations could be created for any country in the world. For most countries, however, the dependent variable would take on the value zero. Thus, only countries, which actually turn up in the database - i.e. for which at least one innovation event is reported - are considered; that is 48. Further, periods prior to 1500 cannot be considered because of a lack of GDP data.

difficult.[97] The interaction term (column (3)) indicates that in an economy, which operates close to the frontier (i.e. $eff = 1$), a further shift affects its innovative potential stronger, the coefficient being closer to one than before. Further, it suggests that the state of efficiency (i.e. the extent to which internationally available technology is actually being applied) within the economy is extremely relevant for its innovativeness. Given the location of the technological frontier in the 1990ies ($\log I^* \approx 10$), a catch-up of $\Delta eff = 0.5$ would lead to roughly 90% more innovation events per period, respectively 70% when human capital and democracy are controlled for.

Table 4.4 - Poisson estimates of equation (4.9)

Dependent Variable: Number of innovation events per decade (Metz, 2003), 1500-1990				
log(*N*)	0.978***	0.793***	1.421***	1.421***
	(0.045)	(0.049)	(0.073)	(0.073)
log(*I**)	0.585***	0.590***	0.111	0.111
	(0.14)	(0.13)	(0.21)	(0.21)
log(*I**) × *eff*		0.185***	0.141***	0.141***
		(0.016)	(0.018)	(0.018)
log(*h*)			-0.291***	-0.291***
			(0.058)	(0.058)
inst			0.187***	0.187***
			(0.012)	(0.012)
geo2 (dummy)				-0.174
				(0.44)
geo3 (dummy)				-2.779***
				(1.02)
geo4 (dummy)				-0.133
				(0.31)
geo5 (dummy)				-7.057***
				(0.90)
Constant	-34.37	-32.38	-31.11	-15.48***
	(18246)	(16259)	(5927)	(1.91)
Observations	1096	945	505	505
Pseudo R-squared	0.926	0.926	0.934	0.934

Notes: Standard errors in parentheses. Time/country dummies are not reported. *** p<0.01, ** p<0.05, * p<0.1.

[97] Note that with Poisson estimation, the dependent variable is the absolute number of innovations per period, not the log of it. The interpretation of the coefficients, however, is the same.

Apparently, the stock of previous innovations picks up the effect of institutions. It is no longer significant, when executive constraints are included in the regression (see column (3)). The latter exert a vigorous effect on a country's innovativeness. A one-point increase on the 7-point scale causes an 18% rise in the number of innovations per period. Running the whole scale roughly doubles the number of innovation events.

Surprisingly, the effect of human capital turns out negative. Obviously, an increase in human capital, which leaves the economy's efficiency unaffected, reduces the number of innovations the latter is able to generate. At first glance, this is a totally counterintuitive result. But consider for a moment the idea that schooling duration is altogether irrelevant for innovativeness. Because additional education is time-consuming, it would be consequent to think of it as actually being detrimental to innovativeness, if many potential innovators decide to waste time in the educational system. Alternatively, one might reason that public education impairs the unrestricted flourishing of a creative mind. To judge the size of the effect, consider a one-year increase in average years of schooling. If the average length of academic education is 5 years, such a gain could be reached by inducing an additional 20% of the population to complete this type of program. In an industrialized country with $h \approx 0.6$, this is roughly equivalent to a 10%-change in h. The coefficient implies a reduction of innovation events by about 4%, respectively 3% in the complete specification. This is a rather small and hardly economically relevant effect. But in spite of a high degree of collinearity between the explanatory variables, it turns out significant and should not be ignored.

The geography dummies indicate that countries which do not belong to the innovative center of Europe produce fewer innovations. Nevertheless, it would be hard to make the case that distance aggravates the effect. Three borders separating a country from the most innovative ones seem to be worse than two borders. Then, again, the periphery dummy is non-significant; merely being located outside of Europe is of greater disadvantage. The size of the effects is an average over time, hence further interpretation would be meaningless.

4.5.3 Robustness

A couple of additional analyses serve to test the robustness of the results; see Table 4.5, column (2).

Table 4.5 - Robustness Tests

Dependent Variable: Number of innovation events per period (Metz, 2003), 1500-1990				
	(1) Decades	(2) Halfcenturies	(3) w/o DE	(4) 1500-1890
log(*N*)	1.421***	1.450***	1.233***	0.212
	(0.073)	(0.067)	(0.077)	(0.22)
log(*I**)	0.111	-0.184**	-0.119	1.006***
	(0.21)	(0.080)	(0.22)	(0.31)
log(*I**) × *eff*	0.141***	-0.00246	0.188***	0.0946
	(0.018)	(0.016)	(0.023)	(0.079)
log(*h*)	-0.291***	0.226***	0.0760	-0.388***
	(0.058)	(0.027)	(0.065)	(0.12)
inst	0.187***	0.180***	0.0954***	0.0740**
	(0.012)	(0.011)	(0.017)	(0.032)
geo2 (dummy)	-0.174	-1.569***	-0.0828	
	(0.44)	(0.33)	(0.44)	
geo3 (dummy)	-2.779***	-2.866***	-2.262**	
	(1.02)	(0.90)	(1.02)	
geo4 (dummy)	-0.133	-1.780	0.666**	
	(0.31)	(1.28)	(0.32)	
geo5 (dummy)	-7.057***	-6.962***	-13.76	
	(0.90)	(0.75)	(2195)	
Constant	-15.48***	-9.959***	-11.22***	-10.70***
	(1.91)	(0.59)	(1.93)	(2.36)
Observations	505	138	484	154
Pseudo R-squared	0.934	0.952	0.883	0.877

Notes: Standard errors in parentheses. Time/country dummies not reported. *** p<0.01, ** p<0.05, * p<0.1.

First, the period length is set to 50 years resulting in a potential maximum number of 480 observations. Robust findings regard the coefficients of population size and executive constraints. They remain nearly the same. The stock of innovation events, however, has as slightly negative effect now, and the interaction term is non-significant. The coefficient of human capital, on the other side, turns positive. Even though the coefficient is significant, its size is still small and of little economic relevance. The insight of rising complexity of ideas remains unaffected. Note that, with halfcenturies, the number of subsequent periods for a country is 10 at the maximum; very few, given that only time variability is exploited by the estimation technique.

Next, subsample estimates ought to ensure that the results are not due to distortions in the database. The first subsample excludes Germany from the regression (column (3)), the second is additionally based only on periods prior to 1900 (column (4)). This is because of a potential discontinuity in documentation behavior as well as a potential bias in favour of German innovation events. Excluding Germany does not alter the general insights in comparison to the original sample. Human capital has no effect, the impact of institutions is reduced, and all other statements made above remain valid. Prior to 1900, however, the returns to the stock of existing knowledge are higher than in the full sample. The coefficient points at constant returns and suggests that - at the prevailing level of technology- ideas had not yet started to get more complex. The interaction term suggests that a gap to the technological frontier was not detrimental during times of generally lower technological levels. Also, according to column (4), population size did not matter prior to 1900. Note, however, that the low number of observations may not provide enough variability to bring out some effects in the presence of highly collinear covariates.

Detailed results of all further robustness checks are documented in Appendix B.3. None of them, however, calls the principle findings into question. Hence, at this point, a brief summary of the performed tests should suffice. A negative binomial regression has been fitted to the data to account for potential violation of the Poisson assumption due to overdispersion. Further, a lagged dependent variable was included in the Poisson regression to eliminate serial correlation.[98] As would be expected, the coefficients are reduced in size, but all statements remain generally true. Next, endogeneity is likely to be an objection against the analysis. Especially population size is under suspicion. In the complete specification of Table 4.4, its coefficient exceeds the value 1. This may be due to spillover effects on the one hand, or due to reversed causality on the other. Imposing the restriction $\psi = 1$, however, does not change the regression results drastically. Moreover, reversed causality should not affect the coefficients of the knowledge stock, which is insignificant, and human capital, which is negative. Also, the coefficient of the interaction term is argued to be intact, because national innovations are not important for economic growth as demonstrated in section 4.4. Admittedly, institutional change might be an outcome of innovative activities rather than the driving force behind them. This is especially true in light of the broad notion of innovation events. The database encompasses events, which rather express institutional than technological improvements. For example, regulations related to technological development may in fact be an outcome of the latter. Including those in the left-hand side variable might lead to an upward bias in the right-hand side measure of institutions. Hence, the regression was performed for an alternative dependent variable adjusted to reflect only actual

[98] If the dependent variable did contain a unit root or a time trend, first differencing might be necessary. Time trends owing to the rise in the international stock of knowledge or population are controlled for explicitly. A potential trend due to changes in the documentation behavior of innovation events, on the other hand, is eliminated by including times dummies in the regressions. Also, apart from trends, it appears from Figure 1 that the individual series do not contain that much dependency. Given the difficulty of unit root testing in unbalanced panels, this graphical evidence must suffice at this point. That is, differencing does not seem necessary. Including a lagged dependent variable, however, actually requires dynamic estimation techniques, because it is correlated with the individual effects by construction. Such methods have been applied in a count data context by Crepon and Duguet (1997) or Blundell, Griffith and van Reenen (1999). The respective procedures, however, are not implemented in standard econometric software packages. A new user-written Gauss-program by Windmeijer (2006) is capable of performing such analyses. Applying this program would be a way to further substantiate the robustness of my findings. So far, potential bias from including an LDV is ignored. Anyhow, there is little economic reason to think that innovation frequency in one period depends that strongly on the number of innovations in the previous period, given that period length is 10 years, and that the stock of international knowledge already contains the innovations of all preceding periods. Much of what may cause serial correlation can most likely be captured by the individual effects in the model., because the latter reflects the entry level innovation knowledge stock, i.e. the stock of past innovations of each country (also see Blundell, Griffith and van Reenen, 1999, p. 534).

technological improvements, such as discoveries, inventions, constructions etc. Once again, the findings are not changed fundamentally. Nevertheless, this adjustment does not abandon the possibility of institutions being endogenous. Finding an instrument, which captures the exogenous variation in institutions over time, however, is a challenge that could not be mastered in this work. In consequence, not being able to disprove this criticism calls for caution in interpreting the results. Last, in some cases, the place of an event deviates from the country, where the person(s) associated with it received their education. A final check makes sure that the coefficients are stable, when the dependent variable is based on the place of education instead of the place of innovation.

4.6 Interpretation of results

This section formalizes assumptions about the process of innovation and growth. These are immediate implications of the preceding analysis. Note that it is not the goal to develop and solve a complex model of economic growth; this task is left to theoretically oriented economists who are more competent to do so. Rather, the purpose is to interpret the empirical findings and provide hints for further theoretical efforts.

4.6.1 Production

Let the aggregate production function of an economy be specified by

$$Y_{jt} = A_{jt} K_{jt}^{\alpha} L_{jt}^{1-\alpha} \tag{4.10}$$

where A_{jt} denotes a country-specific productivity parameter. Unlike in Romer (1990), it is not to be interpreted as the stock of knowledge, but as the productivity level of an economy. It reflects the degree to which worldwide available technological knowledge has been implemented in an economy’s production sector. As already emphasized by Nelson and

Phelps (1966), the adoption capability of a country is in turn presumed to depend crucially on its endowment with human capital.[99] Other potential facilitators of technology transfer may include the institutional conditions (North 1990; Acemoglu, Johnson and Robinson, 2001; Hall and Jones, 1999), which are thought to encompass trade regulation determining an economy's openness, as well as a country's geography (Sachs, 1997; Diamond, 1998). Hence, $A_{jt} = A_{jt}(h_{jt}, inst_{jt}, geo_t)$.[100] In order to generate sustained economic growth, A_{jt} needs to be able to grow without bound.

Next, human capital of a worker *k* is given by the duration of schooling typically associated with the specific teaching program completed by this person, d_k, relative to the potential maximum number of school years, *D*. That is, $h_k = d_k / D$ with $0 \le h_k \le 1$. At the aggregated level, $h_{jt} = \sum_{k=1}^{N} \frac{h_{kjt}}{N_{jt}} = \sum_{k=1}^{N} \frac{d_{kjt}/D_{jt}}{N_{jt}}$, $0 \le h_k \le 1$. This conceptualization of human capital is meaningful, because it can most easily be measured and permits the derivation of unambiguous recommendations for the design of economic policy. Restricting human capital per worker to the value 1 and simultaneously allowing A_{jt} to grow without bound implies a relationship between *A* and *h* of the general form

$$A_{jt} = A_{jt}(h_{jt}, \bullet) = f_{jt}(\bullet)\frac{1}{(1-h_{jt})^{\gamma}}, \text{ for } h_{jt} \le h_t^* \text{ and } 0 \le h_t^* \le 1 \qquad (4.11)$$

or, solved for *h*:

---

[99] In Nelson and Phelps (1966), however, the level of human capital determines the speed of adoption and convergence, whereas here, it merely determines the level of technology that may be adopted at the maximum. Nothing is said about the speed of convergence. Also, in Nelson and Phelps (1966), a gap between implemented technology and what they call theoretical knowledge, necessarily remains, whereas here, closing the gap to the technological frontier is in principle possible, if the human capital stock is sufficiently high.

[100] Certainly, the relative importance of those factors may have changed over time. While geography might have been important for the adoption of technology in times of slow information transport, today this factor may lose relevance.

$$h_{jt} = 1 - \left(\frac{f_{jt}(\bullet)}{A_{jt}} \right)^{1/\gamma}, \quad A_{jt} \geq 0 \tag{4.12}$$

The level of human capital needed to employ the respective level of technology, increases along with the latter and asymptotically approaches the value 1. In other words, extensions of the human capital stock buy less technological advancement at a relatively low level of development than at a relatively high level.[101]

A country at the technological frontier, which applies the most efficient available techniques in every respect, has $A_{jt} = A_t^*$. Standardizing institutional and geographical conditions by setting $f(\bullet) = 1$, the human capital stock needed to reach this productivity level is denoted by h_t^*. That is, $A_{jt}(h_{jt} = h_t^*) = A_t^*$. More generally, A_{jt} may be expressed in terms of A_t^*:

$$A_{jt}(h_{jt}) = A_t^* \left(\frac{1 - h_t^*}{1 - h_{jt}} \right)^{\gamma}. \tag{4.13}$$

Now, assume that the labor force L_{jt} is given by $L_{jt} = (1 - h_{jt})N_{jt}$, where N_{jt} is the size of the population.[102] Then, with (4.11) the per-capita version of the production function reads

$$y_{jt} = \frac{Y_{jt}}{N_{jt}} = f(\bullet) k_{jt}^{\alpha} (1 - h_{jt})^{1-\alpha-\gamma}, \qquad h_{jt} < h_t^*. \tag{4.14}$$

---

[101] This is a very narrow assumption. It demands that human capital exhibit continuously decreasing returns, i.e. $dA/dh > 0$ and $dA/d^2h < 0$. One might argue that it is not natural to restrict the relationship to such a specific shape, but Figure 4.9 shows that it adequately reflects reality.

[102] For this to be true, *D* must equal the maximum number of years an individual could potentially participate in the labor market, i.e. roughly 50-60 years. The exact value does not matter for the analysis, however. For Figure 4.9, *D* was set equal to 50.

If $h_{jt} = h_t^*$, it becomes $y_{jt} = A_t^* k_{jt}^{\alpha} \left(1 - h_t^*\right)^{1-\alpha}$. Hence, for a follower economy with $h_{jt} < h_t^*$, shifting the technological frontier, i.e. increasing A^*, does not have an immediate impact on its income level. The latter solely depends on its ability to adopt technologies and catch up with the frontier.

From (4.14), the regression equation

$$\log y_{jt} = \log C + (1 - \alpha - \gamma)\log(1 - h_{jt}) + \boldsymbol{\beta Z_{jt}} + \varepsilon_{jt} \qquad (4.15)$$

is derived. It does not include physical capital on the right-hand side. Because of endogeneity, the latter is rather an alternative for the left-hand side of the equation.[103] The constant term reflects the intuition that even with no human capital, output is unlikely to be zero. $\boldsymbol{Z_{jt}}$ contains the measures of institutions and geography already applied in section 4.5.

Table 4.6 - OLS regression of equation (4.15)

Dependent Variable: Avg. GDP per capita (Maddison, 1995), 1500-1990			
log(1-*H*)	-11.50***	-10.12***	-10.26***
	(0.32)	(0.42)	(0.43)
inst		0.0557***	0.0551***
		(0.011)	(0.011)
geo2 (dummy)			-0.0256
			(0.067)
geo3 (dummy)			-0.0279
			(0.089)
geo4 (dummy)			0.122
			(0.092)
geo5 (dummy)			-0.00775
			(0.065)
Constant	6.808***	6.701***	6.691***
	(0.034)	(0.049)	(0.074)
Observations	632	525	525
R-squared	0.68	0.67	0.67

Notes: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

[103] According to the 'stylized facts' by Kaldor (1961), the capital-output ratio is constant over long periods of time.

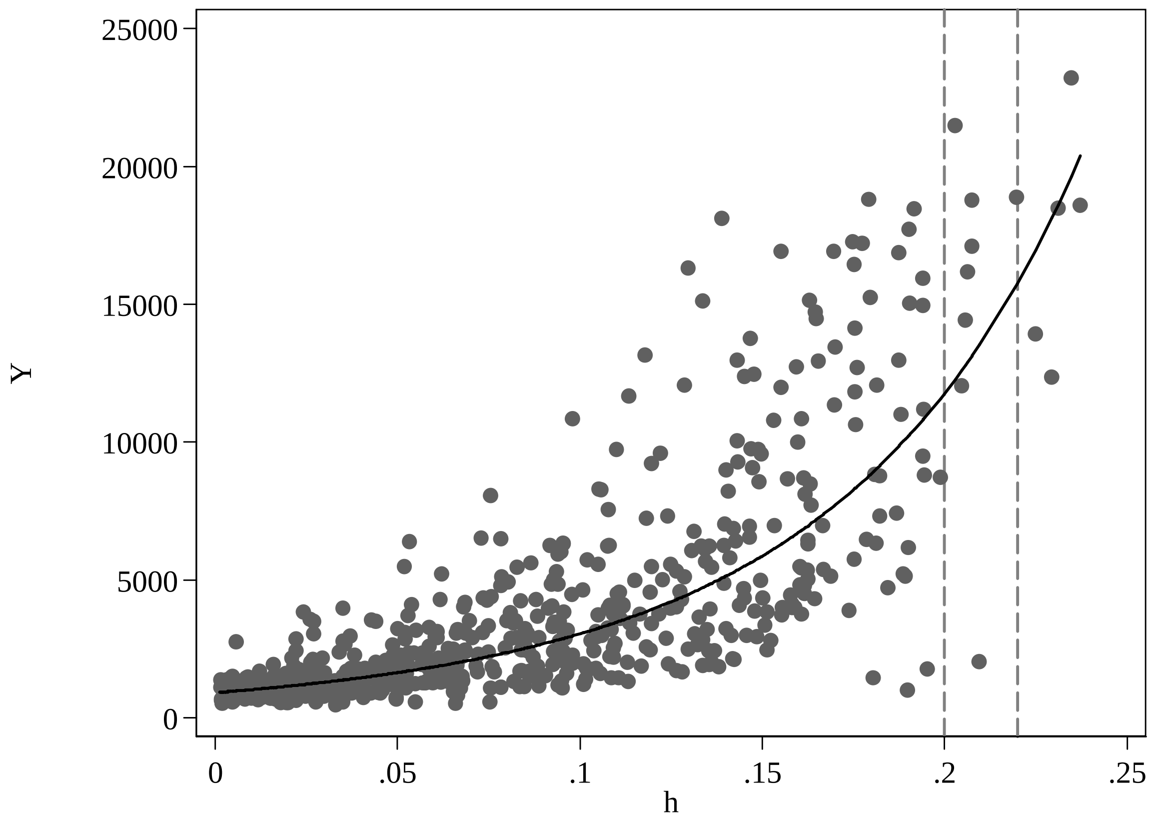

Figure 4.9. GDP per capita versus schooling duration

Sources: GDP from Maddison (1995), human capital measure as explained by Appendix B.2.

Figure 4.9 depicts a scatter chart of GDP per capita by Maddison (1995) versus schooling duration, the construction of which is described in detail in Appendix B.2, as well as the prediction based on equation (4.15). With $\alpha \approx 0.3$, the OLS results imply $\gamma \approx 12$; see Table 4.6, column (1).[104] To judge the size of the human capital effect, consider a one-year increase in average years of schooling in an industrialized country with $h \approx 0.2$. If the average length of an academic education is 5 years, such an increase could be reached by inducing an

[104] When measure of geography and institutions are included, the regression coefficient drops to roughly -10.3. With $\alpha \approx 0.3$, this implies $\gamma \approx 11$. Democracy is significant and quite important. An improvement of one point on the seven-point democracy scale causes a 5.6% rise in GDP per capita. Of course, this is in ignorance of the potential indirect effect of democracy that might work via investment in human capital. Finally, the location relative to central Europe is of no importance for technology adoption.

additional 20% of the population to complete this type of program. This 10%-change in h buys a tremendous increase in Y of about 30% (see Figure 4.9). Advanced economies, on the other hand, with $h = h^*$, are limited in their potential for economic growth by movements of the technological frontier[105].

4.6.2 Knowledge

The number of technological ideas a country is able to produce in one period, $\dot{I}_{jt}$, depends primarily on the size of the population, and the international stock of innovations or technological knowledge,

$$\dot{I}_{jt} = CN_{jt} I_t^{*\phi_{jt}} . \tag{4.16}$$

Importantly, the pure existence of technological knowledge does not suffice to incite further innovations. Rather, having it at one's disposal is what sparks consecutive creative action. The degree to which it is currently applied within the economy, i.e. the distance to the technological frontier, A_{jt} / A_t^*, contributes to the determination of $\phi_{jt} = \phi_{jt}\left(A_{jt} / A_t^*\right)$. Via that channel, institutions, geography, and human capital exert indirect effects on national innovativeness.

Equation (4.16) reflects the absolute period change in a country's stock of ideas.[106] The absolute change in worldwide knowledge is given by the sum of ideas generated by all countries in this period, i.e. $\dot{I}_t^* = \sum_j \dot{I}_{jt}$. If $\phi = 1$, an economy generates a constant knowledge

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[105] Technically, this formulation is not very different from the one by Lucas (1988), but it adds the insight that knowledge and human capital have to be treated separately.

[106] Equation (4.16) may be interpreted as the innovation hazard rate of a Poisson process, which gives the probability of an event to occur in an infinitesimal time interval, *dt*. Because all the variables are really continuous, it would actually be necessary to multiply both sides by *dt* to obtain the number of ideas per period, *dI*, on the left-hand side, and take the integral over the right-hand side. Because in practice all right-hand side variables are measured on a yearly basis, it makes sense to set $dt = 1$, such that $dI = \dot{I}$.

growth rate over time. The size of the contribution, $\frac{\dot{I}_{jt}/I_t^*}{\dot{I}_t^*/I_t^*}$, depends on the size of the population. Note that this does not imply a scale effect as prescribed by innovation-driven growth models. If $0<\phi<1$, there are diminishing returns in the generation of new ideas. They are increasingly difficult to develop and the growth rate of knowledge, respectively the individual contributions to international knowledge growth, decline over time.

Given that innovations are produced almost predominantly by industrialized countries, i.e. countries with $A_{jt}/A_t^* \approx 1$, the absolute change in international knowledge may be approximated by

$$\dot{I}_t^* = CI_t^{*\phi} \sum_j N_{jt} . \tag{4.17}$$

The empirical tests of section 4.5 suggest that $0<\phi<1$ for countries with $A_{jt}/A_t^* \approx 1$, but ϕ is not significantly different from zero for low-income countries (Table 4.4, column (4)). This implies a declining growth rate of international knowledge.[107] In light of stagnating population in countries close to the technological frontier, this poses the question: why do growth rates in those countries not slow down? The answer is straightforward: Growth of the international technological frontier, $\dot{A}_t^*/A_t^*$, is a function of worldwide technological knowledge growth, $\dot{A}_t^*/A_t^* = g\left(\dot{I}_t^*/I_t^*\right)$. The exact nature of this relationship, however, is moot. Consider the following:

$$\frac{\dot{A}_t^*}{A_t^*} = \frac{\dot{I}_t^*}{I_t^{*\eta}} = \frac{\sum_j \dot{I}_{jt}}{I_t^{*\eta}} . \tag{4.18}$$

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[107] Remember that this holds only if the documenting behavior related to innovation events has not changed over time. In the previous analysis, potential changes have been argued to be captured by the inclusion of time dummies in the regression analysis.

If $\eta = 1$, productivity growth at the technological frontier equals the rate of knowledge growth. When the stock of knowledge reaches higher levels, the number of ideas needed to maintain constant productivity growth rates at the technological frontier increases proportionately. That is, ideas become less effective in terms of their relative productivity improvement. It seems much more likely, however, that ideas cause relatively stable contributions to productivity growth over time. If innovative activities aim at improving productivity, it is plausible that research is carried on until a satisfactory advancement in this respect has been attained. For instance, one might think that there are decreasing returns to the time invested in a research project such that improvements at a specific project get smaller and smaller over time. Hence, inventions may be published at the time when additional research effort just offsets the additional productivity effect. This optimality condition would lead to relatively stable productivity growth rates and at the same time stagnating numbers of ideas per period. Taken to the extreme, $\eta = 0$, that is a constant number of ideas generates sustained economic growth. In other words, $\dot{A}_t^* / A_t^* = \dot{I}_t^*$. To allow for some generality, one might want to assume $-1 < \eta < 1$. That is, increasing effectiveness of ideas in relative terms is allowed for, too. Empirically, economic growth rates have been quite stable at roughly 2% per annum over long periods of time in industrialized countries. Hence, in the long run, worldwide knowledge growth rates must be stable, too, $\dot{I}^* / I^{*\eta} = const.$ According to equation (4.17), this is possible only if $\eta = \phi$. With $0 < \phi < 1$, this implies that ideas get less effective in relative terms at higher levels of technology because higher and higher numbers of ideas are needed relative to the existing stock of knowledge in order to maintain growth rates, but more effective in absolute terms because disproportionately low increases suffice to achieve that. In fact, ϕ being close to zero grants some significance to the thoughts in favor of $\eta = 0$. The observation of stagnating or modestly growing patent rates would be very well in line with this evidence.[108]

Characteristics that cannot be influenced, such as the geographical location, are subsumed under the constant *C* in equation (4.17). Further, institutions have been found to be of prime importance for innovativeness even beyond a potential indirect effect via technology adoption. This result, however, is based on a very crude 7-point-scale measure. Because there is no settled view on how they should be measured and how the respective effect should be modeled, it is subsumed under the constant C. Nevertheless, one had better not be tempted by this treatment to underestimate their importance.

Human capital is thought to exert an indirect effect on innovativeness based on its important role in technology adoption. The empirical analysis in this paper, however, was not successful in substantiating its relevance within the innovation process. This finding is plausible only if humans engage in innovative activity primarily because they are exceptionally talented to do so. For instance, creativity, intelligence, and a pioneering mindset may be crucial characteristics of an innovator's personality. At the same time, those might hardly be manipulated by teaching programs, which first of all impart knowledge and skills. Of course, the latter are still inevitable requirements for successful innovative activities. Nevertheless, people capable of creating innovations may be likely to obtain these qualifications anyway, either self-educated or at school. The fraction of those “innovative minds” in a population may be very small. But it is unlikely to differ significantly across countries. In other words: if the distribution of those types of skills, which are necessary to become innovative, is uniform in the populations of different economies, then the number of ideas an economy is capable of generating should be expected to primarily depend on the size

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[108] $\eta = 0$ would make it easy to explain the decline of nations in terms of innovativeness with the rise of others.

of its population. Educating people beyond the level, which is needed to adopt state-of-the-art-technology, would not induce more innovations, because those, who have not already chosen to be part of the educated group, are unlikely to possess the required capabilites, anyway.[109] Following the same rationale, population size *N*, and not the number of workers involved with the production of ideas (i.e. the share of the labor force in the research sector) would be relevant for innovativeness. Creativity might not be forged by making people work on tasks requiring it. It was assumed that *N* exhibits constant returns, although the empirical evidence could well be interpreted in favor of increasing returns due to spillovers. On the other hand, because more people carry a higher risk of duplicating research efforts, slightly diminishing returns would be plausible as well. The empirical evidence cannot be taken to reject one of these views.

The presented framework builds on the two fundamental models of new growth theory by Romer (1990) and Lucas (1988). On the one hand, as in Lucas (1988), countries can generate endogenous growth by accumulating human capital. In contrast to Lucas (1988), however, human capital is specified solely in terms of education duration. This makes sense, because in practice, the implications of human capital in a theoretical model are usually attributed to the quantity of education anyway. Further, human capital is limited in its growth potential. Rather, it drives countries' capabilities of adopting technological knowledge. Hence, like in Romer (1990), the concepts of human capital in the narrow sense of education and in the wide sense of technological knowledge, are strictly separated. The latter is the ultimate engine of growth. In contrast to Romer (1990), however, knowledge growth is an international process based on contributions by multiple countries. It can only marginally be

[109] This is of course provided that no other sources of market failure, such as credit constraints, exist.

influenced by individual countries. The national contributions depend - besides institutions - primarily on the size of a country and its proximity to the international technological frontier.

Combining Romer's and Lucas' ideas and modifying them in this manner entails a couple of implications. First of all, economies can be classified into technological leaders and followers. Leaders are countries at the technological frontier. They are unable to influence their long-run economic growth rate in an autarkic way, because it depends on the contributions to knowledge growth of all other countries, too. Follower countries instead may grow exclusively based on human capital accumulation. Movements of the frontier do not affect their growth potential in the short run. Also, homemade innovations are not necessary for growth. Anyhow, as an economy approaches the technological frontier, not only convergence in income levels but in innovativeness, too, should take place according to the outlined framework.

Further, in this framework human capital does not exhibit externalities à la Lucas (1988). Its productivity-enhancing value is expected to be anticipated and compensated accordingly by employers. This implies that a specific level of human capital exists, which is optimal from an employer's point of view.[110] Actually, deviations from this optimum would even cause negative externalities. Research activities, on the other hand, do yield positive external benefits that may remain uncompensated. Those gains arise from the production of ideas. They are international in nature, because new ideas improve the theoretical growth potential of all economies worldwide. Some nations harvest others' innovation successes

[110] Obviously, the formulation in this paper is based on the assumption that technological progress is skill-biased. Although there is enough evidence in favour of this hypothesis (e.g. Goldin and Katz, 1998), one might argue that - based on technological advancements – technical devices eventually get even easier to handle. In any case, the stock of human capital would adjust automatically to the level required for a specific productivity level, notwithstanding a notable time lag.

without having to incur the cost of the knowledge generation effort. Thus, national subsidies to idea production might result in international free-riding behavior.

Finally, there is no longer a scale effect in the sense that larger economies grow faster. Of course, the contribution to worldwide knowledge growth differs by country size. Larger countries can shift the frontier further than small countries. But economic growth of followers does not rest on this and the growth of leaders is determined by the collective research effort. Consequently, a scale effect may exist only on the world level.[111] Whether it does or not depends on the exact impact of new ideas on the rate of productivity growth, which is - in contrast to Romer (1990) - not necessarily equal to the rate of knowledge growth.[112]

4.7 Conclusions

Based on a new database of historical innovation events (Metz, 2003), this paper has attempted to shed light on various aspects of technological progress as well as implications of the innovation process for economic growth. It turns out that scale as measured by population is indeed the most important determinant of an economy's innovative potential. Because a country's innovative success does not drive its economic growth, however, a scale effect in growth rates as implied by Grossman and Helpman (1991) may not precipitate on the national level. Whether it exists for the world as a whole depends on the returns to the stock of existing technological knowledge in the production of new ideas. The analysis of Metz's (2003) data suggests that those returns are diminishing and the generation of innovations gets

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[111] A scale effect may be observable in countries, which represent a relatively large fraction of the world population. Population shocks in those countries may lead to greater frontier shifts, directly affecting their own growth rates. Yet, this is not a necessary implication of the outlined framework.

[112] Jones (1995) would also reject a scale effect on the world level, based on the development of the number of researchers versus TFP growth rates. This, however, is probably, because the number of researchers is the wrong measure of scale. It may rather proxy for the level of human capital, which has been found to be at best irrelevant for technological progress. Population size, instead, is what actually determines the number of innovative minds in an economy.

increasingly difficult during the process of technological development. If that holds true, population growth is necessary to maintain constant knowledge growth rates. Anyhow, even with stagnating population, a scale effect on the world level may exist if innovations not only get more difficult but also more effective in absolute terms at higher levels of technology. The observation of non-declining growth rates in industrial countries points in this direction. If innovations did not get more effective, this work would predict declining growth rates in countries with stagnating population some time in the future, provided that the diminishing returns to existing knowledge are not caused by selection bias in the IAB data.

Further findings shed doubt on the frequently accentuated prominent role of human capital in the innovation process. After controlling for distance to the technological frontier, i.e. the extent to which international technological knowledge has been adopted by an economy, human capital has an ambiguous effect. In most of the presented regressions, it even holds a negative sign. That is, whereas average years of formal education in a population do seem to matter for technology adoption, there is no evidence for this being so in the innovation process. On the contrary, the importance of institutions - even beyond their indirect effect through technology adoption capability - is emphasized by the analyses. The evidence indicates that countries with fewer constraints on the executive are more innovative. Admittedly, reversed causality cannot entirely be ruled out in this context. The direct influence of geography is put into perspective by this study.

This paper does not deliver a complete story of innovation and growth. Also, the underlying data contain some weaknesses. Nonetheless, if the results are interpreted very carefully, exploiting quantitative data on the entire human history of technology fills a gap. An important contribution consists in hints regarding the nature of the long-run innovation and growth process. Those may help guide the way for future theoretical efforts in innovation-driven growth theory. Of course, in formulating those implications based on the empirical results, it was assumed that the nature of the innovation process has been unchanged during the last 500 years. This is radical and in reality, it may differ from region to region or change over time. Note, however, that the interest of this paper is really in the unchangeable aspects of the innovation process, which can indeed be generalized over time and across countries. For instance, stating in the context of this work that human capital does not matter for innovativeness is not equivalent to saying that it never did in any country. It means that - taking all periods and countries together - there is no pattern that would suggest a consistent positive effect of human capital quantity on innovation, after controlling for an economy's distance from the technological frontier.

Appendix B

B.1 Coding of country details in IAB data

31% of the IAB observations provide information on where the respective incidences took place. This appendix explains how the information was completed for roughly 85% of the cases. Because the explanatory variables are usually related to current borders (e.g population and income per capita by Maddison, 1995), innovation events also need to be assigned to current territories. To do so for those observations, which lack the respective information, the following steps were taken (the order represents the priority):

1. If available, the country detail (attribute *coe* in Table 1) was adopted (roughly 5,000 events).[113] More specifically,
    a. if a region was specified instead of a country (e.g. Saxony, Bavaria etc.), the respective state comprising the region today was assumed (e.g. Germany).
    b. if the specified state is no longer existent, the successor state in the respective territory is assumed (e.g. 'Germany' if the database states 'Deutsches Reich').
    c. if a state no longer exists and two or more states are eligible as immediate successor states, steps 2-7 were taken to determine which of them is applicable (e.g. Austria vs. Hungary).
2. If the country detail was unavailable, the place detail (attribute *poe*) was applied by assigning the country which comprises the place today (roughly 1,400 events).

[113] Only in very few - probably less than ten - cases, corrections were made to the database information. This regards cases, for which it was obvious that the inventor's country of birth had mistakenly been used as the country of the event. The same applies for step 2.

3. If neither place nor country details are given, the institution associated with an event (attribute *ins*) could be of help. The headquarter's location in the respective year could be obtained from internet sources in most cases (roughly 2,500 events).

4. If none of the preceding attributes was helpful to assign a country, the name of the person associated with an event (attribute *inn*) provided a straw (roughly 3,900 events):
   a. in many cases, internet sources revealed where the event associated with a specific person occurred. If not so,
   b. the place or country of birth as given by the database (attributes *pob* and *cob*) was assumed to be identical with the place of the event. If not given by the database,
   c. the place of birth as obtained from internet sources.[114]

5. Finally, the description of the event itself (attribute *des*) contained valuable hints on the country in some cases (<500 events).

To account for migration and obtain a measure that is suitable in particular to analyse the effect of education on innovation, a second category has been created, which may differ from the specification implied by steps 1 through 5:

6. Whenever the place or country of birth implied by steps 4b and 4c was in conflict with the result from steps 1 through 4a as well as step 5, it has been presumed that the person received his/her education in the country of birth and contributed the innovation event

[114] For all internet research, the free online-encyclopedia Wikipedia.org was of great support. Also, manifold other online sources such as company websites or private enthusiasts' homepages were used that cannot all be listed. In light of the low degree of complexity of the required information (e.g. a company's headquarter location or an inventor's place of birth) as well as the extraordinary effort associated with a literature research, an internet research seems adequate to complete the data in a sufficiently reliable manner. Potential errors in the sources are not likely to bias the empirical analysis.

after migration to another country. Hence, the result of steps 4b and 4c was used in this case. Else, the result from 1 through 4a was preserved.[115]

[115] This procedure does not ensure that all migrations can be detected. To guarantee this, the biography of every single person in the database would have to be scrutinized. However, it is moot whether the potentially achievable degree of accuracy would justify such an effort. At this point, additional research has been restricted to suspicious cases; for instance, if the spelling of a name indicated an origin different from what had been figured out to be the country of the innovation. Especially exhibitions, where inventors only go for presentation purposes, are problematic in this respect.

B.2 Construction of explanatory variables

Table B.1 gives an overview over the availability of the explanatory variables. Subsequently, the construction of those variables is described in detail.

Table B.1 - Number of observations by country

Country Code	Decades, 1500-1750				Decades, 1800-1990			
	N	Y	inst	h	N	Y	inst	h
am	6	6	0	0	6	13	0	5
ar	6	0	0	0	20	13	17	15
at	6	6	0	3	20	20	20	20
au	6	6	4	0	20	20	11	14
be	6	6	4	1	20	20	17	20
bg	6	6	4	0	20	20	14	6
br	6	6	0	0	20	20	17	10
ca	6	6	0	0	20	20	13	14
ch	6	6	4	3	20	20	16	14
cn	6	6	0	0	20	20	18	14
co	6	0	0	0	20	10	16	10
cz	6	6	4	2	20	20	10	18
de	6	6	4	2	20	20	19	20
dk	6	6	4	1	20	20	19	20
ee	6	6	0	0	6	13	3	5
eg	6	6	0	0	9	13	7	14
es	6	6	4	4	20	20	19	16
fi	6	6	4	0	20	20	10	9
fr	6	6	4	2	20	20	20	16
gr	6	6	4	0	20	20	18	14
hu	6	6	4	2	20	20	15	20
ie	6	0	4	0	20	0	9	19
il	0	0	0	0	5	5	5	5
in	6	6	0	0	20	20	5	12
iq	6	0	0	0	9	11	7	7
it	6	6	4	6	20	20	15	20
jp	6	6	0	0	20	20	19	15
kr	6	2	0	0	17	16	17	6
lt	6	6	0	0	6	13	3	8
lv	6	6	0	0	6	13	3	8
mx	6	6	0	0	20	20	17	10
nl	6	6	4	6	20	20	18	17
no	6	6	4	0	20	20	18	20
nz	6	6	0	0	20	20	14	14
pa	0	0	0	0	0	5	9	8
pl	6	6	4	0	20	20	10	20
pt	6	6	4	0	20	20	19	15
ro	6	6	4	0	20	20	16	12
ru	6	6	4	6	6	20	20	17
se	6	6	4	2	20	20	20	15
sy	6	0	0	0	9	11	4	7
tr	6	0	4	0	11	14	19	14
tt	0	0	0	0	18	5	3	10
uk	6	6	4	5	20	20	20	20
us	6	6	0	0	20	20	20	16

uz	6	0	0	0	6	0	0	5
yu	6	6	4	0	20	20	18	8
za	6	0	0	0	9	11	9	10
total	270	218	96	45	783	786	636	632

N – Population figures up to 1800 are from McEvedy and Jones (1978). In most cases, the latter explicitly provide figures in 50-year intervals. Occasionally, however, the values need to be inferred from curves. For the year 1550, they can be interpolated. A few exceptions require mentioning:

- McEvedy and Jones (1978) provide a common curve for Belgium and Luxembourg. Hence, the figures were divided up based on today's population of both countries, i.e. a fraction of 95.5% was assigned to Belgium and the remainder to Luxembourg.
- In the case of Syria and Lebanon, 80% of the population in 1500 and 1600 was assigned to Syria.
- UK population was computed as the sum of the figures for England, Wales, and Scotland.
- Russian figures were chosen to reflect only the populace on European ground, given that Russian innovation events occurred primarily in this area.
- Armenian, Estonian, Latvian, Lithuanian, and Uzbekistanian population is unavailable from McEvedy and Jones (1978). Here, the 1950 figures by Maddison (1995) were used as a point of origin to impute the remaining observations such that the population growth rates equaled those of Russia.
- Indian figures include the whole of British India, i.e Pakistan as well as Bangladesh.
- Turkish population covers both the Asian and European part.

Starting with 1820, the figures are based on Maddison (1995). If two or less consecutive decades were missing, the values were filled in by interpolation.

Y – Prior to 1820, Maddison (1995) gives GDP per capita only for the years 1500, 1600, and 1700. Thus, the years 1550, 1650, 1750, and 1800 were interpolated for all countries. No extrapolation was made, however. As of 1820, decadal figures are available for many countries from Maddison (1995). Two or less consecutive missing decades were filled in by interpolation. Some exceptions require mentioning:

- In the case of Russia, Mexico, India, Japan, Korea (South), Iran, Iraq, Syria, Turkey, Egypt, and South Africa, interpolations were made to fill the four subsequent decades between 1820 and 1870.
- GDP per capita for Bulgaria, Hungary, Poland, Romania, and Yugoslavia is available only as of 1870, respectively 1820 in the case of Czechoslovakia. All preceding periods were imputed such that the growth rates equal those of the collective category 'Eastern European Countries' according to Maddison (1995).
- USSR figures by Maddison (1995) were used for Russia.
- Figures for Armenia, Estonia, Latvia, Lithuania, and Uzbekistan are available as of 1973. The missing periods were imputed such that the growth rates equal those of the USSR.

Inst – After 1800, this variable is equal to the measure of executive constraints from the Polity IV project. It assigns a score of between 1 and 7, the former indicating unlimited authority of the executive, and the latter representing executive parity. Further details are described in Marshall and Jaggers (2002). Some adjustments were made to the original coding:

- Instances of "standardized authority scores", such cases of transition, interregnum, or interruption, have been prorated, converted to missing, or converted to zero score as suggested by Marshall and Jaggers (2002, p. 16).
- For Russia, *inst* contains the Soviet Union scores from 1930 through 1990.
- In the case of Germany, prior to 1870 *inst* contains Prussian scores, and between 1950 and 1990 the scores of West Germany.
- For Yugoslavia, values prior to 1921 were set equal to the scores of Serbia.
- For Korea after 1950, the scores were taken from South Korea.

For all periods up to 1800, as well as periods thereafter that are not covered by Polity IV, *inst* is equal to the measure used by Acemoglu, Johnson and Robinson (2005, 2002). It is derived from different sources, but follows the same general concept.

geo1-geo5 – Five dummy variables proxy for the distance of a country to the innovative center of Europe. $geo1_j = 1$ for the UK, France, and Germany, Belgium and the Netherlands. $geo2_j = 1$ for all countries, which were for most of the observation period immediate neighbors to one of the previous five countries, i.e. Austria, Switzerland, Czechoslovakia, Denmark, Spain, Hungary (respectively Austria-Hungary), Ireland, Italy, Poland, and Sweden. $geo3_j = 1$ for those countries that have been an immediate neighbor to one of the *geo2* countries for most of the time, namely Latvia, Norway, Portugal, Romania, and Yugoslavia. $geo4_j = 1$ for countries in the periphery of Europe. Those are Bulgaria, Estonia, Finland, Greece, Lithuania, and Russia. Finally, $geo5_j = 1$ for countries that are located outside of Europe, such as Armenia, Argentina, Australia, Brazil, Canada, China, Colombia, Egypt, Israel, India, Iraq, Japan, Korea, Mexico, New Zealand, Panama, Syria, Turkey, Trinidad and Tobago, the US, Uzbekistan, and South Africa.

h – Human capital is defined as the average number of school years divided by the potential maximum of 17 years of schooling. Schooling duration, d_{jt}, was taken from Barro and Lee (2001) for the period 1960-1990. Prior to 1960, or if no information was available from Barro and Lee (2001), schooling duration was constructed based on three different measures:

1. *Primary and secondary enrollment rates*. Those are available from Lindert (2004) for 1830-1930. Countries and periods not covered by Lindert (2004) were supplemented with primary school enrollment rates by Benavot and Riddle (1988). In rare cases, the latter were used instead of Lindert's, because the figures appeared to make more sense. Detailed information on those exceptions can be given by the author upon request. Further, if only primary enrollment rates were available, secondary enrollment rates were completed as follows:
   a. Missing values were interpolated, if only one consecutive decade was vacant.
   b. Else, if at least one observation with secondary enrollment was available for a specific country, the average ratio of secondary to primary enrollment for this country was used to impute the missing secondary enrollment rates.
   c. If, after steps 1a and 1b, secondary enrollment was still vacant, the missing value was converted to zero. Admittedly, this causes underestimation of years of schooling. But the error is small given that secondary enrollment was regularly less than 10% of primary enrollment. Further, given that unobserved heterogeneity is controlled for in the empirical analysis, no bias is entailed in this approach as long as changes in secondary enrollment are in line with changes in primary enrollment.

   Average duration of total schooling, d^e_{jt}, was computed according to

$$d_{jt}^{e} = 6 * e_{jt-3}^{p} + 12 * e_{jt-3}^{s} \tag{B.1}$$

where *e* indicates enrollment rates. Hence, it was assumed that primary as well as secondary schooling last 6 years each in every country of the world. This is simple, but unlikely to cause a bias in a regression analysis, if unobserved heterogeneity is controlled for. Further, tertiary education was neglected; prior to 1950, this does not seem to be a big problem. Finally, a lag of three decades was applied to account for the delayed effect of enrollment rates on average education of the labor force. Of course, a more accurate measure could be obtained by considering birth-cohort-specific enrollment rates and birth cohort sizes. For the purpose of this study, however, it seems admissible to abstain from this type of perfectionism. Constructing a more perfect measure of average schooling duration would be a task for a whole project in its own right.

2. *Numeracy levels*. The numeracy concept exploits the phenomenon of age-heaping, which describes the fact that people round their ages when asked for it in censuses or on other occasions. One way to express the extent of heaping is the Whipple Index (see A'Hearn, Baten and Crayen, 2008). It sums up the frequencies, n_i, of all ages ending in 0 or 5, and expresses the result relative to one-fifth the sample size. It must be defined over an interval, which contains each terminal digit an equal number of times, such as 23 to 62:

$$W = \frac{\sum (n_{25} + n_{30} + n_{35} + ... + n_{60})}{\frac{1}{5}\sum_{i=23}^{62} n_i} * 100 \tag{B.2}$$

Whipple indices are available from Crayen and Baten (2008) for the period 1820-1949 and 165 countries (henceforth referred to as *late numeracy* levels). The data (including additionally the decades 1800 and 1810) were kindly provided by the authors for the purpose of this study. Another collection of numeracy levels is available from A'Hearn, Baten, and Crayen (2008) for the period 1300-1800 (henceforth called *early numeracy* levels). It is based on relatively small regional samples and thus less reliable than the late numeracy levels. To estimate a general relationship between numeracy levels and years of schooling, however, some common observations between both were needed. Morrison and Murtin (2007) provide years of schooling on a world-region level for the years 1870, 1910, and 1950.[116] By computing population-weighted average Whipple Indices, i.e. by aggregating the country-level late numeracy data for the same eight world regions, 20 observations were obtained, on which the estimation of the relationship could be based.[117] Allegedly, the relationship must satisfy the functional form

$$d_{jt}^{W} = \frac{a}{\left(W_{jt} - 100\right)^{b}} \tag{B.3}$$

This is because the theoretical upper bound for Whipple values is 100, which reflects a situation with no age-heaping. Hence, at higher schooling durations, the curve must asymptotically approach a vertical line through $W = 100$. Likewise, years of schooling cannot be lower than zero; hence, at low levels of schooling the curve is likely to approach the *d*-axis. The parameters *a* and *b* allow for slightly different shapes. The regression equation follows directly from equation (C.3):

[116] The regions are: Eastern European countries (eeu), Europe and European Offshores (eu), Japan/Korea/Thailand (jkt), China (cn), Africa (afr), Latin America (la), South-East Asia (sas), and the rest of Asia (oas). The paper is unpublished and currently under review according to the authors' information. It was downloaded for this study in April 2008 from http://www.stanford.edu/-~murtin/EducationInequality.pdf. The only alternative to using the data by Morrison and Murtin (2007) would have been to estimate the relationship with the help of the enrollment-based measure of years of schooling.

[117] No aggregate numeracy level could be computed for South-East Asia in 1870, Latin America in 1870 and 1910, as well as Africa in 1910. Also, two observations had to be excluded from the regression. The explanatory variable as given by C.24 was undefined in those cases because of a Whipple below 100.

$$\ln d_{jt}^{W} = \ln a - b \ln\left(W_{jt-4} - 100\right) + \varepsilon_{jt} . \tag{B.4}$$

Morrison and Murtin's years of schooling were regressed on the Whipple Indices four decades earlier, because the latter refer to birth cohorts. The OLS results imply $a = 6.22$ and $b = 0.46$. With these values, C.3 could be used to convert the numeracy levels by Crayen and Baten (2008) into years of schooling.

3. *Literacy rates*. For single countries, literacy rates are available as early as 1400. A'Hearn, Baten and Crayen (2008) were kind enough to provide their collection of literacy rates, which are based on signature ability.[118] As before, the relationship between literacy and years of schooling was estimated based on years of schooling by Morrison and Murtin (2007). It must allegedly satisfy the functional form

$$d_{jt}^{L} = \frac{a}{\left(100 - L_{jt}\right)^{b}} \tag{B.5}$$

The upper bound for literacy rates is 100. Hence, at higher schooling durations, the curve should asymptotically approach a vertical line through $L = 100$. For $L = 0$, d should be zero, too. The respective regression equation is

$$\ln d_{jt}^{L} = \ln a - b \ln\left(100 - L_{jt-4}\right) + \varepsilon_{jt} . \tag{B.6}$$

OLS estimation for 12 observations implies $a = 204{,}973$ and $b = 2.98$.[119] Inserting those in C.5 gives the rule, according to which the literacy rates were converted to years of schooling. Figure B.1 depicts scatter charts of schooling duration versus numeracy levels, respectively literacy rates, as well as predicted years of schooling. The latter follow from B.3 and B.5 and the calculated parameters *a* and *b*.

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118 For the original sources of the data, see A'Hearn, Baten and Crayen (2008).

119 No aggregate literacy levels were available for 1950 as well as for Africa in 1910, Latin America in 1870 and 1910, and South-East Asia in 1870.

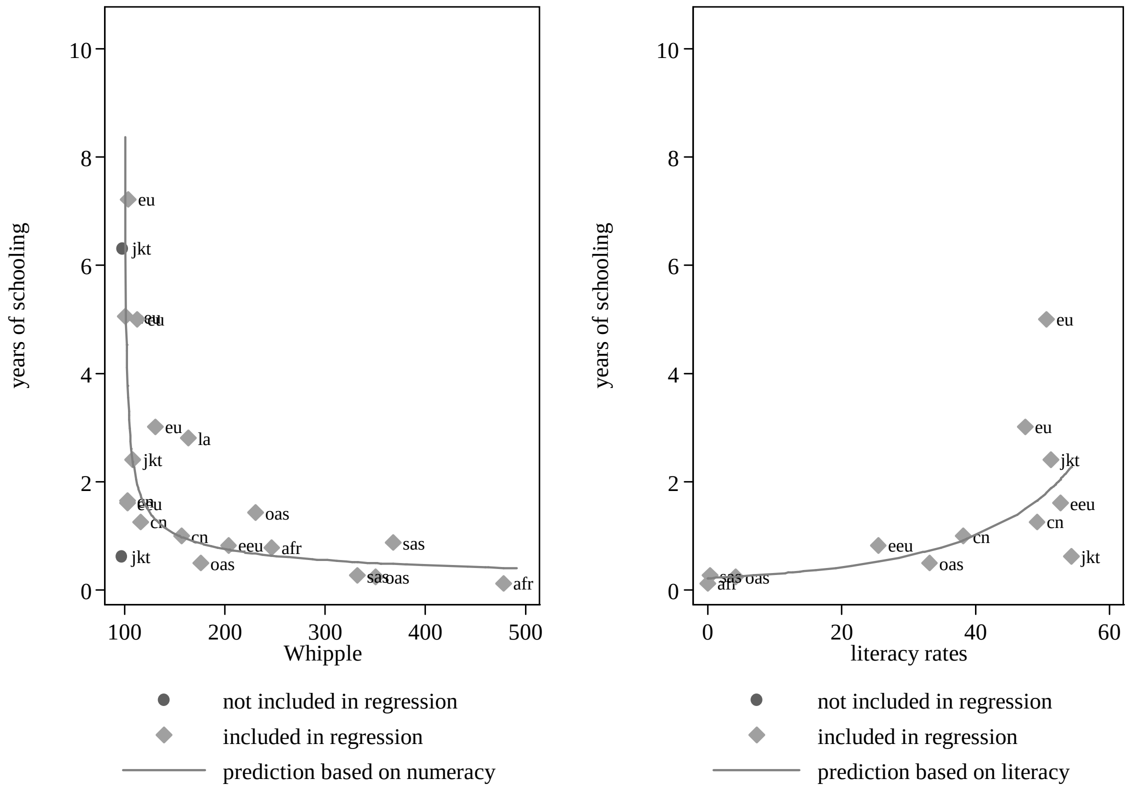

Figure B.1. The relationship between numeracy/literacy and years of schooling

Now, to obtain series of schooling duration without breaks that are consistent over time, the heterogeneous measures had to be brought in line. Therefore, if possible, adjustment factors were derived based on observations common to at least two series. Those were applied to the series before appending them. Further, depending on the reliability of the base-measure and the quality of the estimate, the different series had to be ranked according to their priority. The following rules describe in detail the procedure applied to construct years-of-schooling time series, d_t.

1. Set d_t equal to the Barro and Lee (2001) measure of schooling attainment.
2. If, after step 1, a common observation of d_t and *enrollment*-based years of schooling exists, apply the factor which is implied by the ratio of both measures and replace the missing values in d_t by the *adjusted enrollment*-based schooling duration series. If more

than one common observation exists, choose the year 1960 to derive the adjustment factor.

3. If, after step 2, a common observation of d_t and *late numeracy*-based years of schooling exists, apply the factor, which is implied by the ratio of both measures and replace the missing values in d_t by the *adjusted late numeracy*-based schooling duration series. If more than one common observation exists, choose the earliest possible data point common to both series.
4. If, after step 3, a common observation of d_t and *literacy*-based years of schooling exists, apply the factor which is implied by the ratio of both measures and replace the missing values in d_t by the *adjusted literacy*-based schooling duration series. If more than one common observation exists, choose the one with the lowest estimated value for literacy-based years of schooling, because the estimates are more accurate at lower levels of literacy.
5. If, after step 4, a common observation of d_t and *early numeracy*-based years of schooling exists, apply the factor which is implied by the ratio of both measures and replace the missing values in d_t by the *adjusted early numeracy*-based schooling duration series. If more than one common observation exists, choose the one with the lowest estimated value for early-numeracy-based years of schooling.
6. If, after step 5, no common observation of d_t and *early numeracy*-based years of schooling exists, apply the factor from step 3. and replace the missing values in d_t by the *adjusted early numeracy*-based schooling duration series. Further, interpolate or extrapolate the adjusted series based on literacy-based schooling duration, if the latter is available and early-numeracy-based schooling duration is not.
7. Replace missing values in d_t by the *unadjusted late numeracy*-based schooling duration series *interpolated* with the help of *literacy*-based schooling duration.

8. Replace missing values in d_t by the *unadjusted late* numeracy-based schooling duration series *interpolated* with the help of *early numeracy*-based schooling duration.
9. Replace missing values in d_t by the *unadjusted early* numeracy-based schooling duration series *interpolated* with the help of *literacy*-based schooling duration.

Next, looking at the resulting time series graphically, few corrections were advised to achieve overall plausible curves:

- For China in 1950, 1960, and 1970, the values were replaced by the respective figures from Morrison and Murtin (1970).
- In the case of Czechoslovakia, the converted years of schooling measures could not be matched with the series by Barro and Lee (2001) on the basis of a common observation. Hence, it was aligned with the figure by Morrison and Murtin (2007) for Eastern European countries in 1870.
- In the case of Romania, the literacy-based measure is preferred over the late numeracy-based.
- For Sweden, the literacy-based measure has been appended without applying the respective adjustment factor, because this would lead to implausibly high values for the literacy-based schooling estimates.

Eventually, interpolations were made to the final series, if one or two decades were missing.

B.3 Additional robustness tests

Dependent Variable: Number of innovation events per decade (Metz, 2003), 1500-1990					
	(1) Negbin	(2) Lagged DV	(3) $\psi = 1$	(4) Narrowly defined events	(5) DV based on place of birth
LDV	no	yes	no	no	no
log(*N*)	0.687***	0.545***	restr	1.403***	1.423***
	(0.14)	(0.082)		(0.095)	(0.073)
log(*I**)	-0.696**	-0.703***	0.367*	0.225	0.0960
	(0.29)	(0.20)	(0.21)	(0.26)	(0.21)
log(*I**) × *eff*	0.232***	0.0549***	0.171***	0.0895***	0.140***
	(0.040)	(0.019)	(0.017)	(0.026)	(0.018)
log(*h*)	-0.101	-0.110*	-0.251***	-0.403***	-0.255***
	(0.099)	(0.060)	(0.058)	(0.073)	(0.056)
inst	0.0874**	0.104***	0.161***	0.162***	0.178***
	(0.037)	(0.012)	(0.011)	(0.015)	(0.012)
geo2 (dummy)	1.086**	-0.0984	-2.235***	-2.583**	0.113
	(0.49)	(0.44)	(0.50)	(1.03)	(0.34)
geo3 (dummy)	1.566	-2.233**	-3.327***	-19.15	-1.670***
	(1.74)	(1.02)	(1.01)	(4224)	(0.39)
geo4 (dummy)	-1.569**	0.175	0.184	-0.248	-0.417
	(0.70)	(0.30)	(0.17)	(0.40)	(0.30)
geo5 (dummy)	-1.177***	-3.353***	-16.94	-6.605***	-6.047***
	(0.37)	(0.91)	(1659)	(0.96)	(0.57)
Constant	-4.029	-2.169	-13.16***	-16.51***	-14.95***
	(2.48)	(1.86)	(1.90)	(2.19)	(1.91)
Observations	467	505	505	505	505
Pseudo R-squared	.	0.949	0.928	0.904	0.928

Notes: Standard errors in parentheses. Time/Country dummies not reported. *** p<0.01, ** p<0.05, * p<0.1.
For the estimate in column (4), all types of events were considered that include one of the following words or syllables (translation in parentheses): Patent (patent), Einführung (introduction), Bau… (construction …). Entdeckung (discovery), Konstruktion (building), Einführung (launch), Herstellung (production), Anwendung (application), Aufstellung (installation), Beobachtung (observation), Berechnung (calculation), Beschreibung (description), Beweis (proof), Synthese (composition), Theorie (theory), Entwicklung (development), Erfindung (invention), Entwurf (draft), Versuch (trial), Erkenntnis (insight/knowledge/awareness), Erklärung (explanation), Darstellung (illustration), Erprobung (test), Gerät (device), Erzeugung (generation), Experiment (experiment), Gewinnung (extraction), Idee (idea), Messung (measurement), Nachweis (verification/confirmation), Raumf… (space…/aerospace…), Untersuchung (investigation/analysis), Veröffentlichung (publication), Verbesserung (improvement), Verfahren (method/technique), Vorschlag (proposition/suggestion), Weiterentwicklung (enhancement).

5 Formal Schooling and Innovative Success – Evidence from Inventors' Biographies[120]

Based on the biographies of 267 historically important inventors and engineers, this paper explores whether formal schooling causes individuals to be more innovative. With the number of citations in a comprehensive database of innovation events as a measure of innovative success, count data models reveal that formal teaching may be important under very specific conditions, because it can substitute for a wealthy family or for having a legal guardian working in the same field. Further, teaching programs became increasingly important over time for inventors to acquire the knowledge necessary to utilize their talent. Nevertheless, the analysis fails to prove that formal schooling actually enhances an individual's innovative potential. If this finding reoccurs in larger samples, it calls into question the innovation-driving effect of human capital quantity in Schumpeterian growth models.

[120] An earlier version of this chapter was presented at "Wirtschaftshistorisches Colloquium", July 2008, in Berlin. Comments of participants have been considered in the present version.

5.1 Introduction

The empirical growth literature has dealt extensively with the effect of human capital in the process of economic growth; Temple (2001) provides a review of this literature. But the efforts focus especially on the role of human capital as a facilitator of technology adoption and a catalyst of convergence, which was identified already by Easterlin (1981, p.12): "the more schooling of appropriate content that a nation's population had, the easier it was to master the new technological knowledge becoming available".

Contrarily, one branch of the theoretical literature on innovation-driven growth emphasizes the importance of education for technology creation (e.g. Romer, 1990). To date, however, empirical studies have failed to verify this effect. In fact, Jones (1995) provides evidence opposing this view. Nevertheless, recent theoretical works keep emphasizing that human capital may enhance the probability of innovative success (e.g. Blackburn, Hung, and Pozzolo, 2000; Arnold, 1998; Arnold, 2002; Stadler, 2006).

In part, the conflicts between empirical and theoretical results may be caused by a different understanding of human capital. Especially, subsuming both formal schooling and knowledge under the term 'human capital' seems to be problematic. This paper solely focuses on the quantitative aspects of human capital, i.e. formal schooling. It is motivated by the finding of chapter 4 of this thesis, according to which average years of schooling are not a crucial determinant of innovative success on the country level.[121] To further explore this relationship on a micro-level, it examines whether formal schooling made historical inventors more successful, i.e. more innovative. To my knowledge, only one further study exists, which attempts to connect schooling with innovative output or success on a micro level. Khan and

[121] In order to separate human capital strictly from what has been termed technological knowledge in the innovation and growth literature, it makes most sense to think of it in terms of schooling duration.

Sokoloff (2004) find that many American inventors during the period 1790-1930 had backgrounds of limited formal schooling, even though well-educated inventors were overrepresented in the examined group of individuals. The emphasis of their analysis, however, is on the U.S. patent system and how it enhanced the opportunities available to technologically creative individuals who owned little capital and had attained below-average formal schooling.[122] The paper misses out on actually explaining the individuals' innovative output or success by the level of schooling. Overrepresentation of formally educated individuals in the observed sample does not suffice to support the hypothesis of schooling being a driver of innovation. At the same time, the analysis is not suitable to cast doubt on this rationale, either. Admittedly, with the help of descriptive statistics Khan and Sokoloff (2004) show that inventors with lower levels of formal schooling generated about as many patents on average as those with higher levels. But the number of patents may just be the wrong measure in this context, because they do not reflect technological importance adequately. In fact, the main message of the paper is that the American patent system stimulated particularly low-educated inventors to obtain property rights.

Eliminating these shortcomings is a goal of the work at hand. It is realized by exploiting a superior measure of innovative success and performing regression analyses that control for the biographical background of the individuals. For this purpose, a small database of 267 engineers and inventors has been assembled, which contains the level of schooling and other personal and family characteristics as given by short biographical articles about the individuals. The data is described in section 5.2. Section 5.3 delivers the results of the analysis and discusses technical issues. Section 5.4 provides an interpretation of the findings, and section 5.5 concludes.

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[122] Khan and Sokoloff (2004) actually use education as a proxy for the economic resources of an inventor's family (p.19).

5.2 Data[123]

Three main sources were selected to obtain biographical information on the life of historical inventors. 194 individuals were extracted from Volume 6 of Abott's (1995) *Biographical Dictionary of Scientists*, 45 from Evan's (2004) *They Made America*, and 28 from Browns' (2002) *Inventing Modern America*. In 70 out of those 267 cases, other encyclopedias were used to complete the information.[124] Due to the literature-based approach, only persons with historically large technological footprints have been considered. Obviously, their contributions to technology were found important enough by historians of technology to record their biographical information.[125] Utilizing only few publications may seem a bit arbitrary, but nothing points at a bias towards inventors with exceptionally high or low levels of schooling due to this choice. If anything, it might be argued, that a literature-based approach generally holds the risk of capturing mainly such individuals whose biographies are remarkable in one sense or the other; e.g. because of a substandard level of formal education and great inventive success at the same time. Most inventors in the database are of American or British nationality. This is an advantage, because at all times in those systems, the degree of social mobility has presumably been relatively high, offering the opportunity to rise from rags to riches. Using a sample of persons from a country with lower social mobility, a potential positive relationship between schooling and inventor's success could arise spuriously due to restrictions in opportunities for less educated people. Finally, the coverage is limited to

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[123] At this point I have to thank Benjamin Trunk for spending much effort on collecting the data. In the course of his diploma thesis at the Department of Economic History (University of Tuebingen), he assembled plenty of information on inventors' biographies far beyond their levels of education.

[124] These are Microsoft Encarta (2006), as well as the following online sources: National Inventors Hall of Fame (2007), Encyclopedia Britannica Online (2007), and They Made America Online (2007). The information from the latter three was obtained in November 2007.

[125] 63 individuals could not be classified as originators of discrete product or process innovations, which shifted the production function in the Schumpeterian sense. Rather, they contributed to process of technological change via their continuous effort as engineers (e.g. Gustav Eiffel), constructors (e.g. Robert Stephenson), designers (e.g. Frederick Handley Page), or financiers (e.g. Matthew Boulton).

engineers and inventors. Certainly, scientists play an important role in generating technological progress, but the formal educational requirements for an academic career make this group of individuals useless for the analysis. Of course, schooling duration is usually not explicitly stated in the biographical sources. In many cases, however, information is available on the type of school visited by a particular person. This yields a categorical measure of schooling duration. It indicates the level of school degree completed by an individual.

Innovation success, too, is measured by a literature-based indicator. Metz (2003) presents a database of nearly 15,000 innovation events throughout human history. Those were originally assembled by the *Institut für Arbeitsmarkt- und Berufsforschung* (IAB) in Nürnberg. Many of the observations contain information on the person(s) most closely associated with the occurrence of the specific event. The number of listings in the database does not necessarily reflect the number of actual successful inventions by one person. Nevertheless, it is charming to think that it proxies for the size of a person's technological footprint, i.e. his/her impact on technological development, or in other words: his or her innovative success. A detailed description of this database is provided by Metz (1999).

Figure 5.1 divides the sample of inventors into three groups. The largest consists of those whose name does not once appear in the IAB database (129 individuals). Almost that many appear 1 to 10 times (119 individuals). 16 individuals are listed more than 10 times, and only 3 achieve more than 20 IAB listings. Figure 5.1 also shows that the extraordinarily successful inventors were clearly the youngest in terms of their age at the first invention. Figure 5.2 illustrates the composition of the sample and average innovative success with respect to individuals' formal level of schooling. Even though the uneducated are the smallest group, they are on average the most successful in terms of IAB listings, whereas individuals with primary and secondary degrees are clearly overrepresented in the sample, but less successful on average. Hence, at the first glance, it appears that schooling is at best innocuous

- if not detrimental - for innovative success. However, the effects due to family background and personal characteristics may cover a potential positive impact of formal schooling. Hence, the next section explores whether a thorough econometric analysis can deliver such evidence.

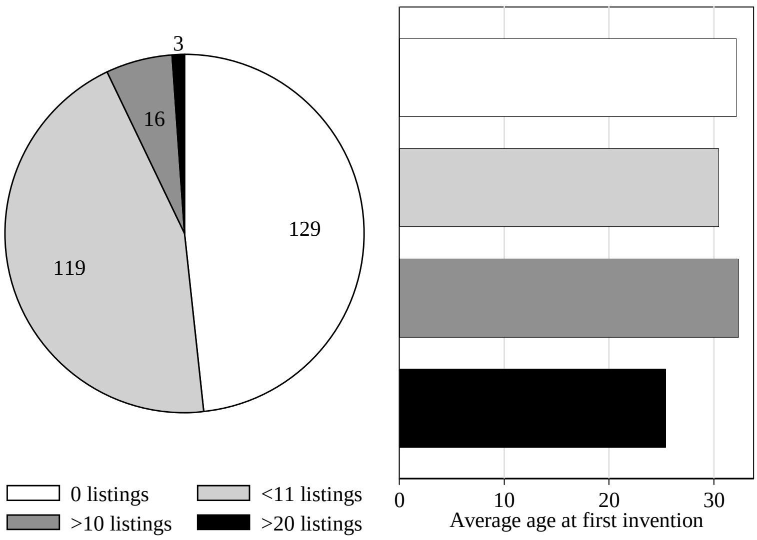

Figure 5.1. Distribution of innovative success (IAB listings) in the inventor sample

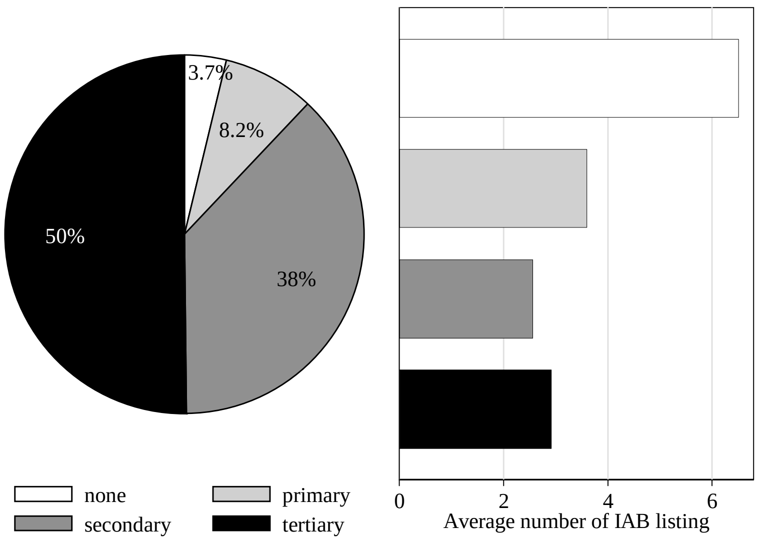

Figure 5.2. Composition of the inventor sample and innovative success by schooling levels

5.3 Empirical analysis

5.3.1 The principal empirical model

The variable to be explained is the number of *listings* in the IAB database. This implies the use of a count data regression model for the analysis. In principle, the Poisson model and the negative binomial model are eligible in such cases (see Greene, 2002). The former is applicable when the non-negative count dependent variable is distributed with equal mean and variance, whereas the latter allows for more flexibility in the variance specification. In this section, results for both models are presented, and a further discussion of model choice is postponed to the next section. For the negative binomial regression, the Negbin I model in the terminology of Cameron and Trivedi (1998) has been selected. It makes the assumption of a linear relationship between variance and mean, as opposed to a quadratic relationship in the Negbin II model. The principal mean function is

$$listings_i = \exp\left(\alpha + \beta \times schooling_i + \boldsymbol{\delta} \times \boldsymbol{fam_i} + \boldsymbol{\gamma} \times \boldsymbol{bio_i}\right). \quad (5.1)$$

Most importantly, the right-hand side contains a categorical measure of formal schooling. The variable $schooling_i$ is equal to zero if no formal degree was obtained. Otherwise, the values 1 through 3 indicate the completed level of schooling, i.e. primary, secondary, and tertiary. A list of family characteristics and further biographical information regarding the inventor himself are included in the vectors $\boldsymbol{fam_i}$ and $\boldsymbol{bio_i}$. These covariates are intended to control for effects that might potentially be picked up by the measure of schooling in a univariate analysis. Most of them are binary or categorical measures. Family characteristics encompass

- the wealth of the family ranging from 1 (poor) through 5 (rich),
- schooling of the legal guardian (usually the father) ranging from 0 (none) through 3 (tertiary),

- a binary variable indicating whether the guardian's profession was similar to the one chosen by the offspring (1) or not (0).

Biographical characteristics cover

- the age at death of the inventor (in years),
- the age of the inventor at the time of his first invention (in years),
- the inventor's mobility (i.e. stays abroad, moves, longer journeys) ranging from 1 (low) through 5 (high).[126]

Table 5.1 provides summary statistics for all variables in the model.

Table 5.1 - Summary statistics

Variable	Description	Var. type	Obs.	Mean	St. Dev.	Min	Max
listings	# of IAB listings	counts	282	2.97	5.21	0	40
schooling	Formal Schooling Level	categorical	267	2.34	0.79	0	3
bio	Age	years	236	72.33	13.07	35	100
	Age at first invention	years	278	31.35	10.35	9	78
	Mobility	categorical	143	3.27	1.17	1	5
fam	Schooling of legal guardian (0-3)	categorical	160	1.39	0.83	0	3
	Professional similarity	binary	148	0.33	0.47	0	1
	Family Wealth	categorical	159	2.74	0.95	1	5

5.3.2 Separate effects

Table 5.2 lists the Poisson regression results.[127] The first column suggests a negative correlation between an individual's level of schooling and its success as an inventor. Given

[126] A detailed description of how the variables were constructed as well as the entire dataset used for the analysis are included in Appendix C. Quite a few more details were available from the biographies. For this analysis, however, characteristics were chosen, which would be strongest suspected to cause a bias in the coefficient on education, if they were omitted from the analysis. Choosing five categories for the wealth and mobility measures may seem pretentious in light of biographical sources giving only vague information in some cases. Repeating the analyses with measures that are based on three or two categories does not change the general insights, however.

Table 5.2 - Poisson estimates of equation (5.1)

Dependent Variable: Number of references in Metz (2003)						
Schooling	-0.174***	-0.0601	0.136*	-0.367***	-0.316***	-0.0646
	(0.042)	(0.044)	(0.070)	(0.055)	(0.053)	(0.090)
Age at death		0.00191	0.00294	0.00777*	0.00280	0.00811
		(0.0027)	(0.0038)	(0.0042)	(0.0037)	(0.0062)
Age at invention		-0.0184***	-0.0102**	-0.0174***	-0.0191***	-0.00178
		(0.0037)	(0.0043)	(0.0055)	(0.0054)	(0.0070)
Mobility			0.237***			0.209***
			(0.049)			(0.070)
Schooling of guardian				0.0399		-0.104
				(0.066)		(0.10)
Prof. similarity				0.0851		0.410***
				(0.11)		(0.15)
Family wealth					0.173***	0.151*
					(0.054)	(0.088)
Constant	1.660***	1.869***	0.0177	2.180***	2.094***	-0.223
	(0.14)	(0.26)	(0.39)	(0.37)	(0.35)	(0.61)
Observations	267	222	123	118	130	67
Pseudo R-squared	0.00769	0.0144	0.0419	0.0523	0.0463	0.0481

Notes: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

the categorical character of the variable, the coefficient implies a reduction of roughly 50% in the number of IAB references going from no degree to a tertiary degree. Accounting for the age of the inventor at his first invention and at death reduces the size of the coefficient and impairs its significance, as is visible in column (2). This is not surprising given that schooling almost naturally delays the beginning of inventive activities. Also, the age at the time of the invention is negatively related to overall success, which seems plausible right away, because one would think that - regardless of the level of education - starting the career early maximizes exposure time. On the other hand, overall lifetime does not seem to matter for the size of the technological footprint. The attempt to bring both findings in line results in the following interpretation: A long life may not have sufficed to compensate for a lack of ability. The able might not have needed much time to build up their reputation of being an important contributor to technological progress, whereas for less able individuals, even a lifetime might

[127] For the interpretation of parameters in Poisson as well as related regression models, see chapter 3.1.4 of Winkelmann (2003).

not have been enough to establish a similar standing. The positive effect of an early career is potentially due to reversed causality. The most able individuals simply deployed their potential as soon as they could. Very creative minds may just not have been dependent on experience or education. The inclusion of further covariates drastically reduces the number of observations available for the regressions, which is why they are first considered separately in columns (3-5) before estimating the complete specification, the results of which are displayed in column (6).

Controlling for the measure of mobility inverts the effect of schooling; see column (3). Given that both variables are positively correlated with each other - the correlation coefficient is 0.23 - this can only be a collateral outcome of the entailed sample size reduction. The mobility variable itself is positively connected with inventors' success, although it is hard to tell whether the primary is the cause or the consequence of the latter. Of course, traveling may have promoted knowledge spillovers and thus have been creativity-enhancing for the observed individuals. A nice example is the case of Samuel Morse. According to Abbott (1985), he "travelled widely […]. […] It was on this voyage that fate took a turn in the shape of fellow passenger Charles Jackson, who had recently attended lectures on electricity […]. He had with him an electromagnet and Morse […] became fascinated with the talk of electricity and the possibilities of this new idea." On the other hand, generating widely accepted products or procedures may have opened up opportunities of traveling in order to present the idea. Eventually, individuals interested in novelties may simply have been the same individuals who were interested in broadening their horizon by traveling. Or similarly, creative individuals may simply have a higher incentive to invest in finding the right place to unfold. For instance, Guglielmo Marconi, Reginald Fessenden, Vladimir Kosma Zworykin, and Denis Papin are clearly individuals who went to places that offered better opportunities. Because "the Italian government was not interested in the device, Marconi travelled to

London where he enlisted the help of relatives […] to introduce his discovery to the British government." (Abbott, 1985) Quite similar reasons motivated Reginal Fessenden to move: "with little opportunities to follow up such interests (*in science*) in Bermuda, he left to go to New York, where he met Thomas Edison." Also, Vladimir Zworykin left Russia for a reason: "he went to Paris to do X-ray research at the College of France […]." Finally, Denis Papin seized various opportunities of this kind: "in 1675 he went to London to assist Robert Hooke […] In 1680, he returned to Paris to work with Huygens and in 1681 he went to Venice […] as the Director of Experiments at Ambrose Sarotti's academy." Overall, it appears that individuals with high potential were simply more flexible and willing to invest in their career by changing places than others. Of course, knowledge spillovers arose from their mobility, but it is questionable whether the latter was a cause for their success. In any case, inventors in the highest mobility category would be expected to have been twice as successful in terms of IAB references as those who altogether abstained from traveling or moving.

When incorporating the variables that indicate the guardian's level of schooling as well as whether the guardian's profession was equal to the inventor's profession, the coefficient of the schooling measure switches signs once again (column (4)). Its size implies an even stronger disturbance of success than the coefficient of column (1). The age effects remain roughly similar. There is, however, no significant direct effect of both newly included variables in this specification.

Replacing the guardian's background with family wealth does not alter the effects of education or age (column (5)). The measure itself, however, turns out positive and significant. A person from an extraordinarily rich family is expected to have achieved 70-80% more references in the IAB data than a person from a very poor family.

Looking at the complete specification, only two results turn out robust. These are the positive relationship of an inventor's success and mobility, as well as the influence of family wealth. Interestingly, the full specification brings out a positive sign in the variable indicating whether the individual adopted a profession similar to the guardian's. If the latter is the case, an inventor achieved 40% more IAB entries than those who entered different fields. The coefficients of schooling and age are stable in sign, but lose significance, casting doubt on the robustness of the respective effects. Note, however, that only few observations are available to estimate the complete model, which increases the risk of random results.

Table 5.3 - Negbin I estimates of equation (5.1)

Dependent Variable: Number of references in Metz (2003)						
Schooling	-0.116	0.0506	0.166	-0.0572	-0.0323	0.0420
	(0.10)	(0.11)	(0.15)	(0.15)	(0.14)	(0.19)
Age at death		-0.00452	0.00202	-0.00151	-0.00420	0.00435
		(0.0060)	(0.0078)	(0.0094)	(0.0081)	(0.013)
Age at invention		-0.0129	-0.0116	-0.0124	-0.0143	-0.00407
		(0.0081)	(0.0087)	(0.012)	(0.012)	(0.014)
Mobility			0.176*			0.153
			(0.10)			(0.15)
Schooling of guardian				-0.0484		-0.219
				(0.14)		(0.20)
Prof. similarity				0.210		0.351
				(0.25)		(0.33)
Family wealth					0.0775	0.216
					(0.12)	(0.18)
Constant	1.472***	1.805***	0.245	1.936**	1.855**	0.0863
	(0.35)	(0.59)	(0.82)	(0.84)	(0.79)	(1.21)
Observations	267	222	123	118	130	67
Pseudo R-squared	0.00115	0.00374	0.0130	0.00404	0.00487	0.0193

Notes: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Now, Table 5.3 provides the results of the Negbin I model. In short, most of the effects vanish. The only robust finding compared with Table 5.2 concerns the positive significant effect of mobility. But even the latter is not robust to the inclusion of all the family background variables. At least, the direction of previously significant effects remains unchanged. Which of the two models is more reliable will be discussed in section 5.4. First, consider some changes in the specification of the mean function (5.1).

5.3.3 Interaction effects

Suppose that the effect of formal schooling is not independent of the other covariates in the model. For example, it may have been important only in specific countries or for individuals with a very specific family background. To test this, interaction terms are added to equation (1). The basic specification now reads

$$listings_i = \exp\left(\alpha + \beta \times schooling_i + \boldsymbol{\delta} \times \boldsymbol{fam_i} + \boldsymbol{\gamma} \times \boldsymbol{bio_i} + \lambda \times it_i\right) \quad (5.2)$$

where it_i is a vector of interaction terms.

Table 5.4 - Poisson estimates of equation (5.2) controlling for country interactions

Dependent Variable: Number of references in Metz (2003)						
Schooling	-0.315***	-0.205***	0.000668	-0.466***	-0.449***	-0.149
	(0.045)	(0.048)	(0.074)	(0.060)	(0.056)	(0.11)
Age at death		0.00589**	0.00956**	0.0136***	0.0131***	0.0156**
		(0.0029)	(0.0041)	(0.0046)	(0.0041)	(0.0069)
Age at invention		-0.0286***	-0.0209***	-0.0304***	-0.0300***	-0.0198**
		(0.0038)	(0.0048)	(0.0058)	(0.0057)	(0.0079)
Mobility			0.252***			0.133*
			(0.049)			(0.076)
Schooling of guardian				0.0165		-0.181
				(0.074)		(0.12)
Prof. similarity				0.182		0.520***
				(0.12)		(0.16)
Family wealth					0.0862	0.126
					(0.057)	(0.100)
UK × Schooling	-0.000988	-0.0605**	-0.0138	-0.0192	0.0156	0.0968*
	(0.027)	(0.028)	(0.037)	(0.041)	(0.038)	(0.057)
FR × Schooling	0.149***	0.0806*	0.0134	-0.0126	0.0204	-0.283
	(0.041)	(0.041)	(0.066)	(0.083)	(0.078)	(0.23)
DE × Schooling	0.413***	0.373***	0.302***	0.367***	0.370***	0.382***
	(0.028)	(0.030)	(0.047)	(0.046)	(0.045)	(0.066)
OTH × Schooling	0.218***	0.166***	0.284***	0.559***	0.446***	0.805***
	(0.052)	(0.053)	(0.058)	(0.15)	(0.061)	(0.19)
UNK × Schooling	-0.659**	-0.749**	-0.558**	-0.653**	-0.630**	-0.269
	(0.29)	(0.29)	(0.25)	(0.32)	(0.31)	(0.26)
Constant	1.880***	2.222***	0.134	2.330***	2.093***	0.170
	(0.14)	(0.28)	(0.42)	(0.40)	(0.38)	(0.68)
Observations	267	222	123	118	130	67
Pseudo R-squared	0.119	0.133	0.129	0.134	0.140	0.158

Notes: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Table 5.4 and Table 5.5 add interactions terms between country dummies and the schooling measure. The country dummies indicate where an individual realized his/her most famous invention. There are six such dummies for the United States (US), the United Kingdom (UK), France (FR), Germany, (DE), other countries (OTH), and for a missing country detail (UNK). The coefficient β now indicates the effect in the United States, which is the reference category. None of the previously discussed findings is altered in principle.

Table 5.5 - Negbin I estimates of equation (5.2) controlling for country interactions

Dependent Variable: Number of references in Metz (2003)						
Schooling	-0.243**	-0.0907	0.0400	-0.166	-0.218	-0.101
	(0.11)	(0.12)	(0.16)	(0.16)	(0.15)	(0.22)
Age at death		-0.00292	0.00373	0.00253	0.00246	0.0131
		(0.0060)	(0.0081)	(0.0100)	(0.0088)	(0.014)
Age at invention		-0.0232***	-0.0244***	-0.0266**	-0.0280**	-0.0263
		(0.0079)	(0.0094)	(0.012)	(0.012)	(0.017)
Mobility			0.193**			0.132
			(0.098)			(0.15)
Schooling of guardian				-0.180		-0.472**
				(0.15)		(0.23)
Prof. similarity				0.178		0.260
				(0.25)		(0.35)
Family wealth					0.0319	0.179
					(0.13)	(0.20)
UK × Schooling	0.0839	0.0182	0.0498	0.0963	0.108	0.256**
	(0.058)	(0.061)	(0.078)	(0.086)	(0.079)	(0.12)
FR × Schooling	0.279***	0.195**	0.159	0.265*	0.216	0.284
	(0.081)	(0.081)	(0.12)	(0.15)	(0.14)	(0.24)
DE × Schooling	0.464***	0.409***	0.361***	0.436***	0.426***	0.519***
	(0.067)	(0.070)	(0.10)	(0.10)	(0.10)	(0.15)
OTH × Schooling	0.149	0.0967	0.247*	0.998***	0.423***	1.131***
	(0.14)	(0.14)	(0.14)	(0.36)	(0.15)	(0.39)
UNK × Schooling	-0.231	-0.314	-0.248	-0.0534	-0.111	0.124
	(0.27)	(0.27)	(0.26)	(0.30)	(0.29)	(0.29)
Constant	1.480***	2.172***	0.588	2.310***	2.084**	0.623
	(0.35)	(0.59)	(0.85)	(0.87)	(0.82)	(1.29)
Observations	267	222	123	118	130	67
Pseudo R-squared	0.0377	0.0376	0.0381	0.0373	0.0359	0.0684

Notes: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

The most noteworthy insight applies to both the Poisson model (Table 5.4) and the negative binomial model (Table 5.5): the negative schooling effect turns out slightly stronger for the US as compared with the average effects in Table 5.2 and Table 5.3, but - again - not robust in the complete specification. The interaction terms for the UK and France do in most cases not indicate a significant difference compared to the effect of formal schooling in the US. Those for Germany and other countries are positive and significant. Depending on the size of β, this leads to an overall positive effect of schooling in some of the specifications. In light of only few observations being non-US, non-UK, or non-France, however, this result should be treated with caution. Finally, the age effect tends to gain significance when the interaction terms are included. Family wealth, however, is non-significant.[128]

Table 5.6 - Poisson estimates of equation (5.2)

Dependent Variable: Number of references in Metz (2003)				
Schooling	-0.350*	0.671***	1.805***	1.096**
	(0.20)	(0.17)	(0.45)	(0.50)
Age at death	0.00428	0.00429	0.00265	0.00783
	(0.0043)	(0.0037)	(0.0069)	(0.0075)
Age at invention	-0.0188***	-0.0210***	-0.00882	-0.0138*
	(0.0055)	(0.0055)	(0.0074)	(0.0083)
Mobility			0.306***	0.200**
			(0.075)	(0.084)
Educ. of guardian	-0.0812		0.138	-0.552
	(0.27)		(0.52)	(0.66)
Educ. Guardian × Schooling	0.0376		-0.00886	0.146
	(0.082)		(0.15)	(0.18)
Prof. similarity	1.345***		3.936***	4.925***
	(0.38)		(0.69)	(0.82)
Prof. similarity × Schooling	-0.432***		-1.149***	-1.433***
	(0.13)		(0.22)	(0.26)
Family wealth		1.278***	1.772***	1.287***
		(0.19)	(0.43)	(0.48)
Fam. wealth × Schooling		-0.370***	-0.538***	-0.395***
		(0.060)	(0.13)	(0.15)
Country interaction terms	NO	NO	NO	YES
Constant	2.439***	-0.854	-6.254***	-3.703*
	(0.69)	(0.63)	(1.64)	(1.90)
Observations	118	150	67	67
Pseudo R-squared	0.0639	0.0842	0.159	0.261

Notes: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

[128] Nothing changes when a set of country dummies is applied to equation (1), either instead of or additional to the interaction terms.

In Table 5.6 and Table 5.7, interaction terms are added, which serve to test whether the effect of formal schooling depended on the legal guardian's schooling and profession or on family wealth. Turning first to the Poisson model (Table 5.7), it follows from column (1) that inventors who adopted a similar profession as the legal guardian benefitted less from formal schooling than the average inventor in the reference model, which is given by column (4) of Table 5.2. For those who chose a different profession, the computed effect is comparable in size to the reference model. Vice versa, having chosen the same profession as the legal guardian apparently made a difference for success only when the inventor had not obtained a tertiary degree. There is, however, no evidence for an interaction effect between the legal guardian's and the inventor's schooling.[129] In column (2), it becomes obvious that family wealth affected the importance of formal schooling drastically. For instance, a positive impact for the inventor's success was given only if the wealth of his family did not exceed category 2 of the utilized wealth measure (i.e. the family was poor or fairly poor). Else, the regression indicates a negative effect of schooling. Vice versa, family wealth was beneficial for success, unless the inventor had obtained formal schooling up to a tertiary degree. In the latter case, family wealth was no longer relevant. Those findings are robust to the use of the complete specification (column (3)) and to the inclusion of country interaction terms as discussed in the previous paragraph (column (4)). Now, looking at the negative binomial model (Table 5.7), the interaction effects are robust at least in part. Considering column (2), the previous statements in terms of family wealth stay valid. Turning to column (1), the interaction between the guardian's and the inventor's education, is non-significant at conventional levels, but the standard errors are relatively small. Hence, the effect might turn out significant in

[129] Note that testing for no interaction in Poisson regression models is a little more complex than the usual t-Test on the coefficient of the interaction term in linear regression models (see Winkelmann, 2003, chapter 3.1.4). Hence, this statement is not actually statistically validated. The computation of the individual marginal effects, however, is straightforward.

larger samples. In fact, it does turn up in the complete specifications of columns (3) and (4). Here, however the family wealth interaction is non-significant.

Table 5.7 - Negbin I estimates of equation (5.2)

Dependent Variable: Number of references in Metz (2003)				
Schooling	-0.412	0.784*	1.567	0.366
	(0.72)	(0.45)	(1.02)	(1.10)
Age at death	-0.000216	-0.00663	-0.0000578	0.00379
	(0.014)	(0.013)	(0.020)	(0.019)
Age at invention	-0.0195	-0.0178	0.00228	-0.00324
	(0.019)	(0.017)	(0.024)	(0.022)
Mobility			0.262	0.157
			(0.18)	(0.18)
Schooling of guardian	-0.329		-0.150	-0.970
	(1.13)		(1.83)	(1.67)
Schholing Guardian × Schooling	0.120		0.0267	0.253
	(0.32)		(0.52)	(0.47)
Prof. similarity	2.023		4.082*	4.822**
	(1.40)		(2.09)	(2.02)
Prof. similarity × Schooling	-0.672		-1.223*	-1.399**
	(0.43)		(0.66)	(0.64)
Family wealth		1.414**	1.569	0.641
		(0.59)	(1.07)	(1.07)
Fam. wealth × Schooling		-0.395**	-0.459	-0.166
		(0.17)	(0.35)	(0.35)
Country interaction terms	NO	NO	NO	YES
Constant	2.963	-0.656	-5.209	-1.389
	(2.72)	(1.65)	(3.75)	(4.00)
Observations	118	130	67	67
Pseudo R-squared	0.0122	0.0152	0.0406	0.0641

Notes: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. Country interaction terms not reported.

5.3.4 Technical issues

Now, which of the regression models delivers the more reliable estimates? Typically, one would use the Poisson model, if the data were not overdispersed, i.e. if the true variance equaled the true mean. There is reason to believe, however, that this special case is not on hand. According to Figure 5.3, the observed frequency distribution matches a negative binomial distribution with overdispersion way better than a Poisson distribution with equivalent mean. Also, a Likelihood ratio test comparing the likelihood values of a Poisson model and a negative binomial model rejects the null hypothesis of the data being Poisson.

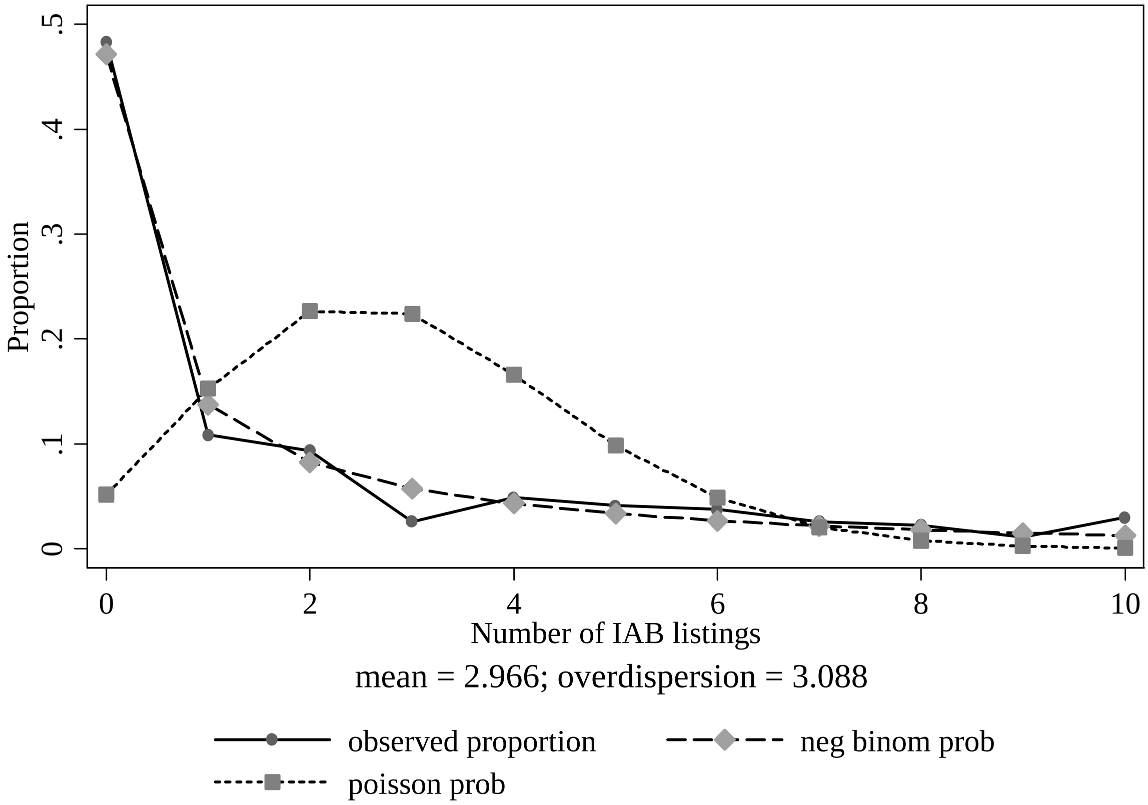

Figure 5.3. Observed versus Poisson and negative binomial distributions[130]

Nevertheless, according to Winkelmann (2003), "erroneously assuming the Poisson distribution if the true model is […] the negative binomial distribution, yields […] consistent estimates […]". Even so, the standard errors are biased and lead to spurious inference. Hence, to obtain accurate standard errors, a negative binomial regression model should be fitted to the data. Anyhow, in the previous section I presented both the Poisson as well as the negative

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[130] This chart was created via the user-written Stata command -nbvargr- (Ender, Ph., nbvargr: command to graph the observed proportions along with the poisson and negative binomial probabilities for a count type variable. UCLA: Academic Technology Services, Statistical Consulting Group. http://www.ats.ucla.edu/stat/stata/-ado/analysis/.). The overdispersion parameter of 3.069 reflects mean dispersion. The command does not allow computing a constant dispersion factor.

binomial estimates for the following reason: the negative binomial regression delivers only few statistically significant effects. This may be partly due to the small sample size. The Poisson regression yields in principle the same signs, but here, many effects are significant. As just stated, overly optimistic estimates of the standard errors are most likely the reason for this. Nevertheless, the Poisson model can serve to strengthen the notion of some interaction effects that may in fact exist in a larger sample, but do not turn out significant in the negative binomial regression with the small sample at hand. Also, if there was a positive effect of schooling on innovative success, the Poisson estimates would be more likely to bring it out. Of course, the Poisson estimates do not suffice to make a strong case in favor of the observed effects. But they certainly justify collecting more data and further speculating about the role of human capital for innovative success. In any case, however, they cast doubt on the role of formal schooling as an enhancer of individuals' innovative capabilities.

A couple of modifications in the estimation procedure do not lead to different conclusions. For instance, altering the variance specification in favor of the Negbin II model according to Cameron and Trivedi (1998) does not affect the principal results of the analysis. Also, none of the conclusions is affected when all estimates in this section are restricted to a subsample of inventors, which omits the 63 individuals referred to in footnote 125. Further, it could be argued that the period at risk varies between the observations. Individuals who reached a high age may have been able to generate a larger technological footprint than those who died young. Hence, instead of including the inventor's age as a covariate, individual lifetime is alternatively specified as exposure variable in the regression models. That is, the log of lifetime enters the log-link function with the coefficient being restricted to the value 1. Lifetime is computed as the number of years between the age of sixteen - which is considered to be the age an inventor could potentially start working on his footprint - and the age at death. Once again, the general interpretations of the results do not change based on these estimates.

The presence of many zero value observations (129 out of 267) may tempt one to think of zero-inflated regression as an alternative way of estimating equation (5.1). Unfortunately, however, no information is available that could explain why some inventors do not appear at all in the IAB data. After all, it seems unreasonable to assume that the zero-generating process differs from the process generating other values. Zeros are just as good a measure of innovative success as any other higher score.

Table 5.8 - Exceptionally successful inventors (# of IAB listing>10)

Name	# of IAB listings	Level of education
Siemens, Ernst Werner von	40	3
Edison, Thomas Alva	38	0
Watt, James	31	1
Marconi, Guglielmo	20	3
Hollerith, Herman	16	3
Stephenson, George		0
Daimler, Gottlieb Willhelm	15	3
Trevithick, Richard	14	.
De Forest, Lee	13	3
Da Vinci, Leonardo		1
Zworkykin, Vladimir Kosma		3
Wright, Wilbur		2
Parsons, Charles Algernon	12	3
Morse, Samuel Finley Breese		3
Wright, Orville		2
Otto, Nikolaus August		2
Diesel, Rudolph Christian Karl		3
Lilienthal, Otto	11	3
Baekeland, Leo Hendrik		3
Talbot, William Henry Fox		3
…	…	…
Total	838	

One might further argue that outliers cause the lack of evidence for a positive effect of formal schooling. For instance, four individuals in the sample - James Watt, Thomas Alva Edison, Werner von Siemens, and Guglielmo Marconi - were extremely successful. The number of IAB references achieved by those four accounts for roughly 15% of the listing achieved in total by the 267 inventors (see Table 5.8). Two of them - James Watt and Thomas Alva Edison - were hardly educated in a formal sense. Discarding those four cases indeed reduces the evidence for a negative effect of education. Nevertheless, a case for a positive effect can still not be made based on this change. Also, the evidence in favor of the interaction effects is weakened in the Negbin I model, whereas the Poisson estimates still give hints in the previously described direction. After all, the exclusion of outliers is always controversial, because they provide information that may be relevant for the analysis.

Finally, maximum likelihood estimates are generally biased in small samples. Nevertheless, the bias is small enough to be economically irrelevant in the present analysis (see Winkelmann, 2003, chapter 3.2.4).

5.4 Discussion

Summarizing the findings, the schooling measure reveals a positive effect only under very specific circumstances. For instance, according to the third column of Table 5.6 and Table 5.7, this is true if the inventor ventured into a new profession and his family was ranked lower than or equal to 3 in terms of wealth. According to column (4), these conditions are even more restrictive. Hence, overall, the results suggest that a certain degree of financial and professional coverage may have been crucial for a creative mind to flower out and become a successful inventor. A sound educational endowment seems to have acted as a substitute for this type of family-provided securities by granting its owner the possibility to earn a living himself. Nevertheless, once an inventor was given the chance to flourish, formal schooling may not have further enhanced his innovative capabilities. To make sense of this phenomenon, a notion may be helpful, according to which an individual's capability of creating new knowledge depends primarily on character traits or inherited abilities. For instance, a critical mindset, an intrinsic discontent with things being, and resistance to frustration may be essential constituents of a mindset that encourages individuals to get involved with inventive activities in the first place. Creativity and general analytical skills, on the other hand, may be indispensable to actually be successful. Of course, education matters for the individual attempting an innovation, but it may be argued that persons capable of performing successfully acquire the necessary knowledge anyway, be it formally or informally. Obviously, by inheriting the profession of the legal guardian and possibly starting professional life early in his own business the relevant skills and knowledge could be just as easily - or maybe better - acquired as in school.

Now, it could be presumed that the effect of formal schooling depends on the state of technology. In other words, early inventors might not have needed formal schooling as much as contemporaneous colleagues, because the level of technology at that time required fewer skills. This is certainly true, and estimating a simple model with formal schooling as the only explanatory variable for three different periods clearly supports this view (see Table 5.9).[131] There is a negative correlation between schooling and innovative success for inventors who died prior to 1870; the coefficient is significant at the 10% level. For those who died after 1869, there is a positive correlation; it does not turn out significant, however. The coefficient is even higher after 1939. But it is crucial to note the following: if schooling did actually enhance an individual's innovative capabilities, such an effect should first of all be significant.[132] But most importantly, it should surface in the group of early inventors, too. In light of the opposite result, however, the positive sign in the latter two groups must be interpreted as a sign of reversed causality. That is, because knowledge turned increasingly

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[131] No other variables are included, because this would reduce the sample size drastically and reliable estimates could hardly be obtained.

[132] In a Poisson model, all three coefficients are highly significant with the signs keeping their directions.

complex over time, formal teaching programs must have become more and more important for creative individuals to attain it; they simply had to attend school, if they wanted to utilize their talent.

Table 5.9 - Schooling and innovative success by period (Negbin I)

Dependent Variable: Number of references in Metz (2003)			
	Year of death < 1870	Year of death > 1869 & < 1940	Year of death > 1939
Schooling	-0.356*	0.175	0.466
	(0.19)	(0.16)	(0.52)
Constant	2.284	0.902	-0.930
	(0.19)	(0.24)	(1.90)
Observations	64	90	70
Pseudo R-squared	0.0119	0.00243	0.00297

Notes: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

If personal character traits of humans are more important for innovative success than the received amount of schooling, and if those are similarly distributed in all countries across the globe, the results strengthen the findings of chapter 4 of this work. One would expect population size to be the prime determinant of a nation's innovative potential. Institutions may support or hinder the realization of this potential. Mass schooling or human capital, however, may be a consequence and necessity of technology adoption rather than a crucial driver of a nation’s innovative potential.

5.5 Conclusions

In the past, the most important technological innovations were not necessarily generated by formally educated individuals. Quite a few had been exposed to only little or no formal schooling. Famous examples include Thomas Alva Edison, James Watt, and George Stephenson; less famous are Isaac Merrit Singer (sewing machine), or Joseph-Marie Jacquard (loom). A regression analysis based on biographical information on 267 historical engineers and inventors did not reveal an unambiguous relationship between formal schooling and the number of references in the capacious innovation database by Metz (2003). If the latter measure is capable of evaluating an individual's contributions to technological progress, i.e. the size of an individual's technological footprint, this study has failed to substantiate the notion of formal schooling being an important driver of innovative success on the micro level.

Only under very specific conditions education turned out to have been beneficial in the past. For instance, individuals originating from a poor family background were more successful, if they had achieved higher educational degrees. When the family was wealthy or the legal guardian's profession was inherited by the inventor, however, schooling did not seem to matter. In fact, there is tentative support for a detrimental effect in those cases. It seems plausible that a creative mind flourishes better if its future is not altogether uncertain. Technological progress was pushed in particular by individuals who were given the chance to deploy their creativity. Formal schooling may have served as a substitute for inherited security, acting as a warranty of material well-being and thereby creating the opportunity of exploiting one’s creative vocation.

But the analysis does not support the notion of schooling being an enhancer of individuals’ innovative potential. For this to be true, a robust positive relationship with the success as an inventor would have been expected independent of family background or state of technology.[133] Admittedly, as in Khan and Sokoloff's study (2004), individuals with higher education degrees are clearly overrepresented in the sample. Hence, the average educational level of inventors might exceed the one prevailing in the respective country's populace at a given time. But this fact is plausibly explained by the tendency of technologically creative

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[133] Of course access to existing knowledge and predecessor technologies, and the ability to reap the fruits of one's work are important determinants of innovative activity, but these aspects were not under investigation in this paper.

people to acquire the skills and knowledge necessary to unfold. In other words, capable individuals can be thought to have an intrinsic desire to get educated for the same reason they develop a desire to improve or invent things. Among those who decide to get educated and invent things, however, the level of formal schooling may not improve the chances for success.[134] This interpretation receives support from the positive relationship between inventors' mobility and their innovative success. Specific examples suggest that a simultaneous mechanism is at work here: talented individuals were willing to incur the inconveniences associated with moving and staying abroad, because they expected to earn a return from this investment of whatever kind. It is not digressive to think that such a mechanism exists for the acquisition of skills, too.

Overall, the results are of a tentative nature, primarily because of the small sample size. But they are well in line with the finding of decreasing returns to scale in the production of innovation (e.g. Crépon and Duguet, 1997) and the observation of stagnating TFP growth in light of increasing research effort (Jones, 1995). Hence, they do shed some doubt on the prominent thought of human capital quantity being a driver of technological progress. In either case, it is justified to collect more and qualitatively better data to further explore this supposition. If larger samples, too, fail to substantiate the innovation-driving effect of human capital quantity, this would carry consequences for today's economic policy. Of course, the latter ought to ensure that creative individuals with a disadvantageous background are given the opportunity of acquiring state-of-the-art knowledge. Full subsidization of university teaching programs, however, appears in a more dubious light. It would not make sense to

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[134] Inventors like George Stephenson, who acquired formal schooling as an adult or after their first entry to the labor market are counted as uneducated in this study. Their educational effort is considered to be equivalent to the skills acquired informally during professional life in this study. Altering this treatment and counting this type of education as formal would not affect the interpretation of the potential for innovative success and the desire to acquire further education being determined simultaneously by the individual's character, and of the effort not being the cause of the enhanced innovative opportunities.

artificially inflate the demand for university teaching, if the latter cannot build up innovative potential. Taking the situation in industrialized countries, it is very likely that individuals with innovative potential receive sufficient schooling to make use of their talent. Hence, cries for more tertiary enrollment might wrongly be derived from the commitment to promote innovation.

Appendix C

A multitude of characteristics were extracted from the biographies of 267 inventors. For instance, the raw data contain details regarding sicknesses, the inventor's employer, his position, or the type of inventions he made. Only the most reliably coded characteristics and the ones most relevant for the purpose of this study were selected for the quantitative analysis. This appendix describes the respective variables and their construction.

C.1 Explanation of variables

NAME – Name of inventor.

INAGE – Inventor's age at death (in years). It is computed as the difference between year of death and year of birth.

INAGEI – Inventor's age at first invention (in years). It is computed as the difference between the year of the inventor's first invention (the year of the invention, which the individual is most commonly associated with, unless otherwise stated in the sources; if the individual was one of the 63 engineers in the sample, the year when the individual started his first job was assumed) and the year of birth.

INMOB – Inventor's mobility (categorical: 1 through 5). The variable codes the extent of moves, stays abroad, or long journeys:

- 1 = hardly any change of places
- 2 = some travel activity or moves within home country
- 3 = intense travel activity or moves in home country
- 4 = some international travel activity, stay abroad, or move
- 5 = intense international travel activity or many moves and stays abroad.

Because this information was usually not given explicitly by the sources, the coding is almost solely based on text interpretation, making it a rather inaccurate measure.

INED – Inventor's level of schooling (categorical: 0 through 3):

- 0 = no formal schooling
- 1 = primary schooling
- 2 = secondary schooling
- 3 = tertiary schooling

The zero coding was applied only when the text source gave explicit hints on an individual not having achieved a formal educational degree, or not being able to read and write by the age of 18, etc. Whenever the text made reference to a stay or visit at a school, it was assumed that a formal degree was actually obtained. In some cases, the information had to be inferred from the context. For instance, if the source stated that an inventor started the first job at a certain age and went to school until then, the level of education was elicited based on the person's age at this point in time. In general, less than six years of formal schooling were coded as a primary degree, 6 to 12 years as a secondary degree, and more than 12 years as a tertiary degree.[135]

FAED – Legal guardian's level of schooling (categorical: 0 through 3). This variable refers to the formal educational degree obtained by the person who was the inventor's legal guardian. Typically, this was the father. But in some cases, inventors were raised by or grew up with an uncle or grandfather. The categories are equivalent to those of the variable *INED*, but explicit information regarding the guardian's formal education was more sparse than for

[135] In doing so, it was assumed that school entry took place at the age of six. Further, note that formal schooling in this paper refers to schooling typically received as a child, youth, or young adult before entering the labor market for the first time. For instance, George Stephenson, one of the fathers of railways, started visiting evening classes as an adult. This type of education is considered informal in the context of this paper.

the inventor's themselves. Thus, unless explicitly mentioned in the source, the schooling level of the guardian was inferred from his profession or from the financial situation of the family. Admittedly, this measure is rather inaccurate making it susceptible to attenuation bias. The correlation coefficient between *FAED* and the measure of family wealth is 0.53, which is not surprising given the construction of both variables.

FAESIM – Binary indicator of professional similarity (0 – 1). The variable equals 1, if there was an obvious connection between the profession chosen by the inventor or the field of his invention and the profession or the business of the legal guardian.

FAWEALTH – Family wealth (categorical: 1 through 5). As with *FAED*, the coding was inferred from the profession of the legal guardian, unless explicit information on the financial situation was given in the biographical source. The categories are:

- 1 = poor
- 2 = fair
- 3 = well-off
- 4 = wealthy
- 5 = rich.

The categories 1 and 5 were assigned only if the terms "poor" and "rich" or synonymous expressions were applied by the text source. If the father was a worker, category 2 was applied; category 3, if he was a craftsman, manufacturer, or other qualified worker. And if the family owned a business or was of aristocrat origin, category 4 was assumed.

C.2 Complete dataset

No.	Name	INAGE	INAGEI	INED	INMOB	FAED	FAEQ	FAWEALTH	# IAB listings
1	Andreessen, Marc	.	22	4	.	.	.	.	0
2	Appert, Nicolas	91	45	1	1	2	1	3	1
3	Arkwright, Richard	60	35	1	2	1	.	1	5
4	Armstrong, Edwin Howard	64	22	4	2	3	.	2	8
5	Armstrong, William George	90	29	3	.	.	.	.	7
6	Ayrton, William Edward	61	34	4	5	4	.	3	2
7	Babcock, George Herman	61	22	3	2	2	.	3	0
8	Baekeland, Leo Hendrik	82	25	4	.	1	.	2	11
9	Baird, John Logie	58	37	4	4	2	.	2	9
10	Baker, Benjamin	67	20	3	3	.	.	.	1
11	Bazalgette, Joseph William	72	17	3	2	.	.	.	0
12	Bell, Alexander Graham	75	27	3	4	3	1	3	10
13	Bell, Patrick	70	28	4	.	1	1	2	0
14	Benz, Carl	85	34	4	2	2	.	2	10
15	Berners-Lee, Tim	.	34	.	.	.	.	.	0
16	Berthoud, Ferdinand	80	33	3	2	4	.	3	0
17	Bessemer, Henry	85	25	3	4	2	1	3	8
18	Bickford, William	60	57	3	2	.	.	.	0
19	Bigelow, Erastus Brigham	65	23	2	.	1	.	1	0
20	Booth, Herbert Cecil	84	30	4	.	.	.	.	0
21	Bosch, Karl	66	34	4	2	3	.	3	5
22	Boulton, Matthew	81	41	3	1	2	1	3	2
23	Bourdon, Eugène	76	24	3	1	2	.	2	1
24	Boyer, Herbert	.	30	4	3	.	.	.	0
25	Bramah, Joseph	66	30	3	.	1	.	2	7
26	Brin, Sergey	.	22	4	.	3	1	3	0
27	Brindley, James	56	43	1	3	.	.	.	0
28	Brinell, Johann August	76	33	3	3	.	.	.	0
29	Brunel, Isambard Kingdom	47	27	4	5	3	1	3	4
30	Brunel, Marc Isambard	80	30	3	4	.	.	.	6
31	Burr, Donald Calvin	.	39	4	.	.	.	.	0
32	Bush, Vannevar	84	23	4	.	3	.	2	6
33	Bushnell, Nolan	.	25	4	.	3	.	4	1
34	Callendar, Hugh Longbourne	67	39	4	4	.	.	.	0
35	Carnegie, Andrew	84	38	1	5	2	.	1	1
36	Cartwright, Edmund	85	42	4	3	.	.	.	6
37	Carver, George Washington	79	33	4	3	1	1	1	0
38	Cayley, George	84	35	4	.	3	.	4	7
39	Churchward, George Jackson	76	45	3	2	.	.	.	0
40	Cierva, Juan de la	41	24	4	4	.	.	3	2
41	Cockerell, Christopher (Sydney)	89	25	4	2	.	.	.	0
42	Cockerill, William	73	35	3	5	.	.	.	0
43	Colt, Samuel	48	14	3	4	.	.	.	3
44	Cooney, Joan Ganz	.	39	4	.	.	.	.	0
45	Corliss, George Henry	71	32	.	1	.	.	.	1
46	Cort, Henry	60	44	3	2	.	.	.	5
47	Cotton, William	80	78	3	4	.	.	.	0
48	Cousteau, Jaques-Yves	87	32	4	.	.	.	.	0
49	Crompton, Samuel	95	13	3	5	.	.	.	2
50	Cugnot, Nicolas Joseph	79	19	3	4	.	.	.	7
51	Da Vinci, Leonardo	67	30	2	5	3	.	4	13
52	Daimler, Gottlieb Willhelm	66	49	4	4	.	.	.	15
53	Damadian, Raymond	.	34	4	.	2	.	2	1
54	Dancer, John Benjamin	75	18	3	2	3	1	3	1
55	Darby, Abraham	40	27	3	4	1	.	2	3
56	De Forest, Lee	88	26	4	.	3	.	2	13
57	De Havilland, Geoffrey	83	27	3	1	3	.	3	2
58	De Laval, Carl Gustaf Patrik	68	33	4	.	.	.	.	0
59	De Lesseps, Ferdinand	89	49	4	4	4	.	4	1
60	Dicksee, Cedric Bernard	93	41	4	4	.	.	.	0
61	Diesel, Rudolph Christian Karl	60	39	4	4	2	.	2	12
62	Disney, Walt	65	18	4	4	2	.	2	0
63	Djerassi, Carl	.	19	4	4	4	1	4	0
64	Donkin, Bryan	87	35	3	2	.	.	.	0
65	Doriot, Georges	88	39	4	.	3	.	3	0
66	Dowty, George	74	30	3	3	.	.	.	0
67	Drake, Edwin	61	35	3	3	.	.	.	1
68	Dunlop, John Boyd	81	37	4	4	.	.	.	10
69	Eads, James Buchanan	67	22	3	1	.	.	.	0
70	Eastman, George	78	25	3	.	2	.	1	4

71	Eastwood, Eric	.	33	4	2	.	.	.	0
72	Eckart, John Presper	.	23	4	.	.	.	.	5
73	Edgerton, Harold "Doc"	87	27	4	3	3	.	3	0
74	Edison, Thomas Alva	84	19	1	.	2	.	3	38
75	Edwards, George	95	27	4	.	.	.	.	0
76	Eiffel, Alexandre Gustav	91	54	4	4	.	.	.	2
77	Elkington, George Richards	64	31	3	.	.	.	.	0
78	Ellet, Charles	52	36	4	5	.	.	.	0
79	Engelbart, Douglas	.	43	4	2	2	1	2	0
80	Ericsson, John	86	23	3	4	.	.	.	6
81	Evans, Oliver	64	20	3	2	.	.	.	5
82	Evinrude, Ole	57	23	2	3	2	.	2	0
83	Eyde, Samuel	74	35	4	5	.	.	.	0
84	Fairbairn, William	85	26	3	4	1	.	1	1
85	Farnsworth, Philo T.	65	16	4	3	2	.	1	5
86	Ferguson, Henry George	76	24	3	.	2	1	2	0
87	Ferranti, Sebastian Ziani de	66	18	4	3	.	.	.	8
88	Fessenden, Reginald Aubrey	66	34	4	5	.	.	.	10
89	Fitch, John	55	42	2	.	1	.	2	3
90	Fleming, John Ambrose	96	40	4	3	3	.	3	1
91	Fogarty, Thomas	.	12	4	1	3	.	2	0
92	Ford, Henry	84	30	3	2	2	.	4	7
93	Fourneyron, Benoit	65	25	4	.	4	1	3	2
94	Fowler, John	81	27	3	4	.	.	.	3
95	Fox, Sally	.	30	4	5	.	.	.	0
96	Foyn, Svend	85	55	.	.	.	.	.	0
97	Francis, James Bicheno	70	32	3	4	3	1	3	0
98	Friese-Greene, William	66	34	2	.	.	.	.	0
99	Froude, William	69	67	4	3	.	.	.	1
100	Fuller, Buckminster	88	34	4	.	3	.	4	0
101	Fulton, Robert	50	14	3	4	.	.	.	10
102	Gabor, Dennis	79	47	4	4	.	.	.	4
103	Gadgil, Ashol	.	43	4	5	2	.	2	0
104	Gates, Bill	.	17	3	.	.	.	.	1
105	Gatling, Richard Jordan	85	17	4	3	2	.	4	2
106	Giannini, Amadeo Peter	79	34	3	2	2	.	2	0
107	Giffard, Henri	57	27	4	.	.	.	.	4
108	Gilchrist, Peter Carlyle	80	24	4	.	4	.	3	2
109	Goddard, Robert Hutchings	63	21	4	.	2	1	3	1
110	Gooch, Daniel	73	24	3	.	.	.	.	0
111	Goodyear, Charles	60	33	3	3	2	1	1	6
112	Greatbatch, Wilson	.	39	4	4	2	.	2	0
113	Gresley, Nigel	65	35	3	.	3	.	3	0
114	Gross, Al	.	20	3	1	.	.	.	0
115	Gutenberg, Johann	71	43	3	.	.	.	.	8
116	Hadfield, Robert Abbott	82	24	3	.	2	1	4	0
117	Hall, Charles Martin	51	23	4	.	.	.	.	6
118	Hancock, Thomas	79	34	.	.	2	.	3	1
119	Handler, Ruth	86	40	4	.	2	.	2	0
120	Handley Page, Frederick	77	23	4	.	.	.	.	0
121	Hargreaves, James	58	40	1	.	.	.	.	4
122	Harper, Martha Matilda	93	31	2	.	2	.	2	0
123	Heathcoat, John	78	22	3	2	.	.	.	1
124	Hero of Alexandria	.	.	.	.	.	.	.	3
125	Héroult, Paul Louis Toussaint	51	23	4	.	.	.	.	8
126	Herzog, Bertram	.	34	4	2	.	.	.	0
127	Heyman, Jacques	.	33	4	4	.	.	.	0
128	Hodgkinson, Easton	72	33	2	1	1	.	1	0
129	Hoe, Richard March	74	25	3	.	2	1	3	0
130	Hollerith, Herman	69	21	4	.	.	.	.	16
131	Hooker, Stanley	.	31	4	.	.	.	.	0
132	Hoover, Erna Schneider	.	39	4	.	.	.	.	0
133	Hopper, Grace Murray	86	46	4	.	2	.	3	1
134	Horlock, John	.	20	4	.	.	.	.	0
135	Hounsfield, Godfrey Newbold	85	32	4	.	.	.	.	0
136	Howe, Elias	48	24	2	4	1	.	4	1
137	Hussey, Obed	68	41	3	.	.	.	.	0
138	Insull, Samuel	79	33	3	3	3	.	2	0
139	Issigonis, Alec	82	30	4	.	.	.	.	2
140	Jacobs, Mary Phelps	78	21	.	.	3	.	5	0
141	Jacquard, Joseph Marie	82	49	2	.	2	1	3	9
142	Jessop, William	69	47	3	3	3	1	3	0
143	Jobs, Steven	.	21	3	4	.	.	.	6
144	Judah, Theodore Dehone	37	34	3	3	3	.	2	0
145	Kamen, Dean	.	18	3	1	.	.	.	0

146	Kaplan, Viktor	58	32	4	.	.	.	.	2
147	Kay, John	76	26	4	3	3	1	4	2
148	Kelly, William	77	40	2	2	3	.	4	0
149	Kildall, Gary	52	30	4	.	3	.	3	1
150	King, Mary-Claire	.	28	4	.	2	.	2	0
151	Korolev, Sergei Pavlovich	60	27	4	.	.	.	.	0
152	Krupp, Alfred	75	35	3	.	2	1	4	5
153	Kurzweil, Raymond	.	12	4	.	2	.	3	0
154	Kwolek, Stephanie	.	41	4	.	2	.	2	0
155	Laennec, René T.H.	45	35	3	3	.	.	.	0
156	Laithwaite, Eric Robert	.	26	4	.	.	.	.	0
157	Lanchester, Frederick William	78	24	4	3	4	.	3	0
158	Land, Edwin	82	17	4	.	2	.	4	0
159	Langer, Robert	.	26	4	.	.	.	.	0
160	Lauder, Estée	96	27	.	.	2	.	3	0
161	Lebon, Phillipe	37	30	4	.	.	.	.	1
162	Lemelson, Jerome	74	32	4	.	.	.	.	0
163	Lenoir, Jean Joseph Étienne	78	25	.	.	.	.	.	6
164	Lilienthal, Otto	48	41	4	.	.	.	.	11
165	Locke, Joseph	55	25	3	4	3	.	3	0
166	Lowell, Francis Cabot	42	36	4	4	2	.	3	0
167	Lumière, Louis Jean	84	16	3	.	3	1	4	10
168	MacCready, Paul	.	.	4	.	.	.	.	1
169	Mannesman, Reinhard	66	31	.	.	2	1	.	5
170	Marconi, Guglielmo	63	20	4	4	3	.	4	20
171	Martin, James	88	31	2	2	2	.	2	0
172	Mauchly, John William	73	35	4	2	.	.	.	4
173	Maudslay, Henry	60	24	2	.	2	1	2	8
174	Maxim, Hiram Stevens	76	26	3	.	1	.	2	4
175	Maybach, Wilhelm	76	46	3	.	.	.	.	4
176	McAdam, John Loudon	80	54	3	4	.	.	.	1
177	McCormick, Cyrus Hall	75	22	3	4	2	1	4	3
178	McLean, Malcolm	88	24	3	.	2	.	2	0
179	McNaught, William	68	32	4	.	.	.	.	0
180	Mead, Carver	.	28	4	.	3	1	3	0
181	Mergenthaler, Ottomar	45	22	3	.	.	.	.	4
182	Messerschmitt, Willy Emil	80	17	4	.	.	.	.	5
183	Mitchell, Reginald Joseph	42	24	3	.	3	.	3	0
184	Montgolfier, Jaques Etiènne	54	37	.	.	3	1	4	7
185	Montgolfier, Joseph Michel	70	42	.	.	3	1	4	9
186	Morgan, Garrett	86	32	3	.	2	.	2	0
187	Morse, Samuel Finley Breese	81	45	4	5	3	.	3	12
188	Murdock, William	85	38	3	3	.	.	.	7
189	Nasmyth, James	82	23	2	3	2	1	2	3
190	Newcomen, Thomas	66	49	3	2	2	.	2	5
191	Nidetch, Jean	.	39	3	3	2	.	2	0
192	Olsen, Ken	.	31	4	4	.	.	.	0
193	Omidyar, Pierre	.	28	4	.	4	.	4	0
194	Otis, Elisha Graves	50	24	3	.	2	.	3	2
195	Otto, Nikolaus August	59	29	3	.	1	.	2	12
196	Ovshinsky, Stanford	.	25	3	.	.	.	.	0
197	Page, Larry	.	23	4	.	4	1	4	0
198	Papin, Denis	65	25	4	5	.	.	.	10
199	Parsons, Charles Algernon	77	31	4	.	3	1	.	12
200	Patterson, John	78	40	4	.	.	.	.	0
201	Pelton, Lester Allen	81	50	3	3	.	.	.	1
202	Pope, Albert Augustus	66	33	4	4	2	.	3	0
203	Porsche, Ferdinand	76	57	4	4	2	1	2	1
204	Pupin, Michael	77	42	4	5	1	.	1	1
205	Rabinow, Jacob	89	9	4	4	3	.	4	0
206	Rankine, William J.M.	52	33	4	.	3	1	3	0
207	Ransome, James Edward	66	63	4	.	2	1	3	0
208	Remington, Philo	73	19	4	.	2	1	3	1
209	Rennie, John	60	19	4	3	1	.	2	2
210	Reynolds, Osborne	70	41	4	.	3	1	3	0
211	Ricardo, Harry Ralph	89	12	4	2	4	.	3	0
212	Roberts, Richard	75	28	2	3	2	.	2	2
213	Roe, Alliot Verdon	81	31	3	5	.	.	.	0
214	Rosenthal, Ida	87	36	3	.	4	.	2	0
215	Royce, Frederick Henry	70	41	4	.	.	.	.	0
216	Rühmkorff, Heinrich Daniel	74	41	3	.	.	.	.	4
217	Savery, Thomas	65	46	4	.	.	.	.	2
218	Seguin, Marc	89	39	2	.	.	.	.	2
219	Shrapnel, Henry	81	22	4	5	.	.	.	1
220	Shreve, Henry Miller	66	27	1	3	2	.	2	0

221	Siemens, Ernst Werner von	76	26	4	.	.	.	.	40
222	Sikorsky, Igor	83	12	4	4	4	.	5	1
223	Simmons, Russel	.	26	3	1	4	.	4	0
224	Singer, Isaac Merrit	64	34	2	.	.	.	.	2
225	Slater, Samuel	57	22	3	.	1	.	2	0
226	Smeaton, John	68	32	2	.	.	.	.	5
227	Smith, Raymond Ingram	81	47	3	3	2	.	1	0
228	Spencer, Percy	76	52	2	.	2	.	1	0
229	Sperry, Elmer Ambrose	70	25	4	3	2	.	2	0
230	Stephenson, George	67	32	1	.	2	.	2	16
231	Stephenson, Robert	56	30	3	5	1	1	4	2
232	Stirling, Robert	88	26	4	1	.	.	.	2
233	Strauss, Levi	73	43	3	3	2	1	1	0
234	Sturgeon, William	67	45	3	3	2	.	2	4
235	Sutherland, Ivan Edward	.	22	4	.	.	.	.	0
236	Swan, Joseph Wilson	86	36	3	.	.	.	.	4
237	Swanson, Robert	52	29	4	3	2	.	3	0
238	Swinburne, James	100	49	3	4	3	.	3	0
239	Talbot, William Henry Fox	77	35	4	4	3	.	3	11
240	Tappan, Lewis	85	53	3	3	2	1	2	0
241	Telford, Thomas	78	29	3	.	1	.	2	1
242	Thomas, Sidney Gilchrist	35	28	3	.	.	.	.	1
243	Thomson, James	70	16	.	.	4	1	4	0
244	Todd, John	.	45	4	5	3	.	4	0
245	Trésaguet, Pierre-Marie-Jérôme	80	.	.	.	3	1	3	0
246	Trevithick, Richard	62	26	.	.	3	1	3	14
247	Trippe, Juan Terry	82	24	4	.	3	.	5	0
248	Tsiolkovskii, Konstantin	78	26	2	.	1	.	1	0
249	Tull, Jethro	67	27	4	.	.	.	.	0
250	Turner, Ted	.	39	3	4	2	.	4	0
251	Vaucanson, Jaques de	73	29	3	.	.	.	.	7
252	Vernier, Pierre	54	46	.	.	3	1	3	0
253	von Braun, Wernher	65	22	4	.	3	.	4	6
254	von Kármán, Theodore	82	62	4	5	4	.	4	0
255	von Welsbach, Freiherr C.A.	71	27	4	4	3	.	3	10
256	Walker, Sarah Breedlove	52	33	1	3	1	.	1	0
257	Wallis, Barnes Neville	92	37	3	.	.	.	.	0
258	Walschaerts, Egide	81	24	2	.	.	.	.	0
259	Wankel, Felix	86	33	3	.	.	.	.	5
260	Watson, Thomas	82	40	3	.	2	.	2	0
261	Watson, Thomas Jr.	79	32	4	.	2	1	5	0
262	Watson-Watt, Robert Alexander	81	27	4	.	.	.	.	4
263	Watt, James	83	31	2	3	2	1	3	31
264	Webb, Francis William	70	30	1	.	3	.	3	0
265	Wedgwood, Josiah	65	24	3	.	2	1	3	3
266	Wenner-Gren, Axel Leonard	80	.	3	.	.	.	.	0
267	Westinghouse, George	68	19	3	.	2	.	3	2
268	Whitehead, Robert	82	24	3	5	3	.	3	2
269	Whitney, Eli	60	28	4	3	1	.	3	2
270	Whittle, Frank	89	21	3	.	2	1	3	2
271	Whitworth, Joseph	84	30	3	3	3	.	3	6
272	Wilcox, Stephen	63	26	2	.	3	.	3	0
273	Wilkes, Maurice Vincent	.	35	4	.	.	.	.	0
274	Williams, Frederick Calland	66	35	4	4	.	.	.	0
275	Winsor, Frederick Albert	67	43	3	5	.	.	.	2
276	Wolff, Heinz Siegfried	.	26	4	.	.	.	.	0
277	Wozniak, Steve	.	11	3	.	3	1	3	6
278	Wright, Orville	77	28	3	.	3	.	3	12
279	Wright, Wilbur	45	32	3	.	3	.	3	13
280	Yalow, Rosalyn	.	29	4	2	2	.	2	0
281	Zeppelin, Ferdinand von	79	53	4	4	.	.	.	9
282	Zworkykin, Vladimir Kosma	93	34	4	5	.	.	.	13

6 Political Implications and Future Research

Externalities of education are at the center of the debate around public education subsidies. For instance, the uncompensated contribution of primary and secondary education to the stability of a society justifies public bearing of the teaching cost at those levels. On the other hand, growth externalities are usually pulled up to explain public intervention at the tertiary level. Chapter 2 of this work refutes the existence of uncompensated effects of education on economic growth. Following this rationale, full subsidization of higher education appears in a dubious light. If the interaction of labor and education markets leads to the efficient size of the human capital stock in the long run, such public intervention may actually cause an excess supply of human capital. Instead of fomenting the quantity of education, governments should concentrate on improving educational quality. More generally, they should explore possibilities for augmenting the efficiency of educational systems, including production efficiency of schools, universities, and vocational training organizations, as well as the matching efficiency of education and labor markets. At the same time, this postulate sets the agenda for future research in education economics.

Another common vindication for the public promotion of higher education is its potential role as a crucial driver of knowledge generation. A researcher or inventor may contribute to everyone’s well-being by generating economic growth. But he or she may not get compensated for the full social benefit due to the activity. This argument, however, is challenged by the findings of chapter 4 and 5. They neither support the notion that average years of schooling determine countries' innovative success, nor that formal schooling enhances an individual's capability of generating contributions to technological advancement. But even if this was the case, public intervention should be aimed at activities directed towards the creation of new knowledge or technologies rather than the provision of schooling. At the end of the day, production of the output knowledge, not the use of the input human capital, is what yields externalities. Hence, the provision of incentives to successful inventors is a more sensible scheme to compensate them for potential externalities from knowledge generation than broadly disseminating subsidies to individuals many of whom may lack the innovative capabilities necessary to be a successful inventor. Even more importantly, governments need to ensure that creative individuals are given the chance to acquire the knowledge necessary to deploy their potential. Chapter 5 underlines that this is vital especially for individuals from an unprivileged background. Educational loans, for example, may provide a possibility to achieve that. Designing the respective credits systems, e.g. entitlement, interest rates, payback conditions, etc. is another task for education economists.

Financial aid to inventors, however, is rational only if spillovers are limited to the boundaries of the economy. Chapter 4 demonstrates that knowledge spills over internationally and the fruits of innovative success may sooner or later be reaped by any country in the world. Consequently, financial support of innovation activities should ideally be an international effort. Otherwise, there would clearly be incentives for governments to free-ride on the positive externalities of other government's research subsidies. Adopting technologies from abroad and confining themselves to catching up with the technological frontier might be more attractive than contributing to pushing it forward. Thus, if states are left with individual decisions on the extent of public sponsorship, too little research may be pursued from an international perspective. Apart from financially encouraging innovation, however, national policy should focus intensively on the design of national innovation systems. Chapter 4, for instance, reveals that the institutional framework determines the extent of innovative activity. In particular, the degree of personal liberty including the protection of property rights seems to be an important aspect of innovation-friendly institutions. Nevertheless, many more aspects of national innovation systems deserve examination, such as the interaction of basic research organizations and entrepreneurial R&D. Also, the evaluation of specific new technologies in terms of their contribution to well-being and their sustainability is an important task to provide a guideline for politics aimed at promoting technology. In light of the challenges posed by climate change and scarce resources, this is, in my judgement, one of the most promising fields for future research in innovation.

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