The Role of Human Capital in the Process of Economic Development: The Case of England, 1307-1900

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Abstract Macroeconomic growth models underline the importance of human capital in the process of economic development. This analysis introduces a new proxy for human capital, which is educational attainment, and examines cohesion between education levels and growth for England between 1307 and 1900. The empirical evidence suggests no significant result between basic skills, such as reading and writing abilities, and growth of per capita GDP. More progressive human capital levels, as measured by average years of higher education, seem to have contributed to the process of development until the mid-eighteenth century.

I. Introductory

The Industrial Revolution can be seen as a watershed for the economic development of England, and more in general terms, that of the Western World. There is, however, an ongoing debate between scholars regarding the origins of the Western offshoot and its transition towards modern economic growth.[1] To begin with, Acemoglu et al. (2005) stress the importance of Britain's connection to Atlantic trade, which enhanced the development of secure institutions that established economic development during the early modern period. In addition to this vision, North and Weingast (1989) emphasize the consequences of the Glorious Revolution (1688) for this institutional change. Countering this institutional view, Allen (2009) argues that England's high wages and cheap energy environment triggered the demand and supply of technology. These inventions were partly transformative, which resulted into a constant stream of technology. It therefore enhanced sustained growth. On the other hand, according to Mokyr (2002), Britain's take-off can be attributed to the accumulation of 'useful knowledge'[2] that existed due to the Scientific Revolution. England's knowledge base reached such a critical level, that it fostered a continuous stream of inventions. Finally, unified growth theory, as pioneered by Galor and Weil (1999; 2000) and Galor and Maov (2002), stress the important role of human capital in the process towards modern economic growth. Succinctly, education is necessary in order to accommodate a changing technological environment.

This analysis is an attempt to confront the theory of Galor and Weil (1999; 2000). It is appealing since most studies that have examined the impact of human capital on England's development utilized literacy rates as a proxy for education levels. These studies could not identify a significant relationship between the two (see Mitch, 1992; see also Allen, 2003). Be that as it may, these analyses did not regard the rise in literacy of women, which increased almost 20% between 1750 and 1850.[3] Moreover, literacy was relatively high in England compared to South and Central Europe.[4] Finally, to follow Baten and Van Zanden (2008), these studies understate increases in literacy, as well as general education levels, that occurred in the centuries prior to 1750. Recent examinations, using more advanced proxies of human capital over a longer time period, find a significant effect between human capital accumulation and economic development (see Baten and Van Zanden, 2008; and Boucekkine et al. 2005; 2007).

Underestimations of English literacy levels by earlier studies, and the findings of Baten and Van Zanden (2008) and Boucekkine et al. (2005; 2007), makes it very attractive to reassess the relationship between human capital accumulation and the process of Britain's development. In doing so, we must acquaint ourselves with 'educational attainment', which is a new indicator for levels of human capital. This new proxy characterizes the average amount of schooling in the period 1307-1900. The series not only measures overall education levels, but also differentiates between

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[1] Modern economic growth is defined as sustained growth in income per capita.

[2] The Scientific Revolution of the seventeenth century produced 'useful knowledge' (e.g. mathematics) that laid the foundation for 'Industrial Enlightenment'. In turn, enlightenment, which can be defined as 'the application of scientific and experimental methods to the study of technology' (Mokyr, 2009, Pp. 29), connected the Scientific Revolution to the Industrial Revolution (Mokyr, 2002; 2009).

[3] Female literacy rates increased from 36% in 1750 to 54% in 1850. For men this is respectively 56% and 69% (Stephens, 1987).

[4] Adult literacy by 1800 (men and women together): England, 53%; The Netherlands, 68%; Belgium, 49%; Germany, 35%; France, 37%; Austria/Hungary, 21%; Poland, 21%; Italy, 22%; Spain, 20% (Allen, 2003).

gender. This study provides sufficient new insights in the cohesion between average years of schooling and development.

The outline of this paper is as follows. Section II addresses the theory underlying unified growth theory, presents evidence on the cohesion between human capital and growth that has been found by earlier studies, and introduces the hypothesis. In section III, a description of the dataset is provided. Additionally, in section IV several regression analyses are conducted, which estimates the magnitude of educational attainment on economic development whilst controlling for technology and institutions. Section V gives a summary of the main findings, and elaborates on the regression outcomes.

II. Theory

The accumulation of physical capital and labour has significant bearing for economic growth, but there is also another factor which certainly may not be neglected. Human capital has a considerable contribution to development as well. Becker (1965) was the first economist who emphasized the importance of the productivity-enhancing role that human capital plays. Human capital is then defined as 'all the attributes of workers that potentially increase their productivity in all or some productive tasks' (Acemoglu, 2009, Pp. 359). An additional view on human capital, as pioneered by Nelson and Phelps (1966), stresses the importance of education for the implementation and adoption of new technologies, rather than just a single increase in workers' productivity. Schultz (1975) enriched Nelson and Phelps' theoretical model. Succinctly, education enables workers to deal more efficiently with economic change, disruptions and the implementation of new technologies. This is the greatest benefit of human capital in a modernizing economy, as Schultz puts it. Recent macroeconomic growth models that include this Nelson-Phelps-Schultz view are of Galor and Tsiddon (1997), Caselli (1999) and Galor and Moav (2000). According to these analyses, technological change increases the return to education. Consequently, inequality between skilled and unskilled workers widens, which reflects the positive effect of technology on the demand for an educated workforce. Hence, educational attainment will increase, which in turn promotes further technological progress. Empirical evidence supports these models. Benhabib and Spiegel (1994) as well as Foster and Rosenzweig (1995) find stronger correlations between growth and levels of human capital than between development and changes in education. This evidence is thus aligned with Nelson and Phelps and Schultz, since they stress the implication of human capital for technology adoption, rather than a single increase in the productivity of workers.

Moreover, the theory of Becker (1981) enriched the original Malthusian model. To follow Becker, there is a trade-off between the quantity and quality of children, which in turn alters the course of development. At a certain point in the growth process, parents will give a higher priority to child quality, rather than the quantity of children, and begin to invest in their education. This demographic effect will manifest dwindling fertility rates. Recent growth models that elaborate on the evolution from a Malthusian growth regime towards one of modern growth incorporates this demographic shift (see for example Goodfriend and McDermott, 1995; Galor and Weil, 1999; 2000).

Nelson and Phelps (1966), Schultz (1975) and Becker (1981) views combine into unified growth theory (Galor and Weil, 1999; 2000). To follow Galor and Weil (1999; 2000), in the Malthusian Regime, which marks the early stages of development, population growth and output per capita are almost negligible. The economy is therefore unable to escape the confines of the Malthusian trap. Nonetheless, a transition to the second stage of growth, the so-called Post-Malthusian Regime, thanks its existence due to the acceleration of technological progress that resulted from population growth during the Malthusian Regime. As a consequence, development starts to accelerate during this second growth regime. Moreover, wages of skilled labourers will increase relatively to that of unskilled labourers because production takes place under a state of technological disequilibrium. As a result, parents start to invest in their children and shift away from child quantity to quality. Levels of GDP rise in tandem with an increase in the rate of population growth and human capital accumulation. Increases in education translate into rapid technological progress, which in turn triggers a demographic transition in which fertility rates are in a permanent state of decline. Sustained growth in income per capita and the level of technology, associated with a negative relation between the level of output and population growth, characterize the Modern Growth Regime.

Earlier studies that examined the impact of human capital accumulation on growth are due to Barro (1991) and Glaeser et al. (2004). Both examinations, utilizing school enrolment rates, find a positive relation between human capital and economic growth. With respect to the early modern period, most analyses examining the influence of human capital formation on development utilized literacy rates as a proxy for education. Allen (2003) underlines an insignificant relation among technological progress and literacy in pre-industrial countries. Moreover, Mitch (1993), who focuses on England during the Industrial Revolution, concludes that Britain possessed only a modestly educated workforce. A more recent contribution of Baten and Van Zanden (2008) shows that human capital, as measured by book production, contributed to economic performance in the centuries prior to the 1800s. In addition to this, Galor and Moav (2002) suggest that human capital formation significantly contributed to the English Industrial Revolution. A positive relation between technological improvement and education contributed to Britain's take-off and its evolution towards modern growth. Both empirical analyses of Boucekkine et al. (2005; 2007) support this conclusion of Galor and Moav.

As explained in the introduction, the subject of this study reconsiders the connection between human capital and economic development in England. In doing so, it utilizes a new proxy for levels of human capital, i.e. educational attainment, for women, men and the overall population. This contrasts the earlier contributions of Mitch (1993) and Allen (2003). It not only measures average literacy among the English population, but includes secondary and higher education levels as well. Furthermore, in contrast to the examination of Mitch, it investigates a longer period (i.e. 1307-1900). The analysis therefore expects a positive relationship between average years of education and economic development.

III. Data and sources

This study utilizes per capita Gross Domestic Product in constant 1990s dollars as a proxy for economic growth for the period 1307-1900. To accomplish this, it was required to combine three datasets. The first estimates cover GDP per capita of England for the period 1307-1700, whilst the second series deal with Great Britain (i.e. England, Wales and Scotland) for 1701-1870. Both datasets were part of a project belonging to Broadberry et al. (2010a; 2010b) and Broadberry and Van Leeuwen (2010) that attempted to reconstruct the national income of Britain and Holland between the Middle Ages and the late nineteenth century. This is extended by means of Maddison's (2003) observations of the United Kingdom.[5] The main characteristics, as well as a graph of per capita GDP, can be found below. As represented in graph 3.1, economic growth increased after 1700, although it starts to accelerate after 1800.

Educational attainment serves as an indicator for human capital accumulation. Observations concerning average years of education of women, men, and the overall population between 1307 and 1900 are provided in this study. More to the point, primary, secondary and higher schooling are combined with population levels and rates of life expectancy to generate annual education levels. The main characteristics of these variables can be found in table 3.1. Furthermore, graphs 3.2 and 3.3 illustrate levels of primary and secondary schooling over time (see appendix A for the exact compilation of these series).

With respect to levels of primary education, literacy rates were used as an indicator. These rates are determined by signature evidence. Data derived for the years prior to 1754 has been collected by scouring church and secular court records. The English law required spouses to sign or make a mark on their marriage contract from 1754 on. Literacy rates focussing on the period after 1754 are therefore obtained from the number of spouses able to sign their marriage contract. Consequently, literacy rates overstate those able to write, but understate couples able to read at a basic level. It therefore gives a sufficient suggestion of the portion of the population that could read easily. Children learned basic reading skills in approximately one and a half year (Schofield, 1968; Cressy, 1980), although the elementary schooling programme lasted for approximately three years during the early modern period (Jewell, 1998). This study sets literacy equal to two years of education.

It is necessary to make a couple of exceptions to this elementary schooling level, as stated here. First, Jewell (1998) mentions that most pupils entering secondary education completed the elementary schooling programme. It is therefore assumed that boys who entered into secondary education completed three years of elementary schooling. Secondly, the *quality* of signatures increased between 1675 and 1775, which also reflects the rise in primary educational opportunities that opened up during the eighteenth century. Many Sunday, writing, charity, monitorial, industrial and workhouse schools appeared during this century (Stone, 1969; Schofield, 1981). The analysis supports a rise of one year of elementary schooling between 1675 and 1775.[6] Finally, education became a nation-wide concern in the nineteenth century. Several Factory Acts and Elementary Education Acts were introduced that had to lower working hours and enhance schooling levels of children. Consequently, school attendances, as well as average years spend on primary education, rose remarkably during the nineteenth century (Williams, 1961; Selleck, 1968; Lawson and Silver, 1973). This study allows thus for additional increases in average years of primary education in the nineteenth century.[7]

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[5] These series contain per capita GDP levels. It was thus not problematic to combine these three datasets, since they are corrected for the population levels of the UK, GB and England.

[6] The increase in educational opportunities is especially visible from the 1750s on. Hence, average years of primary schooling are increased from 2 to 2.25 years between 1675 and 1750, from 2.25 to 2.5 years between 1750 and 1775, and from 2.5 to 3 years between 1775 and 1825. For pupils that went on to secondary education, this level has been increased from 3 to 3.5 and from 3.5 to 4 years.

[7] Literate has been set fixed at 5.04 years of primary education in 1870, and to 5.46 years in 1900. Dates in the interval have been interpolated.

Combining the number of secondary schools and their pupils generates secondary education levels. Children went to these schools to acquire more advanced levels of education, and stayed there for six more years (Stone, 1964; Vincent, 1969; Jewell, 1998). Hence, pupils that went on to these institutions are set at six additional years of education. Matriculations to the University of Oxford, the University of Cambridge and the University of London serve as indicators for levels of higher education. Both studies of Stone (1964; 1974) provide also the number of students that obtained a bachelor or master degree, which made it possible to distinguish between different levels of higher education. More to the point, students who failed to acquire any degree at all are set equal to two years of extra schooling, bachelors to four additional years, and those who obtained a master's degree to seven more years of education. Women were not admitted to secondary or higher education before the 1880s. Their education series is for that reason solely based upon literacy estimations before the late nineteenth century.

Engaging secondary education, foundations for classic grammar schools (i.e. those schools that were concerned with the learning of Latin and Greek grammar) were led all over the country between 1480 and 1530 (Orme, 2006). Additionally, Jordan (1959), Vincent (1969) and Stone (1964) mention the tremendous expansion of secondary and higher education between 1530 and 1660. After the reformation, however, many classical grammar schools declined. These institutions became subject to a narrow church control after the restoration and continued to represent the conservative classical tradition of education. In doing so, it failed to meet the needs of the middle-class who was engaged into industry and commerce (Simon, 1960; Stone, 1964; Vincent, 1969). Moreover, classical grammar schools were affected by competition of private teachers, private schools and the Academies. These secondary institutions paid attention to the learning of foreign languages, as well as mathematics, whilst the classical grammar schools commenced into Latin and Greek Grammar. These middle-class private schools offered an alternative training to that of grammar schools in the eighteenth century (Vincent, 1969; Lawson and Silver, 1973). However, as Vincent (1969) states, the movement to other forms of secondary education did not compensate for the movement away from grammar schooling. Many classical grammar schools disappeared after the 1660s, and the number of pupils attached to these institutions declined significantly during the eighteenth century (Stone, 1964). The same applies to the number of private institutions that sent boys to one of the Universities (Vincent, 1969).[8] As Stone (1964) states, the period between 1530 and 1660 can be seen as an 'educational revolution', which was followed by a severe educational depression that lasted for more than a century. Consequently, 'English higher education did not get back to the level of the 1630s until the first World War' (Stone, 1964, Pp. 68).

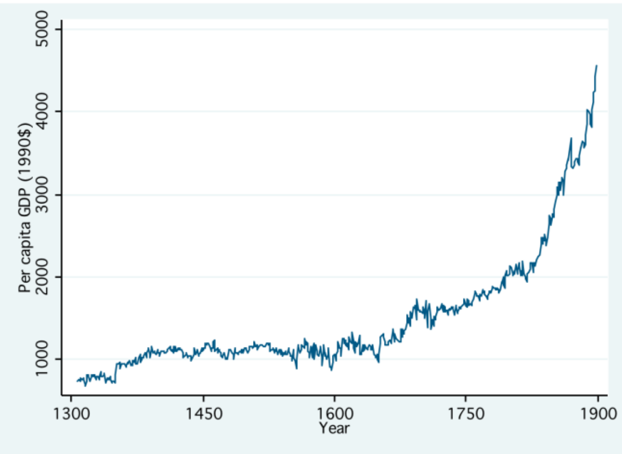
The 'educational revolution', as well as the depression in higher education, is clearly visible in graph 3.3 below. Nevertheless, note that the deterioration emerged after 1700 and not after the 1660s. First of all, Stone (1964) and Vincent (1969) are mainly interested in secondary schools that sent boys to one of the English Universities. They thus considered the decline in classical grammar schools and University enrolment. Boucekkine et al. (2007) provides numbers of secondary schools and their founding date that were still in existence by the 1860s. This list covers not only classical grammar schools, but all secondary schools that provided education beyond the elementary level. As graph A.1 in appendix A shows, still many schools were founded

[8] See appendix A for Vincent's (1969) estimations.

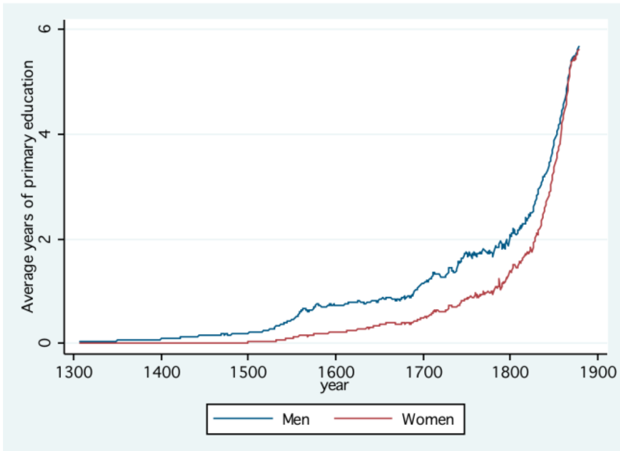
after the 1660s, which contradicts Stone (1964)'s findings. The major decline in secondary schooling emerged after the 1720s (see Graph A.1). Additionally, as explained above, the estimates are coupled to life expectancy in order to generate average years of education. Although the number of pupils attached to institutions of higher education declined after 1720, as well as the number of schools in common, obtained knowledge remained in the English society for two to three decades.

Combining primary, secondary and higher education levels produces the educational attainment series. Graph 3.4 illustrates overall schooling levels for women, men and the overall population. Levels of human capital were already rising before the Industrial Revolution. With respect to higher education, foundations were led during the late Middle Ages. Although male education diminished during the eighteenth century due to a movement away from higher education, increases in primary education levels compensate for this decline.

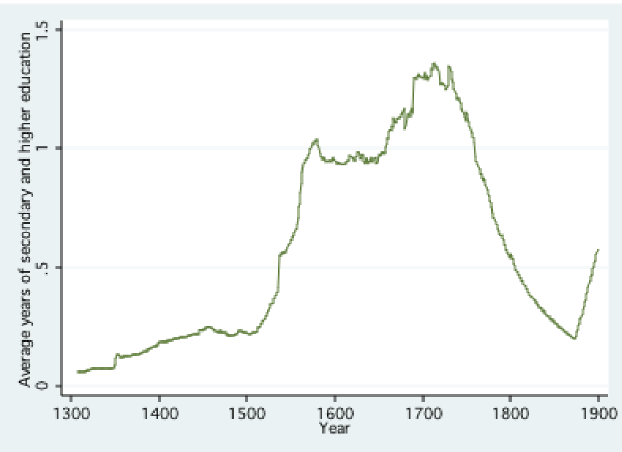
Graph 3.1 –Per capita GDP



Graph 3.2 – Primary education levels



Graph 3.3 – Higher education levels



Graph 3.4 – Overall education levels

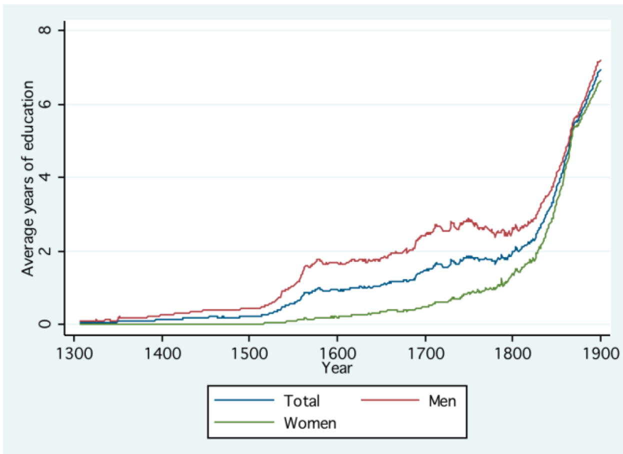


Table 3.1 – Summary Statistics of Variables

Variables	N	Mean	Standard Deviation	Min	Max

Per capita GDP_{1990}	594	1493.44	751.5316	674.9515	4566.952
Education level men	594	1.7761	1.5943	0.1071	7.2147
Education level women	594	0.8372	1.5010	0.0082	6.6420
Education level total	594	1.3067	1.5146	0.0598	6.9284
Primary education level of men	594	1.2063	1.5200	0.0474	6.6372
Higher education level of men	594	0.5698	0.4137	0.0596	1.3638
Per capita Patents	284	46.5052	109.771	0	530.1178
Parliamentary activity	494	164.488	162.486	0	365

The first control variable that is used concerns a proxy for institutions. Research indicates institutions, and especially the role of property rights and the rule of law, as an important determinant of economic success (North, 1990; Acemoglu et al., 2001). According to North and Weingast (1989), the Civil War (1640-1660) and the Glorious Revolution (1688) led to a successful evolution of institutional forms that were favourable for the development of England. There were limited credible commitments to rights under the Absolutist rule of the Stuart before 1688. The Star Chamber enabled the Crown to alter rights in his own interest, without considering the Parliament. This led to fiscal constraints and a revenue-seeking King. Due to the Glorious Revolution, however, new institutions could emerge. It became possible for the Crown to make credible commitments that marked an increase in the security of private rights. One of the most important changes was that wealth holders gained a say in decisions through their presence in Parliament. Policies were thus only implemented if they were in line with their interests.

The empirical analysis uses 'parliamentary activity', or more specific a meeting index of the English Parliament, as an indicator for institutions (see Van Zanden et al., 2010 for more information about the construction of this dataset). Parliamentary activity varies from zero, when no Parliament convened, to 365, when it met year round. An active Parliament serves as a constraint on the executive, which lowers expropriation risks. This in turn fosters development of secure property rights that is beneficial for development (North and Weingast, 1989).

The second control variable concerns annual number of patents granted in England and Wales for 1617 to 1900. This serves as a reliable indicator for the number of inventions, and hence for technological change and progress. Estimations 1617-1852 are taken from Diebolt and Pellier (2010) and MacLeod (1988). Annual numbers of patents granted after 1852 are derived from the Intellectual Property Office (2011). Note that England had no such patent system prior to 1617. As a consequence, the amount of patents prior to 1617 has been set fixed at zero in order to generate observations that cover the overall era. Again, the main characteristics of these control variables can be found in table 3.1 above.

IV. Empirical analysis[9]

In order to estimate cohesion between educational attainment and per capita GDP, it was required to correct for heteroskedasticity, autocorrelation and unit root.

[9] A description of the tests necessary to conduct the results section can be found in Appendix B.

Educational attainment and per capita GDP are both non-stationary series, which become stationary after first differencing. The basic model is therefore:

$$\Delta(\ln)Y_t = \beta_1\Delta(\ln)Y_{t-1} + \beta_2\Delta(\ln)E_t + \underline{x}_t'\gamma_3 + \Delta\varepsilon_t, \quad (4.1)$$

where $(\ln)Y_t$ is the growth rate of real per capita GDP, $(\ln)Y_{t-1}$ is the log of real per capita GDP lagged for one period, $(\ln)E_t$ is the log of the level of education at time *t*, $\underline{x}_t$ is a vector of control variables that consists of parliamentary activity ($Parliament_t$) and per capita patents ($\Delta Patents_t$), and ε_t is the error term. It was not necessary to include differences of parliamentary activity, since this variable is stationary. Concerning per capita patents, it was not possible to convert it into logarithms. England had no patent system before 1617. In order to generate observations that cover the entire period it has set fixed at zero before 1617.

The interest lies in the sign and statistical significance of β_2.[10] Estimating this with Ordinary Least Squares is not accurate. In essence, $(\ln)Y_{t-1}$ - $(\ln)Y_{t-2}$ is correlated with the error term ε_t - ε_{t-1}, and is thus an endogenous variable in the first-differenced equation. To assess this problem, it was required to employ two-stage least squares estimations (henceforth 2SLS). Anderson and Hsiao (1982) recommend instrumenting for $\Delta(\ln)Y_{t-1}$ with $(\ln)Y_{t-2}$ or $\Delta(\ln)Y_{t-2}$, which are uncorrelated with the disturbance in equation 4.1, but correlated with $\Delta(\ln)Y_{t-1}$. To follow Arellano (1989), utilizing $\Delta(\ln)Y_{t-2}$ as an instrument leads to an estimator that has a very large variance. Consequently, although the 2SLS coefficient estimates are consistent (i.e. they approach the true value as the number of observations increases to infinity), the estimates are always biased in finite samples. Additionally, the 2SLS standard errors become too small, which leads to misleading regression results (Wooldridge, 2000; Verbeek, 2008). Nevertheless, it was not possible to use $(\ln)Y_{t-2}$ as an instrument for $\Delta(\ln)Y_{t-1}$, since it does not satisfy the criteria of being a relevant instrument (see details in appendix B). To overcome these difficulties, the difference of lagged per capita GDP is instrumented by two past levels of per capita GDP, that is $(\ln)Y_{t-2}$ and $(\ln)Y_{t-3}$. These results are reported in this section. For the sake of completeness, regressions that use $\Delta(\ln)Y_{t-2}$ as instrument for $(\ln)Y_{t-1}$ - $(\ln)Y_{t-2}$ can be found in appendix C. Using this particular instrument does not alter the results. For now, $\Delta(\ln)Y_{t-1}$ is regressed on all the exogenous variables. Hence:

$$\Delta(\ln)Y_{t-1} = \mu_0 + \eta_1(\ln)Y_{t-2} + \gamma_2(\ln)Y_{t-3} + \delta_3\Delta(\ln)E_t + \phi_4\Delta Patents_t + \theta_5 Parliament_t + \varepsilon_t \quad (4.2)$$

The exclusion restrictions are that $(\ln)Y_{t-2}$ and $(\ln)Y_{t-3}$ do not appear in equation 4.1. Estimations using 2SLS have been performed for the period under consideration. In doing so, it was required to divide the analysis, because parliamentary activity was only available between 1307 and 1800. Table 4.1 shows the regression results for 1307-1800, whilst table 4.2 depicts the estimations for 1307-1900.

Table 4.1 – 2SLS regression results 1307-1800
(Robust standard error between parentheses)

$\Delta(\ln)Y_t$	Model 1	Model 2	Model 3

[10] It is not possible to interpret the magnitude of the coefficient due to omitted variable bias (Verbeek, 2008).

$\Delta(\ln)Y_{t-1}$	0.6378*** (0.2367)	0.6289*** (0.2351)	0.6760*** (0.2408)
$\Delta(\ln)E_t^{Total}$	0.2661* (0.1379)	-	-
$\Delta(\ln)E_t^{Men}$	-	0.2925** (0.1353)	-
$\Delta(\ln)E_t^{Women}$	-	-	0.0626 (0.0806)
$Parliament_t$	0.0030 (0.0195)	0.0046 (0.0195)	-0.0003 (0.0197)
$\Delta Patents_t$	0.2787 (0.3776)	0.2846 (0.3742)	0.3252 (0.3885)
Constant	-0.0017 (0.0044)	-0.0019 (0.0044)	0.0001 (0.0044)
Observations	491	491	491
F-value	3.19**	3.42***	2.21*

*** Coefficient is significant at the 0.01 level
** Coefficient is significant at the 0.05 level
* Coefficient is significant at the 0.10 level
Notes: All regressions reported above are carried out with an intercept. The time trend is omitted, since it was not significant. Including a time trend does not change the regression results. The endogenous regressor is the log of real per capita GDP lagged for one period. The first stage regressions can be found in appendix B.

Table 4.2 – 2SLS regression results 1307-1900
(Robust standard error between parentheses)

$\Delta(\ln)Y_t$	Model 4	Model 5	Model 6
$\Delta(\ln)Y_{t-1}$	0.6762*** (0.2595)	0.6777*** (0.2591)	0.7135*** (0.2581)
$\Delta(\ln)E_t^{Total}$	0.2575** (0.1248)	-	-
$\Delta(\ln)E_t^{Men}$	-	0.2734** (0.1252)	-
$\Delta(\ln)E_t^{Women}$	-	-	0.0810 (0.0780)
$\Delta Patents_t$	0.4439 (0.5108)	0.3747 (0.5138)	0.1327 (0.5268)
Observations	591	591	591
F-value	5.23***	5.40***	3.52**

*** Coefficient is significant at the 0.01 level
** Coefficient is significant at the 0.05 level
* Coefficient is significant at the 0.10 level
Notes: All regressions reported above are carried out without an intercept. The time trend is omitted, since it was not significant. Including an intercept and/or a time trend does not change the regression results. The endogenous regressor is the log of real per capita GDP lagged for one period. The first stage regressions can be found in appendix B.

As the regression outcomes in tables 4.1 and 4.2 reveal, parliamentary activity and per capita patents granted fail to have impact on per capita GDP levels. To follow Rodrik (2006), studies that found a significant effect of institutions on economic performance take the *level* of income in some recent year as dependent variable (see for example Hall and Jones, 1999; see also Acemoglu et al. 2001). Introducing institutional proxies in *growth* regressions gives much weaker results. Hausmann, Pritchett and Rodrik (2005) found little evidence that large-scale institutional changes contributed to processes of economic development. Moreover, with respect to England during the early modern period, several studies of interest rates have been conducted that examined the impact of the Glorious Revolution (1688) on England's success (Clark, 1996; Quinn, 2001). These analyses do not support the hypothesis of North and Weingast (1989) that the Glorious Revolution contributed to the development of Britain. The regression results in table 4.1 underline these previous findings of Clark (1996) and Quinn (2001).

Male education levels and overall education levels tend to be significant at the 5% and 10% level. Average years of schooling of women seem insignificant in both models. As explained in section III, women were simply not admitted to secondary and higher schooling before the 1880s. Their educational attainment series is therefore solely based upon literacy observations. It thus measures the ones able to read fluently, but overstate women able to write at an advanced level (Schofield, 1968). Most elementary schools were concerned with the learning of reading and writing. Only a few of these schools offered basic mathematics (Cressy, 1980; Stephens, 1987). More advanced education was taught at secondary schools and the Universities. It is therefore probable that basic reading and writing skills fail to have an impact on economic development.

In order to examine this more thoroughly, male education levels are divided between average years of primary schooling, which depends completely on literacy estimates as a proxy for basic education levels, and average years of higher education. The latter includes men that completed secondary schooling and those who managed to obtain a University degree. Graphs 3.2 and 3.3 illustrate primary and higher education levels of the male population. As described in section III, levels of secondary schooling were particularly high before eighteenth century. An average English man obtained approximately one year of higher education during the seventeenth century. This disappeared after the 1750s and decreased to just 0.25 years during the mid-nineteenth century. Regression analyses are conducted to examine the cohesion between levels of primary and higher education and per capita GDP growth. The results are depicted in table 4.3 below (model 7 and 8).

Table 4.3 – 2SLS regression results primary and higher education (Robust standard error between parentheses)

$\Delta(\ln)Y_t$	Model 7	Model 8	Model 9 (1750-1900)	Model 10 (1307-1750)
$\Delta(\ln)Y_{t-1}$	0.6779*** (0.2519)	0.7141*** (0.2624)	0.7527** (0.3815)	0.6957** (0.2837)
$\Delta(\ln)E_t^{Primary}$	0.1913 (0.1248)	-	-	-
$\Delta(\ln)E_t^{Higher}$	-	0.1945** (0.0880)	-0.0092 (0.1148)	0.2476** (0.1052)
$\Delta Patents_t$	0.9420	-0.1122	-	-0.0710

	(0.5206)	(0.5936)		(0.0936)
Δ(ln)Patents$_t$	-	-	0.2568*** (0.0959)	-
Observations	591	591	150	441
F-value	3.91***	5.65***	4.57***	5.20***

*** Coefficient is significant at the 0.01 level
** Coefficient is significant at the 0.05 level
* Coefficient is significant at the 0.10 level
Notes: All regressions reported above are carried out without an intercept. The time trend is omitted, since it was not significant. Including an intercept and/or a time trend does not change the regression results. The endogenous regressor is the log of real per capita GDP lagged for one period. The first stage regressions can be found in appendix B.

As the regression results in table 4.3 reveal, only higher education contributed to economic development. Basic skills fail to have a significant effect and are unable to explain differences in per capita GDP levels. Nonetheless, it was also appealing to perform regression analyses covering the period 1307-1750 and 1750-1900. Population growth, technological progress and economic growth start to accelerate from 1750 onwards, whilst higher education levels diminished during the second half of the eighteenth century. These regression outcomes can be found in table 4.3 above (model 9 and 10).

It seems that levels of higher education failed to contribute to England's development after 1750, whilst the level of technology starts to contribute from this date on. It is necessary to make a remark here. As clarified at the beginning of this section, regressions that employed Δ(ln)Y_{t-2} as an instrument for Δ(ln)Y_{t-1} are performed as robustness checks (see appendix C). These results remain fairly equivalent, with an exception for the results depicted in model 9. As a result, the outcomes of this estimation must be viewed with some concern due to possible inconsistency of the parameters (see model 9 in table C.3). On the contrary, though, it is safe to conclude that the positive relation between levels of higher education and growth breaks down during the second half of the eighteenth century due to a sharp decline in average years of higher education.[11]

The findings presented in this section are in line with the earlier findings of Mitch (1993) that utilized literacy rates during the Industrial Revolution as indicator for English schooling levels. Elementary education levels did not contribute to the process of growth. Nevertheless, it seems that more progressive skills, offered at secondary schools and Universities, contributed to England's economic development until the eighteenth century. This conclusion underlines the previous studies of Baten and Van Zanden (2008) and Boucekkine et al. (2005; 2007) that employed more advanced proxies for levels of human capital.

V. Conclusion

This paper attempted to examine the relationship among levels of human capital in the English population and economic development. The main objective was to provide a more advanced measure of human capital than the ones used in previous studies (i.e.

[11] In addition to this, the variables are negatively correlated from 1750 onwards (i.e. Pearson correlation of -0.6086; p-value = 0.0000).

literacy rates). Additionally, it not only focused on levels of human capital during the Industrial Revolution, but included observations focussed on the era prior to the eighteenth century as well. Hence, it combined primary, secondary and higher education levels in order to compile an educational attainment series that covers average years of schooling of men, women and the overall population between 1307 and 1900.

Several 2SLS regression analyses have been performed, which estimated the magnitude of educational attainment on economic growth whilst it controlled for institutions and the level of technology. Institutions tend to have an insignificant effect on per capita GDP levels, which is aligned with empirical analyses that concentrate on the relationship between institutions and *growth*. Technological progress seems to have an insignificant effect on development before the Industrial Revolution. All regression results indicate a significant effect of male education and general education levels on growth. Female education has no such cohesion with development. The educational attainment series of women is solely based upon literacy rates before 1880. It was therefore of interest to divide male education into primary and higher schooling levels. Basic skills, such as reading and writing abilities, had no effect on development. It turned out that only higher education contributed to per capita GDP levels, although this positive relation disappears after the 1750s.

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Appendix A – Construction of the educational attainment series

Primary Education – Literacy rates

Historians diligently paid attention to the level of literacy of the English population during the early modern period (Stephens, 1990). This developed into numerous studies from the 1980s onwards. These analyses not only added new insights to England's social history, but also provided statistical evidence. Data used in these literacy studies focussed on signature evidence. Nonetheless, the availability and nature of signature evidence varied over time. Regarding the level of literacy in England, 1754 can be seen as a watershed. Data derived for the years prior to 1754 has been based on church and secular court records. The laws in effect at the time required a spousal signature or mark on their marriage contract from 1754 onwards. This law made it possible for historians to compile statistical data for both men and women, as well as for different social classes of the British society. As a consequence, there is reasonable evidence available supporting various concepts of the proportion of the adult population achieving basic levels of literacy from the late sixteenth century to the beginning of the twentieth century.

These studies have been utilized to construct a series of primary education levels of the English population between 1500 and 1910. For starters, the analyses of Cressy (1980; 1981) offer estimations of the illiteracy rate of men and women in England between 1500 and 1750. To put it bluntly, Cressy (1980) gives statistical evidence for the years 1500, 1550, 1560, 1580, 100, 1610, 1640, 1660, 1680, 1710, and 1750. His data has been compared with the estimates of Stone (1969) and Stephens (1990), and as a result, sometimes slightly adjusted downwards.[12] Note that it was required to take variations in literacy over this time span into account. More specifically, there has been an unstable, non-cumulative progress in the rise of literacy between 1500 and 1750, and Cressy distinguishes eight distinct phases in the development in literacy (see Cressy, 1981 for more details about theses stages). Subsequently, observations concerning the 1754-1840 period have been taken from Schofield (1981). He used a random sample of 274 English parish registers to estimate the annual percentages of men and women able to sign their marriage contract. These parishes produced almost 1300 marriages per annum in the mid eighteenth century, this number rose to approximately 2900 marriages by the late 1830s. Schofield provided around 40% of the annual estimates. Thirdly, Stephens (1987) gave the percentage of illiterate brides and grooms between 1839 and 1885. His observations were partly annual available, sometimes with intervals of five years. Finally, in order to construct annual data from 1885 to the 1910s, Cressy's (1980) observations are used. Dates in the interval have been interpolated.

The use of literacy rates in constructing an educational attainment series has some limitations. First, as Schofield (1968) points out, data concerning the period before 1754 tends to be flawed due to its survival. Some geographic areas are overrepresented, whilst evidence of others tends to be scarce. Furthermore, these estimations are less reliable for women because of under registration. In the years ensuing 1754, observations refer only to the marrying population, and in addition, only to the age group between 20 and 29 (see Schofield, 1968 for an in-depth discussion of these disadvantages).

[12] Additionally, if the lower estimations are positively related to economic development, then the higher estimates will yield a positive relation as well.

Despite these restrictions, using literacy levels has one distinct advantage: it corrects for all the different kinds of elementary schooling during the early modern period. To follow Jewell (1998), there were ABC, song, reading and petty schools. These schools are not only recorded relatively weakly, many were less continuous than secondary schools were. Additionally, educational opportunities increased from 1750 onwards (Schofield, 1981; Williams, 1961). Sunday, writing, charity, monitorial, industrial and workhouse schools emerged during the late eighteenth century. Regarding charity schools, London and Westminister had 54 of these schools teaching 2000 pupils by the 1704. This increased to 179 schools teaching 7108 children by 1799 (Jewell, 1998). Finally, as Cressy (1980) stresses, there were several other ways for children to obtain literacy in early modern England. They could have learned it at churches, at work, or informally at home. Thus, by exploiting literacy rates, it is possible to assume that the English population obtained a certain level of education, regardless of all the different types of schools and the way in which it was achieved.

This raises the question on how high primary education levels should be set in this analysis. ABC, song and reading schools were concerned with reading, whilst charity and Sunday schools taught moral and religious courses. Concerning the latter, reading was often only a minor consideration (Schofield, 1981; Jewell, 1998). Not only did objectives differ between the diverse schools, length of time spent by pupils in school and the irregularity of their attendance disagreed as well (Schofield, 1968). Schofield (1968), Jewell (1998), Stephens (1987) and Cressy (1980) are all in agreement that children first learned to read, then they acquired some writing skills, and finally some basic mathematics. Pupils obtained advanced writing abilities at secondary schools. Nonetheless, since writing was taught at a later stage than reading, more people were able to read than could sign their name under marriage contracts (Stephens, 1987). The capacity to sign thus overestimates the number of spouses able to write, and underestimates the quantity to read at a basic level. As a result, following Schofield (1968), it gives a sufficient suggestion of the couples able to read easily. According to Jewell (1998), a pupil left elementary schooling after two or three years of education. Schofield (1968) and Cressy (1980) stress that children learned to read in approximately one and a half years. Taking this into account, this study sets literacy equal to two years of elementary schooling.

It is necessary to make a few exceptions to this elementary schooling level here. To start with, most secondary schools included the ability to sign one's name as an entry requirement. This tended to be a good indicator of a fair ability to read and write (Stowe, 1908; Stone, 1969). Additionally, Jewell (1998) states that these children went on to complete elementary schooling. It is therefore reasonable to presume that boys who entered into secondary schooling followed the elementary schooling programme, which lasted for three years. Those entering secondary education are therefore set at three years of elementary schooling. Subsequently, to follow Stone (1969), 'the eighteenth century was a period of growth rather than of stagnation, and the *quality* of literacy of a significant proportion of the population is evident in any comparison of the clumsy signatures in 1675 with the polished and flowing hands of 1775' (Pp. 129). This increase in the quality of signatures reflects the rise of basic educational opportunities in the eighteenth century (Stone, 1969; Schofield, 1981). The analysis allows therefore for an increase of one additional year of schooling between these 1675 and 1775.[13] Finally,

[13] For boys entering into grammar: I allowed for an increase from 3 to 3,5 years between 1675 and 1750, and from 3,5 to 4 years between 1750 and 1775. For those who did not entered into secondary schooling:

with respect to the nineteenth century, mass education became an important public issue in the British society (Lawson and Silver, 1973). Education became a nation-wide concern in which an obvious part was played by the English government (Selleck, 1968). Several Factory Acts and Elementary Education Acts were implemented that had to reduce working hours of children and increase school attendance. The 1860 Elementary School Code set the age of leaving elementary schools fixed at twelve, and the Elementary Education Act of 1870 introduced free and compulsory education for all children aged five to thirteen. Additionally, the Act of 1880 provided fines in cases where ten to thirteen year olds were illegally employed, and the Act of 1891 made elementary education free. As a result, school attendance, as well as average years of attendance, rose remarkably during the nineteenth century.[14] Attendance in weekday schools increased from 68% in 1870 to 82% in 1900. Hence, this analysis allows for an increase in average years of elementary education from 3 to 5.5 years.[15]

Elementary education opportunities arose around the age of five and closed again as children became occupied with work around the age of fifteen (Cressy, 1980; Jewell, 1980). Schofield (1968) states that 73% of the grooms and 70% of the brides were between 20 and 29 years old at time of marriage. This analysis facilitates a lag of fifteen years between primary education and marriage. Furthermore, it is then necessary to calculate annual numbers of children entering into primary schooling. Wrigley et al. (1997) provides percentages of the English population aged between five and fourteen for the 1540s to the 1870s. These estimations of Wrigley et al. are quite stable and increase from 21% during the sixteenth century to 22% in the 1870s. It is therefore assumed that 21% of the English population was aged between five and fourteen for the years prior to 1540. This has been set fixed at 22% for the years following 1870. Combining this with population estimates of Broadberry et al. (2011a; 2011b) and Jefferies (2005), and dividing this by ten[16], gives the absolute number of pupils enrolling into elementary schooling:

$$E^p_t = (\%L_{t+15})\frac{(\text{Aged 5-14}_t)(Pop_t)}{10} \qquad \text{(A.1)}$$

E^p = Number of pupils entering primary education in year t
%L = Literacy rate
Aged 5-14 = Percentage of population aged 5-14
Pop = Absolute population level
t = 1300-1900

The ability to calculate levels of literacy during the late Middle Ages is difficult at best, because of the lack of evidence. Literacy was foremost restricted to the clergy around 1300, but lay literacy began to rise in the late thirteenth century. England became more

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I allowed for an increase from 2 to 2.25 years between 1675 and 1750, from 2.25 to 2.5 between 1750 and 1775, and from 2.5 to 3 between 1775 and 1825.

[14] Average years of attendance rose from one year in 1835 to two years in 1851. Furthermore, in 1816 58% of the children attended *some* elementary school. This increased to 83% by the 1830s, to 90% in 1861 (Williams, 1961).

[15] 68% of the children attended weekday schools in 1870 and 82% in 1900. Assuming that these pupils stayed there for six years, the level of literacy has been set fixed at 5,04 years in 1870 and 5,46 years of education in 1900: [0.68(6) + 0.32(3)] = 5,04 and [0.82(6) + 0.18(3)]= 5,46. The level for pupils that did not enrolled into weekday schools is set fixed at three years of elementary schooling.

[16] It is necessary to obtain one instead of ten years in order to generate primary schooling numbers.

commercialized and economic specialization rose. Moreover, the growth of royal administration and common law required more and more laymen. It was thus necessary that the middle class obtained basic reading and writing skills (Thompson, 1960; Lawson and Silver, 1973; Briggs, 2000). Lawson and Silver (1973) mention that there were around 30.000 ordinary clergy, about 15.000 monks, canons and friars, and 7.000 nuns. If all these people were literate, then they accounted for only 1.5% of the population. When including lay civil servants, lay judges and some common lawyers, a part of the magnates, knights and leading burgesses, merchants and craftsmen, it brings the total to 3%.

The economy of Europe changed after the plague. With respect to England, rural cloth production arose during the fifteenth century and it became a significant producer of finished cloth. The growth in cloth enhanced the expansion of London (Graff, 1987). Moreover, church controlled education started to diminish after 1400 (Leach, 1915). As a result of this, as well it's improved trading position, literacy started to increase. Throughout the fifteenth century literacy in English and even knowledge of Latin spread among the nobility, gentry and the more prosperous trading class. There is also evidence of growing literacy among lower social groups (Lawson and Silver, 1973). Some men of lower status were attached to guilds. This improved their level of education, since reading and writing abilities were a prerequisite for entering one of the guilds. For example, male literacy rates reached 40% in London during the 1460s (Graff, 1987).

Female educational opportunities were particularly limited between 1300 and 1500 (Orme, 1973). Some women learned to read informally at home, others learned some basic skills at the orders of nuns and anchoresses. During 1200 until the reformation the amount of English nunneries remained at a constant 140 to 150 houses. The quantity of nuns attached to them differed. This is estimated at 3300 in the second half of the century, to just over 2000 after the Black Death (Orme, 1973).

In order to translate this into primary education levels, it was necessary to make several assumptions. First, it is assumed that 2.5% of the male population was literate by 1300. Secondly, this rate increased from 2.5% to 10% during the fifteenth century which matches Cressy's findings (1980). Moreover, this also reflects England's improved trading position and educational opportunities. Thirdly, with respect to female education, it is assumed that 0.75% of the women were literate around 1300. This decreased to 0.5% after the Black Death due to a decline in the number of nuns. Finally, this rose from 0.5% to 1% between 1400 and 1500. As a result, equation A.1 is used to calculate the number of pupils entering primary education during the late medieval period.

Secondary education – Grammar Schools

After finishing elementary schooling, pupils could enrol in grammar schools. Grammar schools differed from elementary schools due to Latin being part of the curriculum. Hence, it was required that children had obtained sufficient readings skills before entering into grammar. Pupils entered these schools when they were between eight or eleven years of age, and stayed there for six or seven more years. A superior number of boys must have obtained such an education level compared to girls, as they were simply not admitted to secondary education, regardless of their social class (Stowe, 1908; Stone, 1964; Jewell, 1998).

To compile data concerning secondary education, Orme (2006) offers a list of (endowed) schools between 1300 and 1530. His entries are based on references to a school, schoolhouse or a teacher. Of course, no detailed lists of schools were kept during this period, and Orme's information is therefore incomplete. Dates listed are the earliest ones encountered, and not a founding date unless explicitly mentioned. Nevertheless, it tends to be relatively reliable for the number of grammar schools, especially from the 1450s on. First of all, to follow Orme's list, there were 156 active institutions in 1480 and 234 of such schools by 1530. This more or less resemble the findings of Jordan (1959) who argues that there were 34 active grammar schools in ten counties in 1480, and thus 139 schools at the national level.[17] Additionally, Jewell (1998) and Stone (1964) mention that foundations for grammar schools were led all over the country at the beginning of the sixteenth century. This is well aligned with Orme's observations, since there is a clear increase visible in the number of school foundations from the late fifteenth century on. Secondly, most grammar schools listed are coupled to a date at which the specific institution was encountered in the records. Almost all of these schools became endowed during the late fifteenth century.[18] On the contrary, in the few cases when such institution remained non-endowed, it is assumed that it was active for 100 years. This is reasonable, since Vincent (1969) states that most of these schools had a continuing and long-lived tradition.

Jordan (1959), Vincent (1969) and Boucekkine et al. (2005; 2007) give numbers of school foundations between 1480 and 1660. To follow the calculations of Jordan, 305 endowed grammar schools were found during this period, as well as 105 schools that were not endowed. His estimates cover only ten of the 41 English counties. Assuming that the increase in these ten counties was equivalent to that at the national level, gives a rise of 1681 schools between these dates.[19] The amount of founded schools between 1480 and 1530 is subtracted from this number and the remaining part is added linearly up to the year 1660. Hence, there were 1839 active grammar schools by this specific year. This matches the findings of Vincent (1969) who states that there were between 1320 and 2000 of such institutions during the 1660s.

The list of Jordan seems an overstatement. If there were 1839 grammar schools, then 22975 pupils entered into grammar by 1660.[20] This means that more children entered secondary than primary schooling, since 18552 pupils went to elementary schools in 1660. As Stone (1964) mentions, Jordan (1959) included *all* educational institutions providing education beyond the elementary level. Hence, he overestimates the facilities for education in Latin grammar. On the other hand, Stone (1964) argues that Jordan's list is too short to give the overall picture of secondary schooling. Jordan ignored many private fee-paying institutions. Vincent (1969) states that 857 grammar schools, 301 private schools, and 63 private tutors sent boys up to the four Cambridge colleges between 1600 and 1660. To follow Stone (1964), this proliferation of little private schools means that the growth of secondary education at this period was far greater than the increase in Latin grammar schools would suggest.

Therefore Boucekkine's et al. (2005; 2007) estimations are used. They offer a list of endowed grammar schools that have been recorded by the School Inquiry Commission in 1868, which also gives their number founded per decade between 1480

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[17] There were 34 grammar schools in 10 counties according to Jordan (1959), which means that there were on average 3,4 grammar schools per county. Assuming an equal spread of these schools over the country, gives the result of 139,4 schools (i.e. 41 x 3,4).

[18] 35 of the 156 grammar schools had endowments by the year 1480. This increased to 116 out of 234 by the 1530s.

[19] There were 1250,5 endowed grammar schools, and 430.5 non-endowed institutions.

[20] These schools had a population level of approximately 75 children. Hence, (1838x75)/6 = 22975.

and 1870. One limitation is that this only covers the quantity of endowed schools and the ones that were still in existence by the 1870s. This list is therefore adjusted by taking the ratio of endowed and non-endowed schools that Jordan (1959) provides, and used to compile the increase in schools between 1530 and 1660.[21] A correction for the proliferation of private schools, as well as non-endowed grammar schools, is then captured by this ratio.

Estimations covering the period after 1660 are more problematic. Stone (1964), Vincent (1969), Simon (1960) and Lawson and Silver (1973) mention that many grammar schools declined after 1660. These schools became subject to a narrow church control after the restoration, since it continued to represent the conservative classical tradition of education (Simon, 1960; Lawson and Silver, 1973). Hence, it failed to meet the needs of the middle-class who was engaged into industry and commerce (Vincent, 1969). As Vincent shows, most of the boys who enrolled into Manchester Grammar School between 1740 and 1800 left to go into industry and commerce. Only 14% of these children went on to Oxford or Cambridge University. Additionally, the Latin grammar schools were affected by the competition of private teachers, private schools and the Academies. Pupils learned foreign languages such as French, Dutch and Spanish, as well as mathematics, whilst the grammar schools commenced into Latin Grammar. To follow Lawson and Silver (1973), among the more noteworthy developments of the eighteenth century was the rise of middle-class private schools offering an alternative training to that of grammar schools. Due to the growing middle-class demand for education, more private schools came into existence in the early nineteenth century.

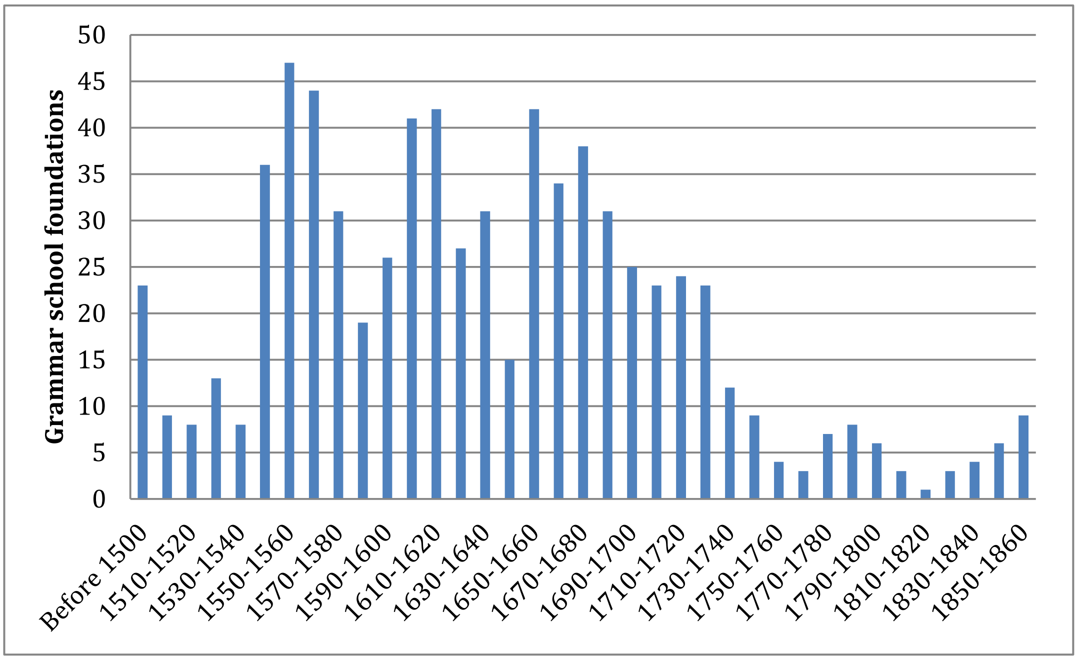
Between 1660 and 1720 the number of grammar schools sending boys to the four Cambridge colleges fell from 857 to 738, and the number of private schools decreased from 301 to 210. Additionally, this declined to 406 grammar schools and 130 private schools between 1720 and 1780 (Vincent, 1969). This decline is thus visible not only of the grammar schools, but also of the private classical schools. Consequently, the movement away from public secondary schooling was not compensated by a movement towards other forms of secondary education provided by the private enterprise (Vincent, 1969; Lawson and Silver, 1973). Boucekkine et al. (2005; 2007) provides the list of secondary schools as summarized by the School Inquiry Commission in 1868. To follow Owen (1964), 'of the roughly 3000 endowed schools, about 800 were of direct concern to the Commission as offering education beyond the elementary level' (Pp. 250). 500 were more than two centuries old and were supposedly classical grammar schools. Though, by the 1860s, 43% did not teach Greek or Latin, only 27% could be considered as classical schools, and fewer than 40 sent scholars up to Oxford and Cambridge (Owen, 1964).

The estimations of Boucekkine et al. (2007) are utilized once more to cover the number of secondary institutions after 1660. The number of institutions founded per decade between 1480 and 1870 are depicted in figure A1 below. As explained above, it underestimates the number of schools founded, since it only covers those that were still in existence by the 1860s. At the one hand, Stone (1964) and Vincent (1969) mention the sharp decline in Latin grammar schools after 1660. On the other hand, however, figure A1 depicts that only after the 1720s fewer secondary schools were founded. This matches Vincent's (1969) statistics concerning the number of grammar schools that sent boys to Cambridge, since there is a sharper deterioration visible between 1720 and

[21] Jordan (1959) mentions that there were 305 endowed and 105 non-endowed schools in ten English counties by the year 1660. This gives a ratio of 1.334.

1780 than between 1660 and 1720. Additionally, Stone (1964) is only concerned with Latin grammar schools that sent boys to one of the Universities. The list of the School Inquiry Commission captures any institution that offered education *beyond* the elementary level (Owen, 1964). Hence, those secondary schools founded between 1660 and 1720 are added linearly. As explained above, after 1720 fewer schools came into existence. The difference between the number of schools by the year 1720 and 1868 is linearly subtracted. Finally, Bolton (2007) mentions that there were 1590 public sector and grammar schools in the United Kingdom by the year 1905. This is adjusted such that it covers England.[22]

Figure A.1 – Number of school foundations per decade (1500-1860)



Stowe (1908) and Jewell (1998) give average number of pupils enrolled in grammar schooling. Jewell argues that grammar schools that had 100 or 150 pupils were common in early modern England. Stowe, however, offers a sample of 31 English grammar schools that were in existence between 1500 and 1600. The number of pupils per school varied greatly. Shrewsbury Grammar School taught 360 pupils by the year 1581, but only three children were attached to Penryn Grammar School. The average population of these 31 schools is 74. It is therefore presumed that the number attached to these institutions averaged 75. (This also corrects for the number of pupils that left secondary education without finishing the program.) Fewer children were attached to grammar schools during the Middle Ages (Parry, 1920; Orme, 2006). Hence, this analysis sets the number of pupils fixed at 50 during the early fourteenth century, and led this decline to 40 in order to cope with the consequences of the Black Death. I allowed for an increase to 50 between 1460 and 1480, which is in line with increases in the population

[22] The population level of the United Kingdom reached 38.328.00 by the year 1901. This means that there was a school for every 24.105 out of the population. The population level of England and Wales reached 32.612.000 by the early 1900s. Subtracting the population of Wales (i.e. two million) gives the population of England. It is then presumed that the ratio of schools to population was equivalent to that of the UK. This gives the result of 1353 grammar schools in England by the year 1905.

level. Thereafter it is assumed that the number of pupils increased from 50 to 75 between 1480 and 1530, which matches the rise in grammar schools at the end of the fifteenth century. According to Vincent (1969), the number of pupils attached to these institutions declined remarkably during the eighteenth century. I therefore allowed for a decrease from 75 to 50 between 1720 and 1800. Approximately 50 boys were attached to these institutions by 1868 (Owen, 1964). It is therefore presumed that the population levels remained constant at 50 pupils per school up to the 1860s. Finally, Bolton (2007) states that there were 178 pupils per school by the year 1909. The rise between 1868 and 1909 has been added linearly.

All these results have been combined into equation A2. The annual number of children enrolled in secondary schooling is a simple function of school population levels times the number of institutions. Dividing this by 6 gives the result.[23]

$$E^s_t = \frac{[(P_t)(S_t)]}{6} \qquad \text{(A2)}$$

E^s_t = Total number pupils enrolled in secondary education in year t.
P = Pupils per school
S = Number of Grammar schools

Higher education – English Universities

With regards to higher education, freshmen admissions to Oxford University and the University of Cambridge are taken from Stone (1974). His estimation spans the admissions in the period of 1500-1909 for Oxford, and 1550-1899 for Cambridge. Nevertheless, only decennial averages are offered. Stone points out, total decennial or annual admission to Oxford prior to 1660, are based on scarce data. He therefore utilized weights to correct for an underestimation of freshmen admissions. To be more specific, multipliers, as well as percentage corrections, are used to adjust the number of admissions to a B.A. degree for the period 1500-1730. With regards to estimated annual admissions to Cambridge, which also suffered from scarce data, corrections were required for the period 1550-1780.

The study of Stone also provides the number of decennial degrees granted in Oxford during the period 1500-1909. It not only gives the number of B.A.'s, but the number of B.D.'s, D.D.'s and M.A.'s granted as well. This made it achievable to distinguish between bachelor students who actually received a degree, and the number of dropouts. In addition, this makes it possible to distinguish between students that started a M.A., and those who left University after obtaining a bachelor's degree. Furthermore, to follow Stone, Oxford had two distinct groups of students enrolled in University since the sixteenth century. The first group opted for a career in the church or in teaching. They thus needed a bachelors degree. Though, the second group studied for a career in other professions, such as in secretary, accountancy, a public career in politics, a private career as country gentlemen, et cetera. These students came to Oxford for approximately two years, and used it primarily as a kind of finishing school. In doing so, weights for Oxford have been compiled with regards to bachelor students, dropouts and master students. The same set of weights is applied for enrolment in the University of Cambridge.

[23] It is necessary to obtain enrollment rates, and no population estimates as such.

In the 1820s, the basis was laid for the University of London. This University had to provide more progressive education for the middle class then Oxford and Cambridge did by the early nineteenth century. It offered laboratory science, modern languages, did not discriminate on religious grounds, and in 1878 the examinations were open to women for the very first time. More the point, women were not allowed to graduate at Oxford until 1920, or at Cambridge until 1923 (Lawson and Silver, 1973; Harte, 1986). Harte (1986) provides the number of graduates (men and women) between 1839 and 1900.

Observations for the Middle Ages are limited because of scant documentation. It was not until the mid fifteenth century that provisions were made for what we know as matriculation. Students entering one of the Universities were required to enter their names on a roll of a master, but not a single example of such roll survived. Moreover, there is no documentation related to Cambridge during the first half of the fourteenth century due to the plague, and no complete class list survived prior to 1575 (Leader, 1988). However, rough population estimates for both Universities are available. With respect to Oxford, Aston (1977) states that there were approximately 1500 students during the late thirteenth and early fourteenth century. This number fell to 1200 in 1400, to under 1000 by 1438, and increased to 1000 by the mid-fifteenth century. Concerning Cambridge, there were between 400 and 700 students by the year 1377, and between 755 and 810 in the middle of the fifteenth century (Aston et al., 1980).

Aston argues in his 1980 article that Oxford's student body reached levels between 1200 and 1700 during the 1450s, which contradicts the findings of his 1977 paper. It is known that only 20% of students entering University obtained a degree (Aston, 1977). This matches Stone's (1974) early modern period findings, since 19% to 25% obtained a bachelor's degree during the sixteenth century. Of those bachelor students 40% left after four years, and 60% enrolled in masters. Using these percentages, it became possible to calculate the number of freshmen during the middle ages.[24] If Oxford's student body reached 1700 by the 1450s, then Oxford attracted 782 freshmen a year, a level as high as during the late nineteenth century. Furthermore, other scholars (Jewell, 1998; Stone, 1964) argue that Oxford was greatly diminished and in decay at the end of the fifteenth century.

It was thus required to compare these findings and to make several assumptions. To begin with, I decided to take the lower population estimates for both Universities. This not only matches the findings of Stone (1974) for the early modern period, but is also aligned with research based on qualitative sources (i.e. Parry, 1920; Stone, 1964; Jewell, 1998). Secondly, assuming that Cambridge's population averaged 400 students by 1377. When interpolating the number of scholars attached to Oxford between 1300 and 1400, and taking into account that Cambridge was one third as large as Oxford during these years (Aston, 1977), gives a fair result.[25] Moreover, it is presumed that Cambridge's size averaged 782,5 during the 1450s, which is the average of Aston et al. (1980) estimates. Furthermore, Cambridge expanded between 1450 and 1500, and its

[24] The population of Oxford consisted of 1700 students. 80% of those students were 'dropouts', and 20% of these students obtained a B.A. or M.A. degree. 0,8 x 1700 = 1360 and 0,2 x 1700 = 340. This means that there were 1360 dropout students and 340 bachelor and master students. With respect to the latter, 40% left University after obtaining a Bachelor degree, whilst 60% stayed for three more years. Hence, the population consisted of 204 master students and 136 bachelor students. Bachelors stayed for 4 years, master students for 3 more years, and I assumed that dropouts stayed for two years. As a result, there were (1360/2)+(204/3)+(136/4) = 782 annual freshmen admissions.

[25] Oxford consisted of 1500 students by the year 1300 and 1200 students by 1400. Interpolating this, and assuming that Cambridge equalled 1/3 of Oxford, gives 400 as a result for 1377.

population approximated to that of Oxford by 1500 (Cobban, 1998). Finally, the interest lies in annual matriculations, and not population levels as such. Calculations have been performed to accomplish this.[26]

With respect to weights, it is presumed that a student who was not able to obtain a bachelor's degree had followed two extra years of education. Students that managed to obtain a bachelor degree, has been given a weight of four additional years. It was necessary to stay three more years at University to get a Master degree. Students who acquired such a level are therefore set at seven more years of education. With respect to women, those who graduated are set fixed at ten more years of education.[27] Finally, students who graduated at the University of London were given the weight of four additional years of schooling.

Educational attainment

In order to combine primary, secondary and higher education levels, it was necessary to take life expectancy into account. Harvey (1995) offers estimates covering life expectancy of the British cohort aged twenty (e^{20}) for 1395-1595. Wrigley and Schofield (1981) give life expectancy estimates for people that reached the age of 25 (e^{25}). This covers the years between 1640 and 1809. The estimates of Harvey are adjusted such that it provides life expectancy at the age of 25 instead of 20 in order to match the observations of Wrigley and Schofield (1981).[28] Dates between 1595 and 1640 have been interpolated. Furthermore, for the years prior to 1395 it has been assumed that this was equal to the 1395 level. Finally, Wrigley and Schofield gave life expectancy at birth (e^0) between 1541 and 1871 and Hicks and Allen (1999) provides this for 1901. These estimates are compared with e^{25}, and utilized to calculate the rise in e^{25} between 1810 and 1900.

As explained, children that entered into elementary schools did so when they were aged between five and eight (Stone, 1969) and stayed there for approximately two or three years before the 1680s. There were also other forms of schools that taught basic reading and writing skills. Generally speaking, opportunities to gain basic skills opened up when children were aged five and closed again when they became occupied at the age of fifteen (Jewell, 1998). It is therefore assumed that pupils were aged ten when finishing elementary schooling. Hence, this has been given the weight of life expectancy at the age of 10 (e^{10}). Additionally, pupils entered into grammar when they were between eight and eleven years old, and stayed there for six additional years (Stone, 1964; 1969). These children reached thus age levels between 15 and 18 when finished. It is therefore presumed that they were aged 17, and given life expectancy at the age of 17 (e^{17}). Finally, students entered one of the Universities when they were between 16 and 18 years old (Jewell, 1998), whereof it is decided to take the average of 17. As a result, dropouts left when they were aged 19, B.A.'s reached the age of 21, and M.A.'s that of 24. This has given the life expectancies e^{19}, e^{21}, and e^{24}.

Combining all of this results into equations A.3 and A.4,

[26] See the calculations in footnote 24.

[27] It is assumed that these women followed the required six years of secondary schooling before entering into University.

[28] It is assumed that life expectancy at the age of 20 equals to that of 25. Hence, if someone had 29 more years to live when aged 20, then this person had 24 more years when aged 25 (i.e. (20+29)-25 = 24).

$$E^{Men}_t = \frac{[(E^p_{t-2})(2)]e^{10} + [(E^s_{t-6})(6)]e^{17} + [(E^{Dr}_{t-2})(2)]e^{19} + [(E^{Ba}_{t-4})(4)]e^{21} + [(E^{Ma}_{t-7})(7)]e^{24}}{(0.5)Pop_t}, \quad (A.3)$$

$$E^{Women}_t = \frac{[(E^p_{t-2})(2)]e^{10} + [(E^{s,h}_{t-4})(10)]e^{21}}{(0.5)Pop_t}, \quad (A.4)$$

where $E^{s,h}_{t-4} = 0$ if $t < 1880$. Both formulas give average years of schooling of women, men and the overall population. For example, educational attainment of men in 1307 is a function of those who entered primary education two years before, those enrolled into grammar by 1301, the number of dropout students that embarked on a study in 1305, the amount of bachelor students that matriculated four years ago, and master students who started in 1300. Multiplying this with the average years of schooling and life expectancy, and dividing this by 50% of the population gives the result.[29]

Appendix B - Empirical Analysis

Several augmented dickey fuller tests are performed in order to test for the stationarity of the variables used (Wooldridge, 2000; Verbeek, 2008). The test results are depicted below. All variables, with an exception for parliamentary activity, are integrated of order one.

Table B.1 – Augmented Dickey-Fuller tests for first order unit root

Critical values

1%	-3.960
5%	-3.410
10%	-3.120

Variable	Test statistic	Unit root – I(1)
(ln)Y_t	-0.682	Yes
(ln)E^{Total}	-1.460	Yes
(ln)E^{Men}	-1.499	Yes
(ln)E^{Women}	-2.866	Yes
(ln)$E^{Men, higher}$	-1.304	Yes
(ln)$E^{Men, primary}$	-1.384	Yes
Patents	3.379	Yes
Parliament	-7.077	No

Table B.2 – Augmented Dickey Fuller tests for second order unit root

Critical values

1%	-2.580
5%	-1.950
10%	-1.620

[29] This assumes that 50% of the English population was of the male sex.

Variable	Test statistic	Unit root – I(2)
$(\ln)Y_t$	-24.900	No
$(\ln)E^{Total}$	-12.482	No
$(\ln)E^{Men}$	-12.907	No
$(\ln)E^{Women}$	-13.647	No
$(\ln)E^{Men, higher}$	-10.160	No
$(\ln)E^{Men, primary}$	-15.826	No
Patents	-18.642	No

It is possible that there exists a long-run relationship (i.e. co-integration) between time series when the variables are non-stationary. Several Johansen tests for co-integration have been performed. This test is based on maximum likelihood estimations and two statistics, i.e. maximum eigenvalues and trace-statistics. This is related to the rank of the matrix. If the rank is zero, then there is no co-integrating relationship, if the rank is one, then there is one, and if there are two, then two relationships persists, etc (Verbeek, 2008). The results are given below.

Table B.3 – Johansen tests for co-integration

Variable	Trace Statistic
$(\ln)E^{Total}$	5.4178
$(\ln)E^{Men}$	7.2394
$(\ln)E^{Women}$	7.0063
$(\ln)E^{Men, higher}$	9.9248
$(\ln)E^{Men, primary}$	7.6715

As these results reveal, it is not possible to reject the Null of having no rank (i.e. trace statistics < 15.41) and there is no co-integration between per capita GDP and the measures of educational attainment.

As explained in the main text, it was necessary to estimate the model with 2SLS. Using $(\ln)Y_{t-2}$ as an instrument for $\Delta(\ln)Y_{t-1}$ was not sufficient, since it does not satisfy the criteria of being a relevant instrument (i.e. its F-value was not larger than the 10). It was therefore necessary to include more than one instrument in these regressions. Hence, it was required to perform Sargan tests for over-identification. The results suggest no over-identification: (R^2 x Number of observations) < 3.84, where 3.84= $\chi^2_{(1; 0.05)}$.

The first stage regressions are depicted below:

Table B.4 – First stage regressions models 1 - 3
(Standard error between parentheses)

$\Delta(\ln)Y_{t-1}$	Model 1	Model 2	Model 3
$(\ln)Y_{t-2}$	-0.2763***	-0.2770***	-0.2774***

	(0.0442)	(0.0442)	(0.0441)
$(\ln)Y_{t-3}$	0.2419*** (0.0442)	0.2423*** (0.0442)	0.2435*** (0.0442)
$\Delta(\ln)E_t^{Total}$	-0.0122 (0.1038)	-	-
$\Delta(\ln)E_t^{Men}$	-	-0.0294 (0.1039)	-
$\Delta(\ln)E_t^{Women}$	-	-	-0.0339 (0.0649)
$Parliament_t$	0.0386** (0.0187)	0.0386** (0.0187)	0.0386** (0.0187)
$\Delta Patents_t$	0.5296 (0.3333)	0.5643 (0.3330)	0.6104 (0.3328)
Constant	0.2390*** (0.0905)	0.2412*** (0.0908)	0.2362*** (0.0901)
Observations	491	491	491
F-value	8.52***	8.54***	8.58***
Adjusted R^2	0.0713	0.0714	0.0718

*** Coefficient is significant at the 0.01 level
** Coefficient is significant at the 0.05 level
* Coefficient is significant at the 0.10 level

Table B.5 – First stage regressions models 4 - 6
(Standard error between parentheses)

$\mathbf{\Delta(\ln)Y_{t-1}}$	Model 4	Model 5	Model 6
$(\ln)Y_{t-2}$	-0.2519*** (0.0401)	-0.2519*** (0.0401)	-0.2543*** (0.0400)
$(\ln)Y_{t-3}$	0.2524*** (0.0401)	0.2524***	0.2549*** (0.0401)
$\Delta(\ln)E_t^{Total}$	0.0117 (0.0954)	-	-
$\Delta(\ln)E_t^{Men}$	-	0.0114 (0.0956)	-
$\Delta(\ln)E_t^{Women}$	-	-	-0.0440 (0.0601)
$\Delta Patents_t$	0.6146 (0.1640)	0.6141 (0.1640)	0.6186 (0.1640)
Observations	591	591	591
F-value	10.61***	10.61***	10.75***
Adjusted R^2	0.0611	0.0611	0.0619

*** Coefficient is significant at the 0.01 level
** Coefficient is significant at the 0.05 level
* Coefficient is significant at the 0.10 level

Table B.6 – First stage regressions models 7 - 10
(Standard error between parentheses)

$\Delta(ln)Y_{t-1}$	Model 7	Model 8	Model 9	Model 10
$(ln)Y_{t-2}$	-0.2569*** (0.0401)	-0.2513*** (0.0400)	-0.1896** (0.0809)	-0.2615*** (0.0463)
$(ln)Y_{t-3}$	0.2576*** (0.0402)	0.2518*** (0.0400)	0.1906** (0.0809)	0.2618*** (0.0463)
$\Delta(ln)E_t^{Men, primary}$	-0.1008 (0.0910)	-	-	-
$\Delta(ln)E_t^{Men, higher}$	-	0.0421 (0.0756)	0.800 (0.1072)	0.0573 (0.0062)
$\Delta Patents_t$	0.6289 (0.1638)	0.5604 (0.1642)	-	0.4939 (0.4626)
$\Delta(ln)Patents_t$	-	-	-0.0041 (0.0850)	-
Observations	591	591	150	441
F-value	10.94***	10.69***	3.38***	8.38***
Adjusted R^2	0.0630	0.0616	0.0596	0.0628

*** Coefficient is significant at the 0.01 level
** Coefficient is significant at the 0.05 level
* Coefficient is significant at the 0.10 level

Models 9 and 10 are tested for stationarity, co-integration and over-identification in a similar vein as above. All variables are integrated of order one. There is no co-integration between the variables and per capita GDP levels. Finally, the Sargan tests do not suggest over-identification.

Appendix C – Robustness checks

As explained in section VI, it is also possible to employ $\Delta(ln)Y_{t-2}$ as an instrument for $\Delta(ln)Y_{t-1}$ (Anderson and Hsiao, 1982). The difference of lagged per capita GDP is then instrumented by $(ln)Y_{t-2}$ - $(ln)Y_{t-3}$. Consequently, $\Delta(ln)Y_{t-1}$ is regressed on all the exogenous variables. Therefore:

$$\Delta(ln)Y_{t-1} = \mu_0 + \eta_1\Delta(ln)Y_{t-2} + \delta_3\Delta(ln)E_t + \phi_4\Delta Patents_t + \theta_5 Parliament_t + \varepsilon_t \quad (C.1)$$

The exclusion restriction is that $\Delta(ln)Y_{t-2}$ does not appear in equation 4.1. Equivalent estimations as in section IV have been performed. The results are shown below.

Table C.1 – 2SLS regression results 1307-1800
(Robust standard error between parentheses)

$\Delta(ln)Y_t$	Model 1	Model 2	Model 3
$\Delta(ln)Y_{t-1}$	0.7112** (0.2857)	0.7090** (0.2850)	0.7353*** (0.2867)
$\Delta(ln)E_t^{Total}$	0.2613* (0.1419)	-	-
$\Delta(ln)E_t^{Men}$	-	0.2882**	-

		(0.1390)	
$\Delta(\ln)E_t^{Women}$	-	-	0.0632 (0.0833)
$Parliament_t$	0.0025 (0.0204)	0.0041 (0.0205)	-0.0001 (0.0205)
$\Delta Patents_t$	0.2840 (0.3940)	0.2899 (0.3919)	0.3252 (0.3885)
Constant	-0.0017 (0.0046)	-0.0020 (0.0046)	0.0001 (0.0045)
Observations	491	491	491
Adj. R-square	0.0600	0.0600	0.0608
Prob >F	2.98**	3.20**	1.96*

*** Coefficient is significant at the 0.01 level
** Coefficient is significant at the 0.05 level
* Coefficient is significant at the 0.10 level
Notes: All regressions reported above are carried out with an intercept. The time trend is omitted, because it was not significant. Including a time trend does not alter the significance of the results above. The endogenous regressor is the log of real per capita GDP lagged for one period.

Table C.2 – 2SLS regression results 1307-1900
(Robust standard error between parentheses)

$\Delta(\ln)Y_t$	Model 4	Model 5	Model 6
$\Delta(\ln)Y_{t-1}$	0.7026** (0.2781)	0.7010** (0.2777)	0.7134*** (0.2776)
$\Delta(\ln)E_t^{Total}$	0.2550** (0.1262)	-	-
$\Delta(\ln)E_t^{Men}$	-	0.2712** (0.1264)	-
$\Delta(\ln)E_t^{Women}$	-	-	0.0810 (0.0781)
$\Delta Patents_t$	0.0300 (0.5100)	0.0245 (0.5131)	0.1327 (0.0527)
Observations	591	591	591
Adj. R-square	0.0580	0.0576	0.0567
F-value	5.05***	5.40***	3.21**

*** Coefficient is significant at the 0.01 level
** Coefficient is significant at the 0.05 level
* Coefficient is significant at the 0.10 level
Notes: All regressions reported above are carried out without an intercept. The time trend is omitted, because it was not significant. Including a time trend and/or an intercept does not alter the significance of the results above. The endogenous regressor is the log of real per capita GDP lagged for one period.

Table C.3 – 2SLS regression results 1307-1900
(Robust standard error between parentheses)

$\mathbf{\Delta(\ln)Y_t}$	Model 7	Model 8	Model 9	Model 10

			(1750-1900)	(1307-1750)
$\Delta(ln)Y_{t-1}$	0.6965** (0.2753)	0.7097** (0.2782)	0.5593 (0.6301)	0.7054** (0.2898)
$\Delta(ln)E_t^{Primary}$	0.1911 (0.1260)	-	-	-
$\Delta(ln)E_t^{Higher}$		0.1948** (0.0884)	-0.0065 (0.1049)	0.2467** (0.1057)
$\Delta Patents_t$	0.0829 (0.5219)	-0.1099 (0.5961)	-	-0.0714 (0.9403)
$\Delta(ln)Patents_t$		-	0.2629*** (0.0876)	-
Observations	591	591	150	441
F-value	3.91***	5.42***	3.98***	5.19***

*** Coefficient is significant at the 0.01 level
** Coefficient is significant at the 0.05 level
* Coefficient is significant at the 0.10 level
Notes: All regressions reported above are carried out without an intercept. The time trend is omitted, because it was not significant. Including a time trend and/or an intercept does not alter the significance of the results above. It does, however, change the results of model 9. The endogenous regressor is the log of real per capita GDP lagged for one period.

The general results do not change when using $(ln)Y_{t-2}$ - $(ln)Y_{t-3}$ as an instrument for the difference of lagged per capita GDP. On the other hand, it is not possible to interpret the results in model 9, since the coefficient of $\Delta(ln)Y_{t-1}$ becomes insignificant. The estimates in model 9 are therefore inconsistent.