Barriers to Prosperity: Parasitic and Infectious Diseases, IQ and Economic Development

Jakob B Madsen

Abstract:
IQ scores differ substantially across nations. This study argues that cross-country variations in IQ scores, to a large extent, reflect the burden of parasitic and infectious diseases (PID) and iron and iodine deficiency (IID) in infancy and in utero. Furthermore, it is shown that the prevalence of health insults, through the channel of cognitive ability, is influential for the level as well as the growth in productivity across the world. Using data for 115 countries and an instrumental variable approach, regressions reveal that the prevalence of PID-IIDs is influential for growth and income inequalities globally. Furthermore, the exclusion restriction in this paper is found to hold up against the institutional hypothesis of income inequality.

Key words: cross-country income inequality, parasitic and infectious diseases, cognitive ability
JEL Classification Numbers: O1, O3, O4

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Introduction

The relationship between health, growth and development is controversial. Some studies argue that health is important for income (Kalemli-Ozcan et al., 2000; Kalemli-Ozcan, 2002; Iyigun, 2005; Arora, 2001; Sachs, 2001; Soares, 2005; Chakraborty, 2004; Cervellati and Sunde, 2005; Zhang and Zhang, 2005; Lorentzen, McMillan and Wacziarg, 2008, Bloom, Canning and Fink, 2009; Andersen, Dalgaard and Selay, 2011), while others argue that the income effects of improved health are negative (Acemoglu and Johnson, 2007), small (Weil, 2007; Ashraf, Lester and Weil, 2008) or non-linear (see e.g. Cervellati and Sunde, 2011; Hansen, 2012).

This paper suggests that health is a crucial determinant of cross-country inequalities through the channel of cognitive skills. Referring to recent medical evidence showing that health in utero and early childhood is decisive for cognitive ability during adulthood (Heckman, 2007), this paper argues that the marked cross-country income inequality is a result of different exposures to parasitic and infectious diseases (PDIs) and the prevalence of iron and iodine deficiencies (IIDs). A high burden of PID-IIDs severely impairs average cognitive ability, which in turn can significantly and permanently reduce the quality of human capital. Since most of the brain’s development occurs from half way through pregnancy until a child reaches the age of two, this period is by far the most important for cognitive development (Niehaus, Moore, Patrick, Derr, Lorntz, Lima and Guerrant, 2002). Adequate development of the brain during infancy requires an adequate supply of energy and oxygen, bearing in mind that the brain in a newborn baby uses at least 87 percent of the body’s energy budget compared to only 20 percent in adulthood (Holliday, 1986; Drubach, 2000).

Most infants and young children in countries with a high prevalence of PID-IID carry one or more parasites in their body during most of their childhood, have frequent bouts of diarrhea and often suffer from IID (Watkins and Pollitt, 1997). Furthermore, the burdens from these diseases are often compounded by generally poor nutrition and, in some countries, malnutrition due to famine etc. Under these conditions children’s cognitive development is at risk from being impaired further by an inadequate energy supply to the brain while they are growing up. As shown in the next section, reduced cognitive ability due to PID-IID goes a long way in explaining why the average IQ in many tropical countries is often found to be below 70 (Lynn and Vanhanen, 2006).
Furthermore, this research suggests that the level and the growth in per capita income are strongly related to PID-IIDs through the channel of cognitive ability. Previous studies have demonstrated a positive relationship between cognitive ability and income or growth but have not investigated the reasons behind the differences in cognitive ability and have abstained from using external instruments. Using the Bayesian averaging of classical estimates approach, Jones and Schneider (2006) find IQ to be the most robust predictor of cross-country growth differences; however, due to the nature of their study, they did not investigate the underlying cause of IQ variations.

The hypothesis proposed in this paper extends the conventional explanation in which health insults have adverse economic outcomes due to high absence from work, reduced productivity, and low quantity and quality of educational attainment because of low focus at school, absence from school and low returns from investment in schooling (see for instance Gallup, Sachs and Mellinger, 1999; Sachs, 2001; Sala-i-Martin, 2005; Weil, 2007; Ashraf et al., 2008). Probably the study that comes closest to this research is that of Bleakley (2007), who finds that the hookworm eradication program in the US resulted in a marked relative, as well as an absolute, improvement in school enrollment, school attendance and literacy in counties that previously suffered from high rates of hookworm disease. Similarly, Brinkley (1997) finds that the increasing prevalence of hookworm infection goes a long way in explaining the marked decline in agricultural productivity in the Southern states of the US in the period 1860-1880. Finally, Carstensen and Gundlach (2006) show that malaria has been a more important factor behind cross-country economic inequalities than institutions.

This paper makes two contributions to the literature on growth and development. First, using four different indicators of cognitive ability it is shown that the burden of PID-IIDs in infancy and in utero is influential for cognitive abilities across nations. This issue is important since the alternative hypothesis in which cross-country variations in cognitive abilities are often attributed to schooling or inherited ability (see for example Lynn and Vanhanen, 2006), has completely different policy implications than the hypothesis of this paper. The influence of disease and other factors on IQ are discussed and tested in Sections 2 and 3. As a second contribution, the influence of PID-IIDs, through the channel of cognitive ability, on the level and the growth in per capita income is tested using various instruments (Section 4). It is shown that cognitive ability, through the channel of
PID-IIDs, goes a long way in explaining cross-country income inequalities.

Four sets of instruments are used for identification: 1) per capita foreign health aid to recipient countries; 2) pathogen (biological agent causing disease to its host) prevalence circa 1900; 3) pathogen prevalence circa 1940; and 4) ecozone variables representing the variety and density of pathogens. Health aid is a good instrument because, as demonstrated below, it is directed towards countries with the highest pathogen prevalence and yet it is likely to be strictly exogenous because other foreign aid indicators, which would perhaps be inversely related to per capita income, are uncorrelated with indicators of health insults as shown below. Pathogen prevalence circa 1900 and 1940 are likely to be exogenous and, at the same time, give an indication of the historical prevalence of pathogen stress. The key here is that cross-country per capita income inequality was not nearly as pronounced around 1900 and 1940 as it is today, as shown in Section 3.2, ensuring that pathogen prevalence, at that time, was unlikely to have been driven by income. Particular ecozone variables are useful instruments because pathogen prevalence, as argued in Section 3.2, is related to ecozones.

The next section discusses the medical evidence on the relationship between PID-IID and cognitive development in utero and during childhood, Section 3 tests for the influence of PID-IID on cognitive development and Section 4 shows the influence of PIID-IID on cross-country income and growth inequalities through the channel of PID-IID. A simultaneous equation system of income, IQ and PID-IID-stress is estimated and the alternative hypothesis that the exclusion restriction in this paper does not hold up against the institutional hypothesis, is examined in Section 5. Section 6 concludes.

2 PID-IIDs and cognitive development

Referring to recent medical and microeconomic research, this section argues that the burden of PID-IIDs is highly influential for cognitive development, where the most widespread PIDs are helminth (any parasitic worm), giardiasis (beaver fever), malaria, diarrhea, and tuberculosis (WHO, 2004). It is argued that the cognitive development of young children is highly sensitive to the presence of PIDs as their brains compete fiercely with parasites and the immune system over the energy supply, on which a child’s brain is so dependent. In addition to their direct effects some PIDs cause iron deficiency-induced anemia and impaired intestinal absorptive capacity that leads to malnutrition and exacerbates the cognitive decline (Ijaz and Rubino, 2012).
PIDs influence the brain and, therefore, cognitive development in several ways. First, some parasites feed off the host’s tissue and the tissue loss reduces the metabolic budget (Eppig, Fincher and Thornhill, 2010). Second, some parasites inhabit the intestinal tract and cause diarrhea, which in turn reduces the body’s energy budget (Eppig et al., 2010). Diarrheal disease is particularly important in this context because it is the second largest cause of death among children under the age of five in the high disease environments (WHO, 2004). Third, viruses use the host’s macromolecules and cellular machinery in their reproductive cycles, again limiting the host’s absorption of valuable nutrition (Watkins and Pollitt, 1997; Ijaz and Rubino, 2012). Furthermore, repeated bouts of enteric infections result in intestinal injury and, consequently, malabsorption during the critical first years of childhood (Ijaz and Rubino, 2012). This can have detrimental effects on growth and cognitive development that extend long beyond the infection (Ijaz and Rubino, 2012).

Fourth, to fight off an infection the mobilization of the host’s immune system will be at the expense of the energy budget (Watkins and Pollitt, 1997). Fifth, a toxicity effect of helminth leads to biochemical changes in the central nervous system (Holding and Snow, 2001). Sixth, changing behavior, such as loss of appetite due to excitation of the immune system, is observed in hosts being attacked by infectious diseases; thus preventing the intake of valuable energy (Holding and Snow, 2001). Seventh, tuberculosis meningitis injures the brain of many children in developing countries (Olness, 2003). Eighth, worms cause intestinal bleeding, resulting in loss of iron. This inhibits the formation of hemoglobin, which carries oxygen to the brain (Caulfield, Richard and Black, 2004).

PID aggravates the direct effects through malnutrition since a substantial proportion of malnutrition across the world is caused by impaired intestinal absorptive function resulting from multiple and repeated enteric infections (Ijaz and Rubino, 2012). Malnutrition often results in a reduction in brain size, and a reduction in the number of brain cells; both of which are associated with irreversible impaired cognitive ability (Strupp and Levitsky, 1995). In fact, several studies find that IQ can be reduced by approximately 10 points in children that have been exposed to long spells of malnutrition (for a survey, see Scrimshaw, 1998).

In the IID family iron deficiency anemia results in cognitive deterioration and the alteration of neurological functions as iron plays an important role in oxygen transportation and in enzymatic reactions (Scrimshaw, 1998). Iodine deficiency causes hypothyroidism, symptoms of which are extreme fatigue, goiter, mental retardation, and depression and is the leading cause of preventable
mental retardation (Felig and Frohman, 2001). IID during infancy and, particularly, *in utero* are highly influential for a child’s cognitive development because, as noted earlier, the brain is growing fastest during this time (Scrimshaw, 1998). Several studies find impaired cognitive abilities among children born to mothers who suffered from IID during pregnancy (Ma, Wang, Wang, Chen and Chi, 1988; Allen and Gillespie, 2001; Olness, 2003; Scrimshaw, 1998). Furthermore, Devlin, Daniels and Roeder (1997) find that maternal effects account for 20 percent of the IQ variation across individuals. This result suggests that a large variation in IQ scores can be attributed to fetal development in the womb, which, according to the discussion here, can be attributed to health insults before birth.

How severe are the potential PID-IID-induced cognitive problems across the world? Olness (2003) finds that approximately 780 million children under the age of 15 have significant cognitive limitations, which corresponds to a third of all children in the developing countries, where a large proportion of the cognitive limitations is caused by parasitic diseases, anemia, and malnutrition, particularly in infants and young children. Watkins and Pollitt (1997) find that children in the poorer areas of the tropics have, on average, 19 diarrheal episodes per year. Since persistent childhood diarrhea is associated with a 5 point lower IQ score in children tested between the ages of 6 and 10 (Niehaus *et al*., 2002), those living in areas with high disease prevalence are likely to be cognitively disadvantaged by this source. The cognitive effects from helminth are particularly severe due to their significant influence on cognitive development as discussed above and because they are widespread in tropical and subtropical regions (Eppig *et al*., 2010). It is estimated that 1.1 billion people around the world carry the hookworm in their gut, 1.5 billion people carry the one-foot long roundworm and 1.3 billion are affected by whipworm (Watkins and Pollitt, 1997).

Like PIDs, IID is globally prevalent. Hetzel (1986) estimates that six million people show signs of cretinism and even more have milder degrees of mental retardation or other neurological disorders due to iodine deficiency and WHO (2004) estimates that almost all these cases are concentrated in Africa and South East Asia. Based on meta-analysis of 18 studies, Bleichrodt and Born (1994) found that iodine and non-iodine deficient groups were 13.5 IQ points apart. Similarly, WHO (2004) finds iron deficiency to be widespread in the tropical zones and estimates that IID results in around one year of life lost in the tropics. Part of the reason why IIDs are more prevalent in the tropics than temperate areas is the greater incidence in the tropics of PID-induced reduced absorption of minerals in the digestive system. Furthermore, while most people in rich countries get sufficient iodine through
iodine-fortified salt, large fractions of the population in Africa, for example, do not have access to iodine fortified salt because they live as subsistence farmers and nomads without having any access to processed salt.

The finding in medical research that PID-IID reduces cognitive development gains support in the economic literature. Several microeconomic studies endorse the hypothesis that health in utero and early childhood is influential for economic and educational accomplishment in adulthood (Bleakley, 2007; Chen and Zhou, 2007; Cunha and Heckman, 2008; Almond, Edlund and Palme, 2009; Currie, 2009; Maccini and Yang, 2009; Cutler, Fung, Kremer, Singhal, and Vogl, 2010; Cunha, Heckman and Schennach, 2010; Currie, Stabile, Manivong and Roos, 2010; Almond and Currie, 2011).

Figure 1 shows the relationship between IQ and the natural log of infant mortality, where infant mortality is one of the PID-IID-stress measures used in the empirical section. The figure does not, of course, say anything about causality, but it does suggest that PID-IID is potentially influential for IQ. Furthermore, the graph shows that there is a huge cross-country variation in IQs, spanning 57 to 107. While one may dispute the accuracy of the IQ measure (discussed and tested below) the significant cross-country variation in cognitive abilities must have significant real economic consequences. How can a nation possibly function economically and politically if the average IQ is below 70 or so?

Note. The data on the horizontal axis are the natural log of infant mortality.

3 Cross-country relationships between cognitive ability and PID-IIDs

It has been argued above that PID-IID impairs cognitive development. However, the question is to what extent can the variation in the burden of PID-IIDs explain the considerable cross-country variation in cognitive ability prevails? This section examines the influence of the prevalence of
PID-IIDs on cognitive ability across countries while controlling for the feed-back effects from
cognitive ability to PID-IID.

Restricted and unrestricted versions of the following model are regressed:

\[
\ln IQ_i = \alpha_0 + \alpha_1 \ln \Omega_i + \alpha_2 EA_i + \alpha_3 \ln y_i + e_{1i},
\]

where \( IQ \) is cognitive ability, \( \Omega \) is the burden of PID-IID, \( EA \) is educational attainment among the
adult population in 2006, \( y \) is per capita income in 2006, the subscript \( i \) refers to country \( i \), and \( e_i \) is a
stochastic error term. Educational attainment and income are not instrumented because they are not
the focus variables and because there are no obvious channels through which \( EA \) and \( y \) influence \( IQ \).

Educational attainment and per capita income are included as regressors in the model to check
whether the significance of \( \Omega \) is influenced by potentially important omitted variables. The level of
education is included in the regression because educated parents are more likely to cater for their
child’s learning than uneducated parents or education elevates IQ – a claim that is rejected by Lynn
and Vanhanen (2006), arguing that IQ tests are independent of schooling. Per capita income is
included as a control variable to check how far the PID-IID stress hypothesis can be stretched. The
claim in this paper is that IQ approximately causes \( y \) and not the other way around and there is no
theory suggesting that income influences the level of IQ directly (Lynn and Vanhanen, 2006).
However, inclusion of \( y \) is a powerful check of the PIID-IID stress hypothesis because it will reveal
whether the PID-IID has an independent effect on IQ when the income effect is allowed for and,
therefore, whether a potential negative relationship between PID-IID and IQ is driven by a third
factor influence \( \Omega \) and per capita income simultaneously such as the quality of institutions etc.
Furthermore, a high income environment may be more conducive to the child’s learning and income
may proxy other factors that could influence the child’s cognitive development such as fertility and
mortality in general.

3.1 Data and measurement

3.1.1 Burden of PID-IID

The burden of PID-IID is proxied by the following five measures to ensure that the results are not
driven by the choice of health-insult index and that all aspects of PID-IID-insults are covered by the
data: the death rate due to PID-IIDs, infant mortality, the fraction of underweight childbirths, the contemporaneous pathogen prevalence rate (PID2003), and DALYs lost due to PID-IIDs for children under the age of 14, where DALY shows the number of years lost due to ill health and early death (in units of 1000).

The mortality rate due to PID-IIDs has the advantage of directly measuring the burden of PID-IIDs since the PID-IIDs death rates must be strongly positively correlated with the burden of PID-IIDs. The disadvantage of this measure is that it does not refer specifically to children but to the population at large and important diseases and micro mineral deficiencies, such as helminth, iron and iodine deficiencies are rarely fatal. The infant mortality rate refers directly to the number of infants that have been exposed to diseases, as morbidity and mortality, to a large extent, go hand-in-hand (Watkins and Pollitt, 1997; WHO, 2004). According to WHO (2004), the causes of infant mortality globally in 2002 were as follows: perinatal diseases (infection passed on from the mother to the fetus) (23%), acute respiratory infection (18%), diarrhea which is predominantly caused by PIDs (15%), malaria (11%), measles (5%), HIV (4%), and other (24%). Thus, infant mortality is likely to be highly correlated with the burden of PID-IIDs in utero and during infancy. Another advantage of this measure is that helminth and micro nutrition deficiency among mothers will influence the child’s survival probability during infancy (Scrimshaw, 1998; Holding and Snow, 2001).

The fraction of underweight newborn children is used as an indicator of health insults in utero. It is well documented that low birth weight reduces the strength of the immune system and is associated with poor neurosensory, cognitive, and behavioral development (Holding and Snow, 2001; Currie, 2009). Second, an HIV-infected mother often passes on the disease to her child during pregnancy (Gray, Adle-Biassette, Chretien, Lorin de la Grandmaison, Force and Keohane, 2001). The retrovirus family, of which HIV is a member, is known to cause neurological problems and has been found in the brain as early as 2 days after the initial infection (Gray et al., 2001). One-half of all children with HIV or AIDS have cognitive problems (Gray et al., 2001), as HIV can enter the brain and infect components known as neurons, which are vital for learning. Third, studies show that even mild iodine deficiency in utero influences fetal brain development as well as physical development and in the worst case, results in cretinism (Scrimshaw, 1998; Remer, Johner, Gärnter, Thamm and Kriener, 2010). Fourth, a malaria infected mother is likely to result in anemia to the fetus during a period of rapid brain development and this can also directly cause brain damage (Snow, Guerra, Noor,
The contemporaneous pathogen prevalence rate is used as a proxy for PID-IID because it measures the prevalence of pathogens directly. The measure for pathogen prevalence used here consists of the following PIDs: malaria, schistosomes (bilharzia), trypanosomes (causes sleeping sickness), typhus, filariae (caused by roundworms), leishmanias, and dengue. The data are constructed by Fincher and Thornhill (2008) and are coded on a three-point scale. The advantage of this index is that it allows for non-fatal morbidity such as helminth. The shortcoming of contemporaneous pathogen prevalence as an indicator of PID-IID is that micro nutritional deficiency is not allowed for in this index and, thus rules out a potentially important source of cognitive impairment.

The advantage of DALYs lost due to PID-IIDs for children under the age of 14 is that it gives an indication of the intensity of PID-IIDs among children. The shortcoming of this index is that it does not refer to infants but to children in general and that its size is also influenced by the time lost due to premature death, which is not directly relevant for the cognitive ability of surviving children.

3.1.2 Cognitive skills

Four measures of cognitive ability are used, again, to ensure that the results are not driven by the choice of the measure of cognitive ability. The first is the IQ measure of Lynn and Meisenberg (2010), $IQ^0$, where they have updated and extended the data collected by Lynn and Vanhanen (2002, 2006). To ensure that the data refer to the same year, they have adjusted it for the so-called Flynn-effect, which suggests that IQ is increasing over time. The tests are predominantly taken by a young age cohort – typically in the 7-15 year age group. Data for quite a few countries in the samples of Lynn and Vanhanen (2002, 2006) and Lynn and Meisenberg (2010) are interpolated using IQ test results for neighboring countries. These data are excluded from the estimates in this paper as they do not provide independent information. The IQ score benefits from being the most direct measure of cognitive ability. The shortcoming of this measure is that it is not always representative of the population at large, is dated for some countries and that the test method differs across countries.

A question that comes readily to mind is whether IQ tests are culturally fair and whether all dimensions of intelligence are measurable. Jones and Schneider (2006) have investigated the Lynn and Vanhanen (2002) data for biases in cultural values and other factors; but, they could not find
evidence of any biases. Furthermore, most of the IQ tests collected by Lynn and Vanhanen are non-verbal, culturally fair and culturally free (Lynn and Vanhanen, 2006, p 267). The most commonly used is Raven’s Progressive Matrix Test, which is non-verbal and involves solving a logical sequence and then deducing the next design from a number of given options (Lynn and Vanhanen, 2006, p 267). A number of IQ tests are also based on the Cattell Culture Fair Test where tasks are in design and picture format (Lynn and Vanhanen, 2006, p 268).

Another issue associated with IQ scores is that they only test problem solving ability and, as such, do not test for social skills, creativity and other attributes that are all parts of intelligence. However, Brehm and Rahn (1997) find that the level of social capital, such as social networks and the associated norms of reciprocity and trustworthiness is significantly positively related to cognitive ability measured by the GSS vocabulary test. Thus, IQ test scores are likely to be overall good indicators of cognitive abilities and the ability of individuals to produce effectively and to innovate and imitate – factors that are all essential for economic growth and development. However, whether IQ tests correctly measure true intelligence is not of key concern here, since the tests appear to be of great economic, practical and social importance.

The second IQ measure, \( IQ^4 \), utilizes the dataset provided by Wicherts, Dolan and Van der Maas (2010) and is used for Sub-Saharan African countries to accommodate the possibility that the IQ data provided by Lynn and Vanhanen are underestimated for Sub-Saharan Africa, while the dataset of Lynn and Meisenberg (2010) is used for all other countries. The third measure of cognitive ability, \( PISA \), is the average score of all international tests between 1964 and 2003 in mathematics and science among students in year 8 based on TIMSS and PISA assessments. Psychologists regard it as an excellent measure of cognitive ability among the broad population (see for discussion, Rindermann, 2007, Lynn and Meisenberg, 2010). Although this measure may be influenced by the quality of teaching, Bogetoft and Wittrup (2011) find that the quality of the school explains only five percent of the variation in PISA test scores among students in Danish schools.

Literacy is used as the final measure of cognitive ability, noting that educational attainment is controlled for in the regression to ensure that \( \Omega \) is not capturing education effects. UNESCO defines literacy as the “ability to identify, understand, interpret, create, communicate and compute, using printed and written materials associated with varying contexts” (UNESCO, 2004, p 13). Literacy is a useful indicator of cognitive ability from the perspective that schooling cannot render a cognitively
impaired child literate and children with high cognitive abilities can become literate without formal schooling. For example, despite the lack of a formal schooling system in the UK in 1750, Schofield (1981) finds a literacy rate of around 50 percent, suggesting that formal schooling is neither a necessary nor a sufficient condition for literacy. Furthermore, using numerous different data sets Marks (2010) finds a very strong correlation between IQ and literacy (the correlation coefficient is in the range of 0.78 to 0.98!).

3.2 Instruments for PID-IID

Regressing cognitive ability on various measures of the burden of PID-IIDs during childhood cannot reveal the direction of causality, particularly because richer countries are likely to have the resources to reduce the burden of PID-IID due to ready access to hospitals and doctors, better housing, clean water and sanitation, are better informed about health issues, and do not spread human remains.¹ Per capita foreign health aid to recipient countries (Aid), pathogen prevalence circa 1900 (PID1900), pathogen prevalence circa 1940 (PID1940), and ecozone variables representing the variety and density of pathogens (Eco) are used as four alternative instrument sets to cater for potential endogeneity of PID-IID.

Foreign health aid is likely to serve as a good instrument for the burden of PID-IID because health aid is given to countries that are most in need of health improvements and, at the same time, is unrelated to other factors that may influence cognitive skills of the recipient country including the level and quality of the educational system, the culture of learning etc. Hansen et al. (2013) show that hunger, starvation and infant mortality are the most important determinants of foreign aid. The philosophy behind the aid instrument is, to some extent, the same as the one used by Bleakley and Lange (2009) and Bleakley (2007), in which funds allocated to hookworm eradication in the Southern States of the US during the 1910s are instruments for the influence of hookworm infections on literacy, income and schooling.

Foreign health aid is highly likely to satisfy the exclusion restriction that cognitive ability is unrelated to foreign health aid through channels other than PID-IIDs. Importantly, neither institutions nor culture among the recipient countries can possibly influence cognitive ability through foreign

¹ Eppig et al. (2010) find a positive correlation between IQ scores can be explained by DALY due to PIDs among the entire population. However, they do not deal with endogeneity of the burden of diseases. Furthermore they use DALY for the entire population and not, as here, DALY of children below the age of 14.
health aid. An argument against the exclusion restriction is that foreign aid may be given to the poorest countries that for cultural and institutional reasons are trapped at low income levels and, as a result, have high pathogen prevalence. However, foreign aid for educational purposes or total foreign aid should be significantly correlated with PID-IID stress for this argument to be valid. Educational aid is, particularly, important here because it is the biggest foreign aid item and might influence cognitive ability directly or indirectly by lowering pathogen stress. However, neither of these variables was significant in the first round regressions and, consequently, rules out a finding that the exclusion restriction is invalid because foreign health aid affects cognitive ability through channels other than pathogen stress. Furthermore, the correlation between the quality of property right institutions in 2006 and foreign health aid is 0.23 and negative, suggesting that health aid is not flowing to the countries with the best property right institutions.

Data on PID1900 and PID1940, collected by Fincher and Thornhill (2008) and Murray and Schaller (2010), are constructed as a composite index of seven diseases as contemporary pathogen prevalence similarly to PID2003, as noted in Section 3.1.1. These indexes are likely to serve as good instruments for the current pathogen prevalence in that they capture the persistent fraction of pathogen prevalence that is not affected by the current level of income. Past pathogen prevalence, however, will not be a good instrument if the pathogen prevalence depends on the level of income and if global income inequality has been highly persistent. However, cross-country income inequality is much more pronounced today than a century ago as is evident from Maddison’s (2008) dataset. Based on the 69 countries in which per capita income data are available in 1870 the cross-country standard deviations (in parentheses) have progressed as follows: 1870 (737), 1900 (1146), 1950 (2407), 2006(9294). In natural logs the standard deviation has almost doubled over the period from 1870 to 2006. Thus, potential contemporary income-induced pathogen stress is absent from the pathogen prevalence data in 1900 and 1940. Furthermore, the consensus in the medical literature is that although income plays a role for health, its role has been secondary (Preston, 2007). In summary, the exclusion restriction is likely to hold for the historical pathogen prevalence indexes.

The following ecozone instruments are used for the burden of PID-IID: the minimum and maximum range of precipitation and the monthly minimum and maximum temperatures. Guernier, Hochberg and Guegan (2004) find that these instruments are good predictors of the overall distribution of pathogen species, indicating that pathogen species adapt best to regions with the
highest variations in precipitation and temperature, the conditions that are found in the tropics. Furthermore, Sachs (2001, p 17) argues that the crucial requirement for successful transmission of parasitic diseases such as malaria, trypanosomiasis (sleeping-sickness), and helminthic diseases between human hosts is a sufficiently high ambient temperature. Malaria requires at least 18 degrees centigrade for the anophelene mosquitoes to be effective. Gallup et al. (1999, p 196) note that the following diseases are endemic in zones with hot and humid weather while nearly absent elsewhere: many diseases carried by the mosquito (dengue fever, yellow fewer, malaria, lymphatic filariasis), mollusks (schistosomiasis), and other arthropods (onchocerciasis, leishmaniasis, trypanosomiasis, Chagas disease, visceral filariasis). Finally, Masters and McMillan (2001) find that cold temperatures reduce the prevalence of infectious diseases significantly.

Other geographic variables such as distance from the equator, the fraction of the population living in the tropics, and the Köppen-Geiger’s climate classification, which measures the fraction of various climates in each individual country would also be potentially good instruments for pathogen prevalence (in fact, many of these variables are significant determinants of PID-IID). However, since Köppen-Geiger’s climate classification consists of 16 sub-categories there is a high risk of spurious correlation and the efficiency of these instruments may suffer. More importantly, distance to the equator and the fraction of the population living in the tropics are often used as instruments with quite different identifying assumptions from those used here. The minimum and maximum range of precipitation and the monthly minimum and maximum temperatures are not subject to these criticisms.

3.3 First-round regressions

The $F$-tests of excluded instruments in the first-stage regressions are shown in the first five columns in Table 1. The coefficient estimates are not shown to preserve space and because all instruments have the expected sign, except for a couple of instances where the ecozone instruments are used. The $F$-tests are well in excess of the critical level of approximately 10 in all but two cases, implying that the instruments satisfy the criterion of PID-IID stress being highly correlated with them. Furthermore, the finding that all four instruments are consistently significantly correlated with the health insult variables, suggests that all instruments are capturing the disease environment well. Finally, the significance of foreign health aid is remarkable considering that the cross-country
dispersion, and therefore the identifying variation in the data, has been reduced substantially through the exclusion of the OECD countries (donor countries) from the sample.

### Table 1. First-round regressions (PID-IID stress indicators regressed on instruments).

<table>
<thead>
<tr>
<th>Dep. Var.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ecozone</td>
<td>14.3</td>
<td>F(5,109)=14.3</td>
<td>F(4,110)=20.1</td>
<td>F(4,109)=22.7</td>
<td>F(4,109)=60.6</td>
<td>F(4,100)=3.60</td>
</tr>
<tr>
<td>PID1900</td>
<td>3.72</td>
<td>F(1,53)=3.72</td>
<td>F(4,53)=21.8</td>
<td>F(1,48)=24.9</td>
<td>F(4,109)=91.5</td>
<td>F(1,53)=0.01</td>
</tr>
<tr>
<td>PID1940</td>
<td>35.1</td>
<td>F(1,111)=35.1</td>
<td>F(1,111)=163.1</td>
<td>F(1,111)=86.5</td>
<td>F(1,97)=80.5</td>
<td>F(4,107)=352</td>
</tr>
</tbody>
</table>

**Notes.** $F(x,y) = F$-test for excluded instruments, distributed as $F(x,y)$ under the null hypothesis that the instruments are jointly insignificant. Ω? = PID-IID.

A potential concern is that the instruments are capturing the general mortality rate (life expectancy at birth), therefore, the instruments do not capture PID-IID insults but non-commutable diseases that in turn are only spuriously related to IQ. To that end non-PID-IID mortality is used as a dependent variable in the regression in the last column in Table 1. The $F$-tests are substantially smaller than their counterparts in the other columns and do not exceed 10, suggesting that the instruments used in this paper have captured major aspects of PID-IID insults.

### 3.4 Estimation results of the structural model

The results of estimating Eq. (1), in which the coefficients of $EA$ and $y$ are restricted to zero, are shown in Table 2. The sample size differs across regressions because sample size differs between health-insult indicator and instrument and the maximum number of countries is included in each regression to gain maximum efficiency (the common sample for which all the variables are available is very small).

The estimated coefficients of $\Omega$ are highly significant determinants of $IQ^*$ and have the right sign regardless of whether PID-IID is measured by DALY due to PID-IID insults among children below the age of 14, mortality due to PID-IID insults, PID2003, the percentage of underweight newborns, or infant mortality, regardless of which instrument is used and whether the model is estimated by OLS (first row) or 2SLS (rows 2-5). Thus, the results are very robust to the choices of PID-IID-insult indicator and instrument. The $t$-ratio exceeds 5 in 21 of the 25 cases and $0.64 > R^2 > 0.39$ in the OLS estimates,
suggesting that PID-IID-stress in utero and during infancy is an important determinant of IQ.

Table 2. 2SLS/OLS estimates of $\Omega$ (Eq. (1)).

<table>
<thead>
<tr>
<th>Ind. Var.</th>
<th>$\Omega$-DALY</th>
<th>Infant Mort.</th>
<th>$\Omega$-Mort.</th>
<th>% Underweight</th>
<th>PID2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instr. Set</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None (OLS)</td>
<td>-0.062</td>
<td>-0.004</td>
<td>-0.065</td>
<td>-0.008</td>
<td>-0.098</td>
</tr>
<tr>
<td></td>
<td>(13.3)</td>
<td>(14.0)</td>
<td>(13.3)</td>
<td>(7.93)</td>
<td>(9.06)</td>
</tr>
<tr>
<td></td>
<td>$N=113$</td>
<td>$N=115$</td>
<td>$N=115$</td>
<td>$N=99$</td>
<td>$N=115$</td>
</tr>
<tr>
<td></td>
<td>$R^2=0.62$</td>
<td>$R^2=0.64$</td>
<td>$R^2=0.61$</td>
<td>$R^2=0.39$</td>
<td>$R^2=0.41$</td>
</tr>
<tr>
<td>Health aid</td>
<td>-0.076</td>
<td>-0.135</td>
<td>-0.074</td>
<td>-0.014</td>
<td>-0.436</td>
</tr>
<tr>
<td></td>
<td>(5.50)</td>
<td>(5.36)</td>
<td>(4.32)</td>
<td>(3.27)</td>
<td>(1.58)</td>
</tr>
<tr>
<td></td>
<td>$N=76$</td>
<td>$N=76$</td>
<td>$N=76$</td>
<td>$N=63$</td>
<td>$N=73$</td>
</tr>
<tr>
<td>Ecozone</td>
<td>-0.010</td>
<td>-0.128</td>
<td>-0.087</td>
<td>-0.013</td>
<td>-0.113</td>
</tr>
<tr>
<td></td>
<td>(7.18)</td>
<td>(10.5)</td>
<td>(9.43)</td>
<td>(6.14)</td>
<td>(7.18)</td>
</tr>
<tr>
<td></td>
<td>$N=115$</td>
<td>$N=115$</td>
<td>$N=115$</td>
<td>$N=115$</td>
<td>$N=111$</td>
</tr>
<tr>
<td>PID1900</td>
<td>-0.057</td>
<td>-0.090</td>
<td>-0.077</td>
<td>-0.010</td>
<td>-0.082</td>
</tr>
<tr>
<td></td>
<td>(6.09)</td>
<td>(6.70)</td>
<td>(5.20)</td>
<td>(5.20)</td>
<td>(3.64)</td>
</tr>
<tr>
<td></td>
<td>$N=55$</td>
<td>$N=55$</td>
<td>$N=55$</td>
<td>$N=50$</td>
<td>$N=111$</td>
</tr>
<tr>
<td>PID1940</td>
<td>-0.062</td>
<td>-0.125</td>
<td>-0.084</td>
<td>-0.015</td>
<td>-0.114</td>
</tr>
<tr>
<td></td>
<td>(5.23)</td>
<td>(10.9)</td>
<td>(9.09)</td>
<td>(7.01)</td>
<td>(8.36)</td>
</tr>
<tr>
<td></td>
<td>$N=113$</td>
<td>$N=113$</td>
<td>$N=113$</td>
<td>$N=99$</td>
<td>$N=109$</td>
</tr>
</tbody>
</table>

Notes. The numbers are parameter estimates of the coefficient of $\Omega$, where the figures in parentheses are absolute $t$-statistics. The dependent variable is $IQ^o$ from Lynn and Meisenberg (2010) excluding the countries in which they have interpolated the data. $N =$ number of observations. A constant is included in the regressions. The coefficients of $EA$ and $y$ are restricted to zero, so the regressions are only simple bivariate relationships between $IQ^o$ and $\Omega^o$. $\Omega$-Mort. = the death rate due to PID-IIDs, infant mort. = infant mortality, $\%$ underweight = the fraction of underweight childbirths, PID2003 = the contemporaneous pathogen prevalence rate, and $\Omega^o$-DALY = DALYs lost due to PID-IIDs for children under the age of 14.

The regressions in Table 3 include control variables and use various alternative measures of cognitive skills. Eco and PID1940 are used as instruments for $\Omega$ because these instruments have the broadest country coverage. However, the principal results remain unaltered if PID1900 and Aid are used as instruments for $\Omega$. Consider first the regression in the first column in which mortality rates due to non-PID-IID, Non-$\Omega$, along with PID-IID, $\Omega$, are included in the regression. The parameter estimate of $\Omega$ remains almost unaffected by the inclusion of Non-$\Omega$ and the coefficient of Non-$\Omega$ is insignificant at the five percent level. This result suggests that cognitive ability is not impaired by diseases in general but only by PID-IIDs and, as such, rules out the possibility that a third factor, which is correlated with the burden of diseases in general but unrelated to cognitive ability, is the
underlying force behind the relationship between PID-IID and income as investigated below.

**Table 3. IV estimates of Eq. (1).**

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dep Var.</strong></td>
<td>IQ⁰</td>
<td>IQ⁰</td>
<td>IQ⁰</td>
<td>Lit</td>
<td>PISA</td>
<td>IQ¹</td>
</tr>
<tr>
<td><strong>Ω-Measure</strong></td>
<td>Ω-Mort.</td>
<td>Ω-Mort.</td>
<td>DALY14</td>
<td>DALY14</td>
<td>DALY14</td>
<td>DALY14</td>
</tr>
<tr>
<td>Ω</td>
<td>-0.09(12.4)</td>
<td>-0.06(6.21)</td>
<td>-0.001(5.26)</td>
<td>-0.001(3.05)</td>
<td>-0.08(5.58)</td>
<td>-0.06(10.2)</td>
</tr>
<tr>
<td>Non-Ω</td>
<td>0.07(1.76)</td>
<td>0.01(0.23)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ln(y)</td>
<td>0.01(0.79)</td>
<td>0.01(0.66)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EA</td>
<td>0.01(2.92)</td>
<td>0.02(4.25)</td>
<td></td>
<td></td>
<td></td>
<td>0.02(2.94)</td>
</tr>
<tr>
<td>EA⁰</td>
<td></td>
<td></td>
<td></td>
<td>0.026(1.96)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>114</td>
<td>114</td>
<td>113</td>
<td>67</td>
<td>96</td>
<td>111</td>
</tr>
</tbody>
</table>

**Notes.** The instruments used for Ω are minimum and maximum temperature and rainfall and PID prevalence in 1940. Educational aid is used as an instrument for educational attainment. IQ⁰ is the data from from Lynn and Meisenberg (2010) (the same data as used in Table 2). IQ¹ = alternative data are from Wicherts et al. (2010) for the Sub-Saharan countries and the rest of the data are from Lynn and Meisenberg (2010). Non-Ω is deaths due to all causes other than PID-IIDs. EA⁰ = the fraction of the population with primary education.

Adding educational attainment and per capita income to the regressions yields the regressions in the second and third columns in Table 3. The coefficients of Ω remains highly significant while the coefficient of Non-Ω is insignificant reinforcing the results in the first column that the significance of Ω does not reflect that Ω proxies the general disease environment and, thus, rule out that a third variable is causing the hypothesized relationship between PID-IID, IQ and income. The coefficients of income are insignificant at any conventional significance levels, which is a very important and strong result because it shows that PID-IID is influencing IQ in its own right and does not proxy a variable that affects IQ and, at the same time, is highly correlated with per capita income.

The coefficient of educational attainment is statistically significant and positive in both regressions; however, this result may be spurious, noting that instruments have not been used for educational attainment because there is no obvious relationship between IQ and education and because a proper instrument strategy requires that school enrollment is instrumented and, subsequently, transformed to educational attainment; a strategy that is not practical since the educational attainment data are mostly based on census surveys. Bils and Klenow (2000), for example, show that education is highly endogenous in growth regressions. However, educational attainment becomes insignificant if educational aid is used as an instrument for education in the regression in the second (third) column, where the F-test for excluded instruments in the first-round
is $F(1,72) = 10.8 (11.2)$. Importantly, even if education is significant in some of the regressions the coefficients of $\Omega$ remain highly significant.

Alternative measures of cognitive skills are used in the regressions in the last three columns in Table 3 and PID-IID is measured by DALY due to PID-IID for children under the age of 14. Education is not included in the PISA regression in the last column since only students that are enrolled in the schooling system are tested and income is omitted from all three regressions because it was consistently insignificant. The coefficients of $\Omega$ remain highly significant when alternative measures of IQ are used for the Sub-Saharan African countries and when cognitive skills are proxied by either literacy or PISA test results. These results remain unaltered if PID-IID is proxied by infant mortality, percentage of underweight newborns, and PID2006 and the coefficients of $\Omega$ Remains highly significant and often more significant than those in Table 3 (the results are not shown). These results reinforce the results in Table 2 and, more importantly, show that the results in Table 2 are neither driven by the IQ scores in low and middle income countries (PISA-sample consists mostly of high-income counties) nor middle and high income countries (literacy-sample consists predominantly of low income countries).

Finally, the results in column 4 in which literacy is used as a dependent variable show that literacy is driven predominantly by $\Omega$. The coefficient of the proportion of the population with primary education ($EA^p$) is only significant at the 10-percent level – not at the 5-percent level. The low significance of $EA^p$ is a remarkable result in the light of literacy often being considered as an indicator of educational attainment.

4 The nexus between income and cognitive ability
To establish a link between PID-IID and income or growth the following two income models are regressed:

$$\Delta \ln y_i = \beta_0 + \beta_1 IQ_i^p + \beta_2 Z_i + \beta_3 \Phi_{i,pop} + \beta_5 \ln y_{i0} + \varepsilon_{2,i},$$

(2)

$$\ln y_i = \gamma_0 + \gamma_1 IQ_i^p + \gamma_2 Z_i + \varepsilon_{3,i},$$

(3)

where $y$ is per capita income or TFP in purchasing power parity (PPP), $g_{pop}$ is the population growth rate, $Z$ is a vector of control variables, $y_0$ is initial per capita income or TFP, the subscript $i$ stands for country $i$, and $\Phi_i$ is the adjusted land share for country $i$ and is defined as $\Phi_i = \beta_i / [1 - \alpha(1 - \beta_i)].$
where $\alpha$ is capital’s income share, which is set to 0.3, and $\beta$ is the income share going to land and is measured as the share of agriculture in total GDP. Oil producing countries are excluded from the sample because their high per capita income does not reflect value added but rather their exploitation of non-renewable resources. These countries are Bahrain, Equatorial Guinea, Gabon, Iran, Iraq, Kuwait, Oman, Saudi Arabia and the United Arab Emirates. The derivations of the models are available from the author. TFP is estimated using a homogenous Cobb-Douglas production function consisting of capital and labor as inputs and labor’s income share is set to 0.7.

Growth as well as level equations are estimated because cognitive ability can have level as well as growth effects and because productivity growth rates are sensitive to the estimation period. Easterly, Kremer, Pritchett and Summers (1993), for example, show that productivity growth rates are highly unstable over time and find cross-decadal correlations of 0.1-0.3. Thus, in addition to level estimates, the growth model is estimated in the periods 1970-2006 and 1820-2006 to ensure that the results are not driven by the choice of estimation period. The estimation period 1970-2006 is, to a large extent, dictated by data availability and the desire to have a large sample. While per capita income is available from 1960 for some countries, the number of countries for which data are available increases substantially after 1970. The period 1820-2006, which is rarely used in regressions, covers the period of human history in which the bulk of growth has taken place. Per capita income of the richest countries exceeded that of the poorest by a factor of less than three in 1820 compared to around 50 times today.

The 1820-2006 sample not only includes contemporary rich Western countries but also contemporary middle income and poor countries such as Brazil, Chile, China, India, Jordan, Egypt, Indonesia, Iran, Jamaica, Morocco, Malaysia, Mexico, Nepal, the Philippines, South Africa, Sri Lanka, Syria, Thailand, and Venezuela. Therefore, there is a sufficiently large identifying variation in the data. As the IQ data are measured in 2002 an objection to regressing over the period 1820-2006 is that IQ has been increasing over time in developed countries (Lynn and Vanhanen, 2006). However, if the ranking of the average IQ over the period 1820-2006 between countries has been constant, then the regression results using 2002 IQ data will be the same as using averages over the period 1820-2006. If, on the other hand, the ranking has changed over the 1820-2006 period, the estimated coefficients of IQ will be biased downward even further and, thus, give evidence against the PID-IID-stress hypothesis.
Cognitive ability has potential productivity growth effects through the ideas production function and level effects through the production function. The growth effects occur when ideas production is conditional on the level of IQ above a certain benchmark that is required for the creation of new ideas and they become permanent if there are constant returns to the stock of knowledge in the ideas production function. The level effects stem from the quality of human capital in the goods production function, and an increase in cognitive ability increases per capita output following the predictions of several classes of neoclassical and endogenous growth models. The initial per capita income is included in the growth model to allow for conditional convergence or the deviation of income from its steady state. Finally, $\Phi_{g,pop}$ is the population growth drag effect in which population growth reduces per capita income growth due to diminishing returns introduced by land as a non-reproductive factor of production.

The following control variables are included in the regressions following the findings of Barro and Sala-i-Martin (2004) and Sachs (2001). First, Coast, which measures the fraction of land within 100 kilometers of the coast, proxies the access to trade routes and the extent to which a country is landlocked (Sachs, 2001). Second, $IY$, which is measured as the investment ratio in 2006, is included to allow for transitional dynamics and the income effects of the $K-Y$ ratio, noting that $IY$ and the $K-Y$ ratio are proportional along the balanced growth path. Third, $OP$ is the Sachs-Warner openness indicator in 1990 (Sachs and Warner 1995) and measures the extent to which a country has access to the world market. This variable is based on tariffs, black market premiums, whether the country is socialist, and governments’ involvement in exports. Fourth, $EA$, which is measured as educational attainment among the adult population in the year 2006, is potentially important for the level and growth in the same way as cognitive ability.

Fifth, Exec, measures constraints on executives in 1990 (Acemoglu, Johnson and Robinson, 2001) and measures the quality of institutions. This variable is not only important from the perspective that Acemoglu et al. (2001) finds it to have been the crucial determinant of growth but also because they argue that the quality of institutions in non-European countries was determined by European settler mortality centuries ago. Since PID prevalence and settler mortality are positively correlated an alternative hypothesis to that posed here is that disease prevalence influences growth through the quality of institutions. Note, however, that the positive correlation between the settler mortality data from Acemoglu et al. (2001) and health aid is very weak ($r = 0.23$), which renders
foreign health aid a particularly good instrument for disease prevalence because the exclusion restrictions are likely to hold. The correlation coefficient between settler mortality and PID1900 is 0.32, between settler mortality and PID1940 is 0.38 and between settler mortality and the ecozone variables is 0.32. Thus, although the correlation is statistically significant it is not high.

Why is cognitive ability potentially important for productivity and why did Jones and Schneider (2006) find IQ to be the most robust predictor of cross-country growth differences among variables that are considered in growth regressions? Microeconomic studies typically find that an increase in IQ by one percent is associated with an increase in earnings of approximately 1 percent (see, for a survey, Jones, G., 2011). Thus, in the absence of externalities cognitive skills can at most account for 50 percent of cross-country income differences. However, like the creation of great ideas the externalities associated with cognitive skills are likely to be enormous. First, small differences in worker skill will have large macro effects because weak links in the production process will have economy-wide repercussions. Kremer (1993) and C. Jones (2011) argue that often, one small error in the production process can drastically destroy the value of final output. In an O-Ring world, Kremer (1993) shows that lower worker quality means a multiplicative increase in errors across the spectrum of production. Furthermore, Jones, C. (2011) shows that an input-output-linked chain is only as strong as its weakest link and, therefore, problems at any point in a production chain can reduce output significantly if inputs enter production in a complementary fashion. Thus, if there are numerous weak links in the production process due to a significant proportion of the workforce that have low cognitive skills, the models of Kremer (1993) and C. Jones (2011) predict that productivity will be much lower than predicted by individual earnings functions.

Second, Bloom et al. (2009) find that bad management among firms in developing countries is responsible for large productivity differences between rich and poor countries and it is plausible that bad management is related to cognitive abilities given that Bloom et al. (2009) find that complex organizations are particularly badly managed. Similarly, Gennaioli, La Porta, Lopez-de-Silanes and Shleifer (2013) present a model in which human capital plays a key role in entrepreneurial and managerial productivities. Third, several studies demonstrate that delay discounting is inversely related to IQ (Heckman, 2007, Shamosh and Gray, 2008, G. Jones, 2011). In other words people with low cognitive abilities tend to have a high time-preference and, therefore, prefer smaller and earlier rewards to larger, later ones. Consequently, we would expect savings and investment in R&D to be negatively related to low cognitive skills. Using the same reasoning we would expect youngsters
with lower cognitive abilities to invest less in schooling because of their high time-preference and because their returns from investment in schooling are lower than for their counterparts. Finally, Botero, Ponce and Shleifer (2012) find that more highly educated countries have better governments because educated individuals are more likely than uneducated individuals to complain about misconduct by government officials. Using the same line of reasoning it is plausible that more cognitively capable populations are likely to be associated with better governance.

4.1 Instruments

Instruments are again used to deal with endogeneity and errors-in-variables problems. The instrument sets used for PID-IIDs in the previous section are used for cognitive ability in the income regressions. The exclusion restriction implied by the IV regressions here is that income is unrelated to ecozone, health aid or historical PID prevalence through channels other than cognitive ability. The implied restriction for historical PID prevalence and ecozone characteristics may not hold if they influence income through institutions – a channel that is tested, and ruled out, in the next section. It is much harder to argue against the health aid channel exclusion restriction since health aid is given to the countries that are most in need of health improvements and is quite independent of institutional and cultural factors as shown in the next section.

4.2 Empirical estimates

4.2.1 Growth Regressions

First consider the growth regressions in the period 1820-2006 in columns 1-6 in Table 4. Control variables are excluded from these regressions because they are not available over the relevant period and it is unlikely that the cross-country ranking of the recent data for IY, OP and EA has been constant the whole way back to 1820. In the simple OLS regression in the first two columns in which per capita income growth is regressed on IQ only, the coefficient of IQ is statistically highly significant regardless of whether IQ is logged (first column) or unlogged (second column), suggesting that the IQ rankings across countries are likely to have been relatively constant over the past couple of centuries. IV regressions of the full growth model are presented in columns 3-6. The coefficients of the initial income are in most cases negative and significant, indicating that $\beta^2$-convergence has taken place among countries over the period considered. The coefficient of the
Population growth drag is negative and significant as predicted by the theory, suggesting that population drags growth down in countries in which land is a significant fixed factor of production. Since $\Phi_{g_{pop}}$ is on average 0.0012 in the sample used it has contributed to an annual growth drag of 0.22% based on the coefficient estimate of 1.63 (second column). The population growth drag has been largest for Nepal where it has dragged growth down by 0.93 percent annually.

The coefficient of $IQ^o$ is quite significant in all the IV-regressions (columns 4-8). The significance of IQ in explaining growth over such a long period is a remarkable result because it shows that IQ has been a potential important driving force behind the Great Divergence that started around two centuries ago and in which some countries took off while others either failed to grow significantly or experienced a delayed modernization. The significance of $IQ^o$ in the regressions not only shows that the results are robust to the choice of instrument but also that the results are robust to the country sample, which is highly dependent on the choice of instrument. The significance of $IQ^o$ is, particularly, remarkable for the regression in column 5 in which health aid is used as an instrument considering that the country sample is reduced to 21 as the OECD countries are omitted.

Table 4. Growth regressions: IV estimates of Eq. (2).

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2*</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dep. Var.</td>
<td>$Y/L$</td>
<td>$Y/L$</td>
<td>$Y/L$</td>
<td>$Y/L$</td>
<td>$Y/L$</td>
<td>$Y/L$</td>
<td>$Y/L$</td>
<td>TFP</td>
</tr>
<tr>
<td>Inst/OLS</td>
<td>OLS</td>
<td>OLS</td>
<td>ECO</td>
<td>PID1940</td>
<td>PID1900</td>
<td>AID</td>
<td>OLS</td>
<td>OLS</td>
</tr>
<tr>
<td>$\ln(IQ^o)$</td>
<td>0.03 (6.78)</td>
<td>0.0003 (6.49)</td>
<td>0.03 (3.42)</td>
<td>0.04 (3.60)</td>
<td>0.06 (3.60)</td>
<td>0.05 (2.24)</td>
<td>0.05 (5.42)</td>
<td>0.03 (4.11)</td>
</tr>
<tr>
<td>$\ln{y0}$</td>
<td></td>
<td>-0.004 (5.24)</td>
<td>-0.006 (6.18)</td>
<td>-0.006 (4.79)</td>
<td>-0.001 (0.45)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Phi_{g_{pop}}$</td>
<td>-1.63 (2.88)</td>
<td>-1.71 (2.89)</td>
<td>-1.06 (1.76)</td>
<td>-0.44 (1.08)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>-0.12 (5.59)</td>
<td>-0.016 (3.40)</td>
<td>-0.08 (2.11)</td>
<td>-0.13 (2.59)</td>
<td>-0.22 (3.02)</td>
<td>-0.20 (2.12)</td>
<td>-0.21 (4.83)</td>
<td>-0.14 (3.91)</td>
</tr>
<tr>
<td>$N$</td>
<td>44</td>
<td>44</td>
<td>44</td>
<td>43</td>
<td>31</td>
<td>21</td>
<td>96</td>
<td>89</td>
</tr>
</tbody>
</table>

Notes. The numbers in soft parentheses are absolute t-statistics. $F$(ex. res.) = $F$-test for excluded restrictions from the first-round regression and the degrees of freedom are presented in the squared brackets. $N$ = number of observations. Oil producing countries are omitted from the sample. Growth and population growth are measured in decimal points.

*: $IQ^o$ is unlogged (second column).
Economically, the estimated coefficients of $IQ^o$ are significant. A 10 percent increase in IQ is associated with a 0.3 percentage point increase in the annual growth rate over the period 1820-2006. Note that the contribution of $IQ^o$ to growth cannot be directly read from the model by multiplying $IQ^o$ and its coefficient since an IQ below a certain benchmark level does not contribute to growth. Supposing that the true model is given by $\Delta \ln y = b(h - \overline{h})$, where $b$ is a constant and $h$ is cognitive ability and $\overline{h}$ is the benchmark level of $h$ which is required to create new ideas, new templates and innovations. Assuming that $\overline{h}$ is fixed it can be recovered from regressing growth on $IQ^o$ and a constant term so that $\overline{h} = -\hat{\alpha}/\hat{\beta}$ where $\hat{\alpha}$ is the estimated constant term and $\hat{\beta}$ is the slope coefficient. Recovering $\overline{h}$ from the regression in the second column in Table 4, in which $IQ^o$ is unlogged, yields the number of approximately 53; suggesting IQ’s contribution to growth is 1.3 percent (the average annual growth in sample is 1.44 percent).

Turning to the estimates in the period 1970-2006, the simple bivariate OLS regressions in the last two columns in Table 4 show that the coefficients of cognitive ability remain highly significant. Unrestricted estimates of Eq. (2) in the period 1970-2006 using instruments are presented in Table 5. All the $F$-tests of excluded restrictions exceed 20, highlighting that these are good instruments from the perspective of the strength of the correlation between $IQ^o$ and the instruments. The coefficients of $IQ^o$ are consistently highly significant in the regressions; thus reinforcing the finding that the $IQ^o$ is an important and robust determinant of growth. Furthermore, the coefficients are quite stable across estimates showing that the results are robust to choice of instrument set, country sample, productivity measurement and inclusion of control variables.

Considering the other variables in the regressions the coefficients of initial income are all negative and significant, indicating $\beta$-convergence. The coefficients of $\Phi g_{pop}$ are also consistently significantly negative showing that population growth is a drag on productivity growth in agrarian economies. Note that the population growth drag also applies to the TFP regressions since land has not been incorporated into the estimates of TFP. The coefficients of openness, landlockedness, constraints on executives and educational attainment are all insignificant in regressions in which control variables are included in the regression (last column in Table 5). Constraints on executives remained insignificant if it is measured in 1960, 1970, 1980, or 2000, noting that $Exec$ is measured in
1990 in the regressions in Table 5. The insignificance of these variables does not mean that they are all unimportant for growth, just that they do not have permanent growth effects. The coefficient of the investment ratio is significant and has the expected positive sign, suggesting that there are positive growth externalities to investment; however, it is only significant at the five percent level if TFP growth is the dependent variable, showing that the growth effects of investment may not be that strong (results are not shown).

Table 5. Growth regressions, 1970-2006: IV estimates of Eq. (2).

<table>
<thead>
<tr>
<th>IV set</th>
<th>PID1900</th>
<th>PID1900</th>
<th>Aid</th>
<th>Aid</th>
<th>Eco.</th>
<th>Eco.</th>
<th>PID1940</th>
<th>PID1940</th>
<th>Aid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ln((IQ^o))</td>
<td>0.08(2.87)</td>
<td>0.08(3.46)</td>
<td>0.13(6.35)</td>
<td>0.09(4.98)</td>
<td>0.07(4.62)</td>
<td>0.06(5.17)</td>
<td>0.06(3.70)</td>
<td>0.06(4.34)</td>
<td>0.08(3.19)</td>
</tr>
<tr>
<td>(lny_0)</td>
<td>-0.01(3.48)</td>
<td>-0.01(4.51)</td>
<td>-0.02(8.05)</td>
<td>-0.02(8.28)</td>
<td>-0.01(6.02)</td>
<td>-0.01(7.59)</td>
<td>-0.01(5.47)</td>
<td>-0.01(6.32)</td>
<td>-0.02(8.63)</td>
</tr>
<tr>
<td>(\Phi_{g,pop})</td>
<td>-3.36(2.47)</td>
<td>-2.87(3.64)</td>
<td>-3.68(5.24)</td>
<td>-2.50(4.49)</td>
<td>-3.62(5.71)</td>
<td>-2.51(5.30)</td>
<td>-3.50(4.96)</td>
<td>-2.68(4.80)</td>
<td>-3.55(5.46)</td>
</tr>
<tr>
<td>((Ln((IQ^o))^2))²</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.004(2.51)</td>
</tr>
<tr>
<td>Ln((IY))</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.004(2.55)</td>
</tr>
<tr>
<td>OP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.000(0.61)</td>
</tr>
<tr>
<td>Coast</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.000(0.17)</td>
</tr>
<tr>
<td>Exec</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-1.00(1.57)</td>
</tr>
<tr>
<td>EA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.000(0.73)</td>
</tr>
<tr>
<td>Constant</td>
<td>-0.23(1.83)</td>
<td>-0.25(2.54)</td>
<td>-0.37(3.94)</td>
<td>-0.24(2.97)</td>
<td>-0.16(2.83)</td>
<td>-0.15(3.36)</td>
<td>-0.15(2.03)</td>
<td>-0.15(2.80)</td>
<td>-0.27(2.47)</td>
</tr>
<tr>
<td>N</td>
<td>46</td>
<td>46</td>
<td>65</td>
<td>58</td>
<td>96</td>
<td>88</td>
<td>94</td>
<td>87</td>
<td>65</td>
</tr>
</tbody>
</table>

Notes. See notes to Table 4. Estimation period: 1970-2006. \(Coast\) = the fraction of the population living within 100 km of the coast, \(IY\) = investment-income ratio, \(OP\) = Sachs-Warner index of openness, \(Exec\) = constraints on executives (coefficient multiplied by 1000), and \(EA\) = educational attainment among the adult population.

The squared cognitive ability is also included as an additional regressor in the regression in the last column in Table 5. The coefficient of \([\text{Ln}(IQ^o)]^2\) is significant at the 1-percent level and is statistically significantly positive at the five percent level if it is added to the regressions in columns 1-8 in 2/3 of the cases (results are not shown). From this it follows that the growth effects of \(IQ^o\) are increasing with the level of \(IQ^o\). This result makes perfect sense in that a relatively high cognitive ability is required to innovate. While people with an IQ of 100, for example, can create new ideas, these are probably not going to move the frontier, while researchers with IQs of 140 are much more likely to come up with significant new ideas.
4.2.2 Productivity level regressions

Estimates of Eq. (3) are presented in Table 6. TFP regressions are not shown because the results are almost identical to per capita income regressions. The coefficients of $IQ^O$ are highly significant in all regressions, independent of the choice of instrument set and dependent variable, suggesting that cognitive ability is not only influential for growth but also for the level of productivity. Cognitive ability has probably gradually improved the level of technology over time and has ensured that the countries with the highest cognitive skills have been able to develop new technologies as well as imitate the technology developed in other countries faster and better than countries with relatively lower cognitive abilities. Economically the coefficients of $IQ^O$ are also significant. A 10 percent increase in IQ increases per capita income by around 60 percent. This means that if the country with the lowest IQ was elevated to the country with the highest IQ it would increase its income level by approximately 500 percent; thus cognitive ability is an important determinant of cross-country income differences.

<table>
<thead>
<tr>
<th>Instruments</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>$ln(IQ^O)$</td>
<td>5.87(11.1)</td>
<td>6.81(3.02)</td>
<td>7.49(5.18)</td>
<td>4.04(4.64)</td>
<td>5.88(6.83)</td>
</tr>
<tr>
<td>Coast</td>
<td>6.82(3.02)</td>
<td>0.15(0.62)</td>
<td>0.88(3.08)</td>
<td>0.69(2.86)</td>
<td></td>
</tr>
<tr>
<td>OP</td>
<td>0.26(3.03)</td>
<td>-0.22(1.88)</td>
<td>0.22(2.94)</td>
<td>0.30(3.94)</td>
<td></td>
</tr>
<tr>
<td>EA</td>
<td>0.07(1.42)</td>
<td>0.06(2.09)</td>
<td>0.11(3.39)</td>
<td>0.10(3.19)</td>
<td></td>
</tr>
<tr>
<td>Exec</td>
<td>-0.02(0.20)</td>
<td>-0.025(0.57)</td>
<td>-0.10(2.06)</td>
<td>-0.08(2.20)</td>
<td></td>
</tr>
<tr>
<td>$ln(I/Y)$</td>
<td>0.27(2.03)</td>
<td>-0.02(0.20)</td>
<td>0.06(0.56)</td>
<td>0.10(0.90)</td>
<td></td>
</tr>
<tr>
<td>$N$</td>
<td>107</td>
<td>50</td>
<td>69</td>
<td>107</td>
<td>105</td>
</tr>
</tbody>
</table>

Notes: see notes to Table 5. The dependent variable is the log of per capita income.

The coefficients of constraints on executives are consistently negative and either insignificant or marginally significant; thus reinforcing the results from the productivity growth regressions. Since the growth experience in the period 1970-2006 is only a snapshot of countries’ growth experiences $Exec$ was also included as a regressor in the 1820-2006 estimates (the results are not shown); however, it was insignificant at any conventional significance levels. Thus, overall it seems that the
quality of institutions measured by constraints on executives is not a robust determinant of cross-country income differences. This is consistent with the results of Glaeser, La Porta, Lopez-de-Silanes and Shleifer (2004) and Albouy (2012).

Among the other control variables the Coast, OP and EA are significant in most cases and have the expected signs, suggesting that countries that are landlocked, relatively closed and with an uneducated population have a developmental disadvantage; however, not a growth disadvantage since the Coast-variable was insignificant in the growth regressions in the previous sub-section. The finding that educational attainment has no growth effects but only level effects makes sense in that individuals with basic primary and, perhaps also secondary education do not innovate and, therefore, are not pushing the frontier with new inventions. Educated individuals are much more likely to render production more efficient than uneducated individuals, through improved communications and by improving the weak links in the production process.

5. System regressions and the role of institutions
Thus far it has been shown that PID-IIIs influence cognitive ability, which, in the second round, affects the level and growth in productivity. This section goes a step further by estimating the IQ and income models as a simultaneous system. Furthermore, it tests the PID-IID-stress hypothesis against the institutional hypothesis of Acemoglu et al. (2001) in which diseases among the European settlers influence economic development through the imposition of institutions. Thus, the prevalence of diseases could influence income through institutions as well as through cognitive skills.

Eqs. (1) and (3) are estimated as a simultaneous system using 3SLS. Cognitive ability, $IQ^*$, and constraints on executives in 1990, Exec, as used by Acemoglu et al. (2001), are the independent variables in the per capita income regression and PID-IID DALY, infant mortality, percentage of underweight births, PID2006 or mortality due to PID-IID are used as regressors in the IQ model. The models are kept as parsimonious as possible because further regressors will require additional instruments in 3SLS regressions and, more problematically, one cannot tighten a particular instrument to a particular regressor. The following two instrument sets are used because the model is underidentified if only one instrument is used: 1) PID1900 and ECO; and 2) PID1940 and Aid. The first set comes closest to the settler mortality hypothesis of the two instrument sets in that the historical disease environment was vital for settlements.
Table 7. 3SLS estimates of Eqs. (1) and (3) including institutions.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ω-meas</td>
<td>DALY</td>
<td>Inf Mor.</td>
<td>Weight</td>
<td>Ω - Mort.</td>
<td>PID2006</td>
<td>DALY</td>
<td>Inf Mor.</td>
<td>Weight</td>
<td>Ω - Mort.</td>
</tr>
<tr>
<td>Inst.</td>
<td>PID1900 / Eco</td>
<td>PID1900 / Eco</td>
<td>PID1900 / Eco</td>
<td>PID1900 / Eco</td>
<td>PID1900 / Eco</td>
<td>PID1900 / Aid</td>
<td>PID1900 / Aid</td>
<td>PID1900 / Aid</td>
<td>PID1900 / Aid</td>
<td>PID1900 / Aid</td>
</tr>
<tr>
<td>IQo</td>
<td>6.39 (3.3)</td>
<td>7.00 (3.4)</td>
<td>6.69 (3.2)</td>
<td>5.05 (2.2)</td>
<td>6.05 (2.7)</td>
<td>8.48 (2.5)</td>
<td>7.66 (1.7)</td>
<td>7.85 (2.9)</td>
<td>6.18 (2.8)</td>
<td>15.6 (4.1)</td>
</tr>
<tr>
<td>Exec</td>
<td>0.14 (1.1)</td>
<td>0.52 (1.1)</td>
<td>0.68 (1.4)</td>
<td>0.82 (0.2)</td>
<td>0.71 (1.4)</td>
<td>-0.62 (0.8)</td>
<td>-0.46 (0.2)</td>
<td>-0.92 (2.4)</td>
<td>0.08 (0.2)</td>
<td>-1.87 (2.1)</td>
</tr>
<tr>
<td>LHS</td>
<td>IQo</td>
<td>IQo</td>
<td>IQo</td>
<td>IQo</td>
<td>IQo</td>
<td>IQo</td>
<td>IQo</td>
<td>IQo</td>
<td>IQo</td>
<td>IQo</td>
</tr>
<tr>
<td>Ω</td>
<td>-0.07 (7.4)</td>
<td>-0.11 (8.5)</td>
<td>-0.01 (5.7)</td>
<td>-0.09 (6.7)</td>
<td>-0.10 (6.7)</td>
<td>-0.09 (9.9)</td>
<td>-0.17 (7.8)</td>
<td>-0.01 (3.9)</td>
<td>-0.12 (5.1)</td>
<td>-0.14 (5.2)</td>
</tr>
<tr>
<td>Non-Ω</td>
<td>0.05 (0.57)</td>
<td>0.05 (0.57)</td>
<td>0.05 (0.57)</td>
<td>0.05 (0.57)</td>
<td>0.05 (0.57)</td>
<td>0.05 (0.57)</td>
<td>0.05 (0.57)</td>
<td>0.05 (0.57)</td>
<td>0.05 (0.57)</td>
<td>0.05 (0.57)</td>
</tr>
<tr>
<td>N</td>
<td>50</td>
<td>50</td>
<td>45</td>
<td>50</td>
<td>48</td>
<td>59</td>
<td>59</td>
<td>54</td>
<td>59</td>
<td>56</td>
</tr>
</tbody>
</table>

Notes. The dependent variable is per capita income in 2006. See notes to Table 4.

The 3SLS results, which are presented in Table 7, show that PID-IID is influential for income through the channel of cognitive ability and, thus, reinforce the findings in Sections 3 and 4. The coefficients of Ω are significant at the one percent levels in all cases in the IQ-regressions and the coefficients of IQo in the income regressions are all significant at conventional significance levels and significant at the one percent level in 80% of the cases. Furthermore, the magnitude of the coefficients of IQo and Ω is similar to, or slightly above, the single equation estimates, suggesting that the sizes of the coefficients are robust to model specification and estimation method. Finally, the coefficients of Non-Ω are insignificant in the regressions in columns 4 and 9, again showing that non-PID-IID diseases do not affect IQ; only PID-IID.

The coefficients of Exec are insignificant except in one case in which it is negative, indicating that PID-IID does not influence income through the quality of institutions but through cognitive skills. Interestingly, however, if IQo is omitted from the income equation the coefficients of Exec become consistently highly significant, signifying that the exclusion restriction maintained by Acemoglu et al. (2001) does not hold. Finally, if Exec is omitted from the system estimates the coefficient of IQo, unsurprisingly, becomes statistically much more significant than if Exec is included in the regressions (Table 8).

In this context it is worth revisiting North Korea and Botswana, which are often emphasized as
examples of how bad institutions (North Korea) lead to low income while good institutions (Botswana) result in high income. These examples appear to contradict the PID-IID-stress hypothesis because one should expect high income in North Korea and low income in Botswana. However, North Korea’s disease environment is not significantly different from that of Sub-Saharan Africa: no less than 17.6% of newborns are underweight and only 63% of the population has access to clean water (World Development Indicators). Furthermore, South Koreans in the 1963 birth cohort (the last year that the data are available) are 9.5 cm taller than their northern counterparts, clearly indicating that the North Koreans have grown up in an environment with malnutrition and a high prevalence of PID-IID. The spectacular income growth in Botswana since the discovery of diamonds in 1966 is almost entirely due to the expansion of the high-productivity mining-extraction-industry and not due to economy-wide productivity gains. Jerven (2010) shows that productivity growth has been dismal in the non-mining sector since 1965 and that income inequality is, today, very pronounced, suggesting that Botswana would be placed among the low income countries in the world did it not have the support of the mining sector. Thus, the examples of North Korea and Botswana are also consistent with the PID-IID-stress hypothesis.

Table 8. 3SLS estimates of Eqs. (1) and (3).

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inst. PID1900/</td>
<td>PID1900/</td>
<td>PID1900/</td>
<td>PID1900/</td>
<td>PID1900/</td>
<td>PID1900/</td>
<td>PID1900/</td>
<td>PID1900/</td>
<td>PID1900/</td>
<td>PID1900/</td>
<td>PID1900/</td>
</tr>
<tr>
<td>Eco</td>
<td>Eco</td>
<td>Eco</td>
<td>Eco</td>
<td>Eco</td>
<td>Eco</td>
<td>Eco</td>
<td>Eco</td>
<td>Eco</td>
<td>Eco</td>
<td>Eco</td>
</tr>
<tr>
<td>ΔIQ</td>
<td>8.0</td>
<td>8.64</td>
<td>9.05</td>
<td>7.9</td>
<td>8.47</td>
<td>8.09</td>
<td>7.81</td>
<td>7.29</td>
<td>7.25</td>
<td>10.1</td>
</tr>
<tr>
<td></td>
<td>(7.6)</td>
<td>(8.5)</td>
<td>(10.2)</td>
<td>(7.3)</td>
<td>(7.8)</td>
<td>(6.4)</td>
<td>(6.1)</td>
<td>(5.7)</td>
<td>(6.4)</td>
<td>(9.2)</td>
</tr>
<tr>
<td>LHS</td>
<td>ΔIQo</td>
<td>ΔIQo</td>
<td>ΔIQo</td>
<td>ΔIQo</td>
<td>ΔIQo</td>
<td>ΔIQo</td>
<td>ΔIQo</td>
<td>ΔIQo</td>
<td>ΔIQo</td>
<td>ΔIQo</td>
</tr>
<tr>
<td>ΔΩ</td>
<td>-0.07</td>
<td>-0.11</td>
<td>-0.01</td>
<td>-0.09</td>
<td>-0.10</td>
<td>-0.07</td>
<td>-0.15</td>
<td>-0.01</td>
<td>-0.11</td>
<td>-0.07</td>
</tr>
<tr>
<td></td>
<td>(7.8)</td>
<td>(9.0)</td>
<td>(6.0)</td>
<td>(6.8)</td>
<td>(6.9)</td>
<td>(6.2)</td>
<td>(4.6)</td>
<td>(4.0)</td>
<td>(4.9)</td>
<td>(3.5)</td>
</tr>
<tr>
<td>Non-ΔΩ</td>
<td>0.06</td>
<td>(0.65)</td>
<td>1.10</td>
<td>(0.65)</td>
<td>0.06</td>
<td>(0.65)</td>
<td>1.10</td>
<td>(0.65)</td>
<td>0.06</td>
<td>(0.65)</td>
</tr>
<tr>
<td>N</td>
<td>50</td>
<td>50</td>
<td>45</td>
<td>50</td>
<td>48</td>
<td>59</td>
<td>59</td>
<td>54</td>
<td>59</td>
<td>56</td>
</tr>
</tbody>
</table>

Notes. The dependent variable is per capita income in 2006. See notes to Table 4.

The results in Tables 7 and 8 are consistent with a large body of literature on disease and growth. For example, based on cross-country growth regressions Sala-i-Martin, Doppelhofer and Miller (2004) and Carstensen and Gundlack (2006) find that malaria is the single most important growth deterrent.
Surveying a large literature on health at birth, test scores and earnings, Currie (2009) finds a strong consensus that poor health in childhood is strongly negatively related to earnings and cognitive ability later in life. Furthermore, Currie (2009) finds that an individual with very good health during childhood earns 24 percent more than its sibling with poor health during childhood. Finally, Birchenall (2010) finds that income in 1500, proxied by impressive monuments, was strongly negatively related to pathogen stress and argues that the pathogen stress lowered income through ethnic diversity; a result that has gained recent support by Cervellati, Sunde and Valomri (2011).

6. Conclusion
This paper has argued that cognitive skills are influential for the growth and development experience (s) across countries and that cognitive skills differ substantially across countries, predominantly because of variations in PID-IID-stress in utero and during childhood. Health aid, ecozone, and PID prevalence in 1900 and in 1940 were used as four alternative instrument sets for contemporaneous PID prevalence, based on the exclusion restriction that these variables influence the level and growth in productivity only through the channel of IQ.

The empirical results gave consistently strong support for the PID-IID-stress hypothesis and the F-tests for excluded restrictions, in the first-round regressions, were consistently high. The PID-IID prevalence was highly significant even when educational attainment, death due to non-PID-IID, and income were controlled for in the IQ-regressions, suggesting that PID-IID genuinely affects cognitive skills and does not proxy variables that are correlated with educational attainment, the disease environment in general or per capita income. Furthermore, cognitive ability was highly influential for the level as well as the growth in productivity regardless of whether control variables were included in the regressions; even in growth regressions covering the period 1820-2006. Finally, the PID-IID-stress hypothesis remained robust in a simultaneous system in which the IQ and productivity models were estimated as a simultaneous system.

A crucial underlying assumption in the PID-IID-stress hypothesis is that PID-IID affects productivity through cognitive ability and not through the quality of institutions introduced by European settlers. To ensure that the PID-IID prevalence satisfied the exclusion restrictions of this paper the quality measure of institutions used by Acemoglu et al (2001) was included in the income regressions in the system estimates. However, it was consistently insignificant; remarkably, however, the coefficient of the quality of institutions became consistently significant if cognitive skills were excluded from the regressions, suggesting that the exclusion restriction maintained by Acemoglu et
al. (2001) does not hold.

The results in this paper have important implications for growth and development. First, tropical ecology appears to be a major obstacle to economic progress and prosperity because of the high PID-IID burden in tropical areas. However, being located in the tropics is not a sufficient condition for a country to be trapped at a low income level as countries that successfully reduce the burden of PIDs can prosper. Bleakley (2007) shows that the eradication of the hookworm in the Southern States was rendered possible through campaigns, and Singapore and Taiwan are examples of countries that have successfully reduced PID-IIDs since WWII and, as such, have prospered. Today the burden of PID-IIDs in Singapore and Taiwan is as low as in the temperate zones. In this context it is interesting to note that high income is not a necessary condition for the eradication of PIDs. Predominantly tropical countries such as Oman and the United Arab Emirates have very high incomes and yet they have not been able to eradicate or even reduce the malaria burden. Consistent with the PID-IID-stress hypothesis, these countries did not become wealthy because of high cognitive abilities but, instead, because of oil. The examples from the Southern States, Singapore, and Taiwan show that the burden of PIDs can be reduced in the tropical zones if the right efforts and policies are implemented.

Second, although the quantity of education does play a role in growth and development, it is ultimately the level of cognitive skills that is important for improving the level of human capital. To the extent that low cognitive skills are caused by PID-IIDs, the way to boost the these skills in areas with a high prevalence of PID-IID is to provide better public health systems including health campaigns, good public vaccination programs, mosquito nets, clean water, and mineral and iron fortified food. Many of these provisions are inexpensive development strategies.

DATA APPENDIX

countries for which TIMSS or PISA scores are unavailable. The data from the data appendix in Hanushek, Eric A and Ludger Woessmann, 2010, “The Economics of International Differences in Educational Achievement,” IZA DP No. 4925. TFP. Is measured as $y/k^\alpha$, where $y$ is output per worker and $k$ is capital per worker. Capital’s income share, $\alpha$, is set to 0.30. Capital stock is constructed using the perpetual inventory method with a 5% rate of depreciation. The initial capital stock is estimated as $I_0/((\delta + g))$, where $I_0$ is the initial real investment for the first year for which investment data is available, $\delta$ is the rate of depreciation, and $g$ the steady state rate of investment growth from the beginning to the end of the data period. The data are obtained from the Penn World Table 6.3.


Country sample: Argentina, Armenia, Australia, Austria, Barbados, Belgium, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, Bulgaria, Cameroon, Canada, Central African Republic, Chile, China, Colombia, Republic of the Congo, Croatia, Cuba, Czech Republic, Democratic Republic of the Congo, Denmark, Dominica, Democratic Republic, Ecuador, Egypt, Estonia, Ethiopia, Fiji, Finland, France, The Gambia, Germany, Ghana, Greece, Guatemala, Guinea, Honduras, Hungary, Iceland, India, Indonesia, Iraq, Ireland, Israel, Italy, Jamaica, Japan, Jordan, Kenya, Kuwait, Laos, Lebanon, Lithuania, Madagascar, Malawi, Malaysia, Malta, Marshall Islands, Mauritius, Mexico, Morocco, Mozambique, Namibia, Nepal, Netherlands, New Zealand, Nigeria, Norway, Pakistan, Papua New Guinea, Paraguay, Peru, Philippines, Poland, Portugal, Qatar, South Korea, Romania, Russia, Saint Lucia, Saint Vincent and the Grenadines, Samoa, Saudi Arabia, Sierra Leone, Singapore, Slovakia, Slovenia, South Africa, Spain, Sri Lanka, Sudan, Suriname, Sweden, Switzerland, Syria, Thailand, Tonga, Tunisia, Turkey, Uganda, Ukraine, United Arab Emirates, United Kingdom, Tanzania, United States, Uruguay, Venezuela, Yemen, Zambia, Zimbabwe
References


Gennaioli, N., La Porta, R., Lopez-de-Silanes, F. and Shleifer, A., 2013. Human Capital and regional


Hanushek, E. and Woessmann, L., 2010. The Economics of International Differences in Educational Achievement, IZA DP No. 4925.


