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COGNITIVE HUMAN CAPITAL AND ECONOMIC GROWTH IN THE 21ST CENTURY

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Human history becomes more and more a race between education and catastrophe.

H. G. Wells: The Outline of History, 1920

ABSTRACT

This chapter explores the interdependency between economic growth and cognitive human capital, which is also described as cognitive skills or intelligence and is measured either as performance in scholastic achievement tests or IQ. It shows that unlike the mere amount of schooling, intelligence has been a robust predictor of economic growth in the recent past. Plausible mediators of the intelligence effect include greater labor productivity, better institutions, more competent management, lower fertility, and wider time horizons.

Based on the observation of secular gains in intelligence that have become known as Flynn effects, a theory of economic growth is

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developed that is based on the trans-generational reinforcement between rising intelligence and economic, technological and institutional advances. It provides a parsimonious explanation for the sustained nature of economic growth since the Industrial Revolution, and a conceptual framework for more specific theories and hypotheses.

The chapter arrives at projections of economic growth for the first half of the 21^{st} century that are based on the empiric relationship between current prosperity, human capital, and economic growth. Longer-term predictions are based on our knowledge of the conditions that are required for continued Flynn effects, and of genetic limits to human cognitive development. The conclusion is that in most countries of Europe and North America, the limits of cognitive growth are being approached or have been reached already by the younger generation. There are ongoing Flynn effects in developing countries today. These countries are now reducing the cognitive gaps separating them from the developed countries, but most of them are expected to reach their cognitive limits before the end of the 21^{st} century. Long-term developments after the end of the Flynn effect will be driven primarily by demographic trends. Without major changes in demographic behavior, intelligence is predicted to eventually decline slowly, ending economic growth in most parts of the world within the next 3 to 4 generations.

1. Intelligence in Space and Time

1.1. Intelligence and Human Agency

The starting point for this chapter is the obvious fact that economic change is the result of human agency. Therefore we need to seek its sources in the physical, mental and moral qualities of the economically active population. In other words, we have to seek explanations for large-scale economic developments in the human capital of the population: how it is formed, and how it is translated into economic outcomes. Cognitive human capital is the aspect of human capital that is variously described as cognitive skills, intellectual ability or intelligence, depending on personal preference, academic traditions, and conventions of political correctness.

My claim is that intelligence is the most general driving force and a major limiting factor for economic growth. It has played this role in the past, and is predicted to continue doing so in the foreseeable future. The face validity of this approach is evident when we realize that sophisticated minds are required to create and maintain complex business enterprises and government bureaucracies, make inventions, and use these inventions in the service of greater efficiency. Fairly high intelligence is needed not only for innovation, but also for the maintenance of industrial and administrative structures once these have achieved high levels of complexity and efficiency.

Human capital theory explains macroeconomic developments in the recent past as outcomes of the interactions of human intelligence with the economic and social conditions that human intelligence has created. These same interactions will, in large part, determine future trend lines as well. Without a realistic understanding of human intelligence and its interactions with economic and social processes, we can neither understand the dynamic of historic change nor can we hope to predict future developments (Flynn, 2014; Meisenberg, 2014).

1.2. Temporal Trends of Intelligence: The Flynn Effect

Although subject to genetic constraints, human intelligence is malleable. This has been demonstrated beyond doubt by the Flynn effect: the rise of intelligence by approximately 30 IQ points or two standard deviations during the 20th century in the economically advanced countries (Flynn, 1987, 2012; Lynn & Hampson, 1986).[1] A person who scored at the 84th percentile of the ability distribution in 1900 would score at the 16th percentile today. It stands to reason that today's most advanced economies would not be sustainable if the intelligence of the population were nearly as low as it was in 1900. Table 1 shows examples of Flynn effects in various countries. We can note several points:

1. Flynn effects can be large, up to 10 IQ points per decade in some cases.
2. Different abilities can rise at different rates.
3. Gains were largest in Continental Europe and Japan during recovery from World War II.
4. In some countries, Flynn effects have ended or reversed in recent years.

[1] IQ tests are scaled to a population mean of 100 and standard deviation of 15. For international comparisons, the IQ of Britain ("Greenwich IQ") is used as a reference. For example, in a country with an average IQ of 85, the average person scores at about the 16th percentile of the British distribution.

Table 1. Some Flynn effect gains in Western countries

Country	Test	Age	Birth cohort	Gain/decade	Source
New Zealand	Otis	10-13	1923/26 – 1955/58	2.42	Elley, 1969
USA	Army Alpha	20	1898 – 1923	7.74	Tuddenham, 1948
USA	Stanford-Binet	6-12	1920/26 – 1960/66	1.95	Flynn, 1984
USA	Stanford-Binet	13-18	1914/19 – 1954/59	2.40	Flynn, 1984
Netherlands	Raven SPM selection	18	1934 – 1964	7.03	Flynn, 1987
France	Raven	18	1931 – 1956	10.05	Flynn, 1987
France	Math/Verbal	18	1931 – 1956	3.74	Flynn, 1987
France	ECNI	10	1955 – 1978	2.61	Bradmetz and Mathy, 2006
Germany	HAWIK	7-15	1941/49 – 1968/76	7.30	Schallberger, 1991
Germany	Intelligenzstrukturtest	22	1948 – 1978	1.60	Pietschnig et al, 2011
Norway	Math/Verbal/Matrices	19	1935 – 1957	4.55	Sundet et al, 2004
Norway	Math/Verbal/Matrices	19	1957 – 1983	0.33	Sundet et al, 2004
Denmark	Børge Prien's Prøve	18	1941 – 1971	2.70	Teasdale and Owen, 2005
Denmark	Børge Prien's Prøve	18	1970 – 1980	1.65	Teasdale and Owen, 2008
Denmark	Børge Prien's Prøve	18	1980 – 1985/86	-1.49	Teasdale and Owen, 2008
Sweden	Block design/memory	35-80	1909 – 1969	2.18	Rönnlund and Nilsson, 2008
Finland	Shapes/Number/Words	19	1969 – 1977/78	4.52	Dutton and Lynn 2013
Finland	Shapes/Number/Words	19	1977/78 – 1990	-2.50	Dutton and Lynn 2013

Country	Test	Age	Birth cohort	Gain/decade	Source
Britain	Raven SPM	52	1890 – 1940	4.44	Raven et al, 1998
Britain	Raven SPM	8-12	1931/35 – 1968/72	2.48	Flynn, 2009
Britain	Raven SPM	8-12	1968/72 – 1996/00	2.00	Flynn, 2009
Britain	Raven SPM	13-15	1928/30 – 1965/67	1.66	Flynn, 2009
Britain	Raven SPM	13-15	1965/67 – 1993/95	-0.87	Flynn, 2009
Japan	Kyoto NX 9-15	10-11	1943/44 – 1961/62	9.23	Lynn and Hampson, 1986
South Korea	Several	5-16	1970 – 1990	7.70	te Nijenhuis, 2012
Sudan	WAIS-R	50 (avg.)	1937 – 1957 (avg.)	2.05	Khaleefa et al, 2009
Dominica	Raven SPM	22/56	1978/87 – 1941/54	5.14	Meisenberg et al, 2005
Saudi Arabia	Raven SPM	8-18 male	1958/68 – 1992/02	0.29	Batterjee, 2011
Saudi Arabia	Raven SPM	8-18 fem.	1958/68 – 1992/02	2.65	Batterjee, 2011
Argentina	Raven SPM	13-24	1940/51 – 1974/85	6.28	Flynn and Rossi-Casé, 2012

This rise in psychometric intelligence occurred at a time when school systems expanded massively in western countries (Benavot and Riddle, 1988; Schofer and Meyer, 2005), and longer and intensified schooling is one likely cause of the Flynn effect. The Flynn effect implies that we can treat intelligence as a fixed input only when explaining short-term economic trends on time scales of years to decades. We cannot do so when trying to explain major secular trends in society and economy that take place on time scales of generations to centuries. Intelligence is a resource that can wax and wane on this time scale, and historic changes of intelligence are plausible causes as well as consequences of social and economic change.

1.3. The Geography of Intelligence

Intelligence is distributed unequally across countries. Average IQs in Sub-Saharan Africa, although difficult to measure with confidence (Rindermann, 2013), are around 70 while IQs in East Asia average 105. With 15 IQ points defined as one standard deviation, this difference is more than 2 (within-country) standard deviations on the "global bell curve" (Lynn, 2008). One likely reason for the great magnitude of cognitive differences between countries is that Flynn effects have been small or absent in today's less developed countries at a time (roughly between the 18th century Enlightenment and today) when mental horizons and psychometric intelligence were rising in the West. The "great divergence" (Pomeranz, 2000) between the West and the rest in economic history was, to the extent that we are able to reconstruct it, accompanied by an equally great cognitive divergence.

Figure 1 shows average intelligence in different world regions, measured as a composite of IQ and school achievement as will be described in section 2. Broadly, intelligence tracks economic development. The "Confucian" countries of East Asia (China, Japan, South Korea, Taiwan, Hong Kong, Singapore) have the highest scores followed by the countries of Protestant Europe, English-speaking countries with predominantly European-origin populations, Catholic Europe, and the ex-communist countries of Eastern Europe and the former Soviet Union. The middle field is formed by the countries of Latin America, the Muslim Middle East (including North Africa), the Pacific islands, and the countries of South and South-East Asia from India to Indonesia and the Philippines. IQs are lowest in the countries of Sub-Saharan Africa.

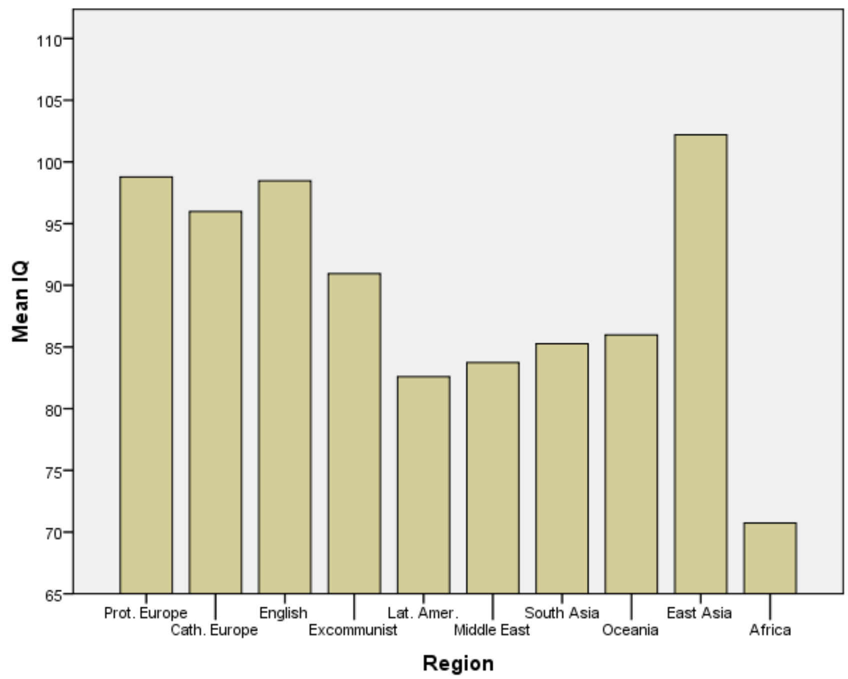


Figure 1. Average intelligence in different world regions. "Middle East" includes the predominantly Muslim countries from Morocco to Pakistan, "South Asia" reaches from India to Indonesia, and Oceania refers to the Pacific islands only, excluding Australia and New Zealand which are counted as "English". "Africa" includes only the Sub-Saharan countries.

2. Intelligence: Its Measurement and Correlates

2.1. Generality of Intelligence

The concept of intelligence would be useless if different cognitive abilities, such as short-term memory, long-term memory, speed of information processing, visuo-spatial ability, word knowledge and verbal comprehension, were statistically unrelated. But in fact, they are related. Robust positive correlations among subtests of complex IQ test batteries such as the Wechsler tests are universal (Jensen, 1998), with the partial exception of highly gifted samples that have been pre-selected rigorously for high general intelligence

(Bakhiet and Ahmed, 2014). In samples representing the entire ability spectrum, between 35% and 55% of the variance in overall test performance can be attributed to the general factor *g*, with the remainder due to more specialized abilities and measurement error. Technically, *g* is defined as the unrotated first principal component of a factor analysis on the subtests of a complex test battery, whereas IQ is a simple summary score. *g* tends to correlate more highly than IQ with most outcomes, presumably because it weights those tests most heavily that are the “purest” measures of intelligence, as well as those that have the highest reliability.

2.2. Microeconomics of Intelligence

Intelligence is related with many real-world outcomes. Correlations tend to be highest with measures of scholastic achievement. The correlation of psychometric *g* with general scholastic achievement, operationalized by factor analysis of achievement tests in curricular subjects such as reading, science and mathematics, can be as high as 0.8 (Deary et al, 2007; Kaufman et al, 2012). Such high correlations require very accurate measures of *g* and scholastic achievement.

These high correlations may seem surprising because in theory, IQ tests are aptitude tests that measure pre-existing learning ability while scholastic assessments are achievement tests that measure attained knowledge and skills. In reality, however, the cognitive skills that are measured by IQ tests have to be acquired by prior learning. Much of this prior learning must occur in school, since each year of additional schooling during adolescence adds between 2 and 4 points to the IQ (e.g., Brinch and Galloway, 2012; Falch and Massih, 2011; Hansen, Heckman and Mullen, 2004). Conversely, the knowledge and skills that are tested in scholastic assessments depend on pre-existing learning ability. At the individual differences level, the two types of test are expected to be highly correlated as long as every child has the same opportunities to learn in school.

Another major use of IQ tests is for hiring decisions and the prediction of job performance or training success. Although high-confidence predictions remain elusive, the usual finding is that general mental ability is the single best predictor (e.g., Kuncel & Hezlett, 2010; Schmidt and Hunter, 2004). The effect of *g* on occupational success is mediated in part by economic preferences, strategic behavior, and job attachment (Burks et al, 2009). In prospective studies, intelligence measured in childhood or adolescence predicts occupational position and income of adults even when educational degrees and childhood socioeconomic status are controlled (Sorjonen et al, 2012; Strenze, 2007). Figure 2 shows results from the National Longitudinal Study of Youth in the United States, in which IQ measured at age 15-23 predicts log-transformed adult family income at age 28-37. In this path model, IQ predicts 15.7% of the total variance in family income directly, and 7.6% indirectly through educational attainment.

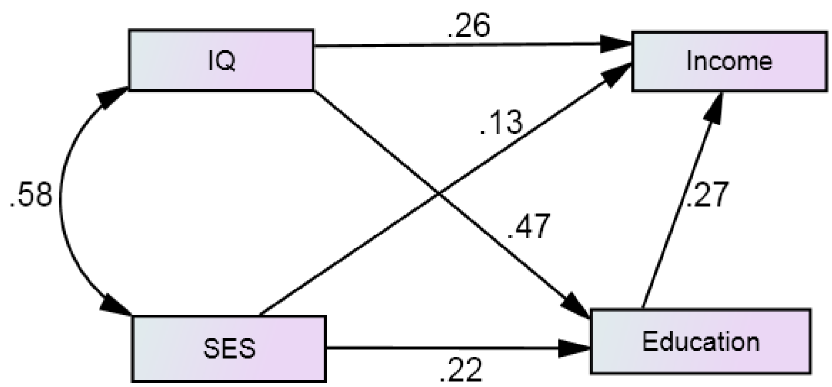


Figure 2. Log-transformed family income at age 28-37 (*Income*) is predicted for males in the NLSY79. IQ was measured with the Armed Services Vocational Aptitude Battery (ASVAB) at age 15-23. Error terms of the dependent variables (each with a regression weight fixed at 1) are omitted. SES = socioeconomic status of family of origin. N = 3525, all path coefficients are significant at $p<.001$.

2.2. Macroeconomics of Intelligence

If Adam Smith was right with his claim that the pursuit of personal gain translates into benefits for the entire economy, and if intelligence promotes personal economic success, it follows that everything else being equal, macroeconomic outcomes will be more favorable in a society with higher rather than lower average intelligence. This argument has been presented by Lynn and Vanhanen (2002, 2006, 2012) in their argument for a causal effect of intelligence on national wealth. This assumes that people pursue personal gain through productive work that creates valued goods and services rather than through rent seeking. Despite this limitation, correlations of average intelligence in the country with log-transformed per capita GDP are between

0.70 and 0.80 in world-wide country samples. Figure 1 gives an impression of this relationship.

3. Causes of Individual Variations in Intelligence

3.1. Quantitative Genetics: Nature and Nurture

Disregarding theories of mind-body dualism, human intelligence is a function of the human brain. As such it is the outcome of developmental processes that are guided by interactions between genetic programming and environmental inputs. Variations in both can cause individual differences in phenotypic (measured) intelligence. The relative importance of genes and environment for individual differences is studied by variance decomposition in genetically informative families, most commonly involving twins or adoptees. We still depend on these descriptive methods of quantitative genetics because only a small proportion of individual variation in general intelligence and school achievement can be explained by known genetic polymorphisms (e.g., Piffer, 2013a,b; Rietveld et al, 2013).

The most common variance decomposition in family studies partitions the phenotypic (observed or measured) variance V_P into additive genetic variance (V_G), shared environmental variance that makes family members such as twins, full siblings, half siblings and adopted children raised in the same family similar (V_C), non-shared environmental variance that makes them different (V_E), and measurement error (E):

$$V_P = V_G + V_C + V_E + E$$

In practice, E cannot be distinguished from V_E. Therefore V_G and V_C tend to be underestimated relative to V_E in heritability studies, and both tend to be higher when measurement is more accurate. Further refinements can be introduced by accounting for non-additive genetic effects (dominance and epistasis), gene-environment correlation and interaction, and assortative mating, but these need not concern us here. Heritability (V_G, also designated h^2 when only additive effects are included and H^2 when all genetic effects are included), is the proportion of the phenotypic variance that is explained by genetic factors.

Studies about the heritability of psychometric intelligence have produced broadly consistent results. Genes account for 30% to 80% of the total variance, and heritability rises with age. Based on results from 11,000 twin pairs from 4 countries, Haworth et al (2010) calculated that broad heritability (H^2) of general intelligence increased from 41% at age 9 to 55% at age 12 and 66% at age 17. As heritability rises, shared environment becomes less important although it still has small effects on individual differences in adult intelligence (Kaplan, 2012).

The heritability of school achievement, measured by tests in curricular subjects such as reading, science and math, is about the same as the heritability of IQ (Bartels et al, 2002; Calvin et al, 2012). Therefore scholastic achievement tests measure not only the quality of schooling, but also the innate ability of the test taker. Conversely, IQ tests measure not only innate ability but also the quantity and quality of educational inputs, as shown by studies in which increased length of schooling raises the IQ (Brinch and Galloway, 2012; Falch and Massih, 2011; Hansen, Heckman and Mullen, 2004). The common practice of using scholastic achievement test scores as measures of schooling quality and IQ as a measure of innate endowments is not justified. Another observation is that in the commonly used IQ test batteries, such as the Wechsler tests, those subtests that are considered most culture-dependent (or "culturally biased") tend to have the highest *g* loadings and the highest heritabilities (Kan et al, 2013). This shows that the essence of the intelligence construct that is tapped by IQ tests is the genetically based ability to acquire culturally mediated knowledge and skills.

3.2. Limitations of Behavioral Genetics

Most heritability studies have been performed in economically advanced societies with subjects who had access to formal education and were not grossly deprived economically or intellectually. High heritabilities of adult intelligence have to be interpreted on the background of a relatively level playing field, created by modern welfare states in which environmental but not genetic inequalities have been reduced to some extent by social engineering. It does not imply that large environmental changes are unable to produce large changes in intelligence. Even in modern societies, the heritability of intelligence tends to be higher for children from higher socioeconomic status (SES) families (Turkheimer et al, 2003; *cf*. Nagoshi and Johnson, 2005; van der Sluis et al, 2008). Where this is observed, most likely environmental conditions are of similar high quality for most high-SES children but are more variable for low-SES children.

The variance decomposition shown above applies only to *individual* differences. In theory, differences in intelligence between countries and historical epochs can be decomposed into genetic and environmental components as well, but there is no established methodology to study this question. Molecular genetic studies can compare the frequencies of intelligence-related genetic variants across countries and their changes over time. First studies of this kind have been done (Piffer, 2013a,b), but conclusive results from this emerging field of IQ population genetics will have to await a better understanding of the molecular genetics of human intelligence.

3.3. The Production of Intelligence

The variance decomposition presented in subsection 3.1 is not a production function for intelligence. It does not predict the level of intellectual attainment, but describes the sources of individual differences. Production functions for intelligence or cognitive skills have been attempted by some authors. For example, Behrman et al (2014) distinguish between pre-school, school, and post-school experiences in their analysis of a longitudinal data set from Guatemala. These factors were assumed to have additive effects.

Alternatively, inputs to human intelligence can be decomposed into genetic factors (or innate endowments), physical factors other than genes, formal education, and social-environmental factors other than formal education. Physical factors other than genes include perinatal factors (LeWinn et al, 2009; Matte et al, 2001), nutrition (Lynn, 1990), toxins (Ferrie et al, 2011), and infectious diseases (Fernando et al 2010), but the extent to which they affect intelligence at the population level is uncertain. Most studies about the effects of nutritional deficiencies and infectious diseases on human intelligence are from developing countries, where these factors are more prevalent than in prosperous countries. The extent to which they contribute to IQ differences between countries and to Flynn effects is difficult to estimate. They can be conceptualized as largely additive with genetic factors, in that they affect physical brain development and thereby the responsiveness to educational efforts and other social-environmental factors.

Formal education is required for a level of intelligence that today is classified as non-retarded (Luria, 1976; Oesterdiekhoff, 2014). Its relationship with genetic and other biological inputs is most likely not additive but multiplicative, meaning that the return to educational efforts is proportional to the quality of the biological substrate. The same can be said of social-environmental factors other than schooling. Therefore, instead of the usual additive production function of the general form

$$IQ = \alpha + \beta_1 \text{ x Gen} + \beta_2 \text{ x Phy} + \beta_3 \text{ x Sch} + \beta_4 \text{ x Env} \quad (1)$$

A more appropriate description would be

$$IQ = \alpha + (\beta_1 \text{ x Gen} + \beta_2 \text{ x Phy}) \text{ x } (\beta_3 \text{ x Sch} + \beta_4 \text{ x Env}) \quad (2)$$

Where Gen = genetic endowment, Phy = non-genetic physical factors, Sch = schooling, and Env = non-school social-environmental inputs.

Equation 2 is still unsatisfactory. It ignores the fact that diminishing returns to rising inputs are inevitable. Even the best school system cannot turn every child into an Einstein because not every child has the genetic potential to advance to that level—unless each child has been genetically engineered for extreme intelligence. Therefore we need to modify production function (2) to acknowledge the law of diminishing returns. One of several possibilities of doing so is:

$$IQ = \alpha + (\beta_1 \text{ x Gen} + \beta_2 \text{ x Phy}) \text{ x } \ln(\beta_3 \text{ x Sch} + \beta_4 \text{ x Env}) \quad (3)$$

The commonly cited example for the law of diminishing returns to environmental inputs is the stimulation of corn production by added fertilizer. At low levels, added fertilizer brings large returns. However, at high levels of fertilization corn yield barely responds to even more fertilizer because genetic and physical limitations, for example in the rate of photosynthesis, become prohibitive. In quantitative genetics, this ubiquitous phenomenon is known as the reaction norm of the trait (Plomin et al, 2012).

4. MEASUREMENT OF HUMAN CAPITAL IN NATIONS

4.1. IQ and School Achievement

There are two measures of country-level intelligence. First, we have a data set for the average IQ in more than 130 countries that has been compiled by the British scholar Richard Lynn. Data are of uneven quality. Some countries have multiple studies including high-quality standardizations of major IQ tests on representative population samples; others have only one or a few studies with convenience samples. Different stages of this data set have been presented in Lynn & Vanhanen (2001, 2002, 2006, 2012).

The second data type are scholastic assessments in curricular subjects such as mathematics, science and reading. Some large-scale international assessment programs have been performed at regular intervals, with PISA (Programme of International Student Assessment, since 2000) and TIMSS (Trends in International Mathematics and Science Study, since 1995) being the most important. These major international testing programs are performed with representative country samples of about 5000 school children. Many of those countries that did not participate in PISA or TIMSS took part in earlier assessments that were generally of lower quality, and many countries in Africa and Latin America only have data from regional educational assessment programs that are sometimes difficult to anchor to the major international assessments. Data quality is about as variable in the scholastic data as in the IQ data (Meisenberg & Lynn, 2011).

Compared to individual differences within countries, differences between countries are approximately 30% to 40% larger for school achievement than IQ. The likely reason is that poor quality of schooling, although important for both school achievement and IQ, depresses school achievement to a greater extent than IQ. Educational quality is likely to be systematically lower in "low-IQ countries," mainly because of lower competence of teachers. For example, at the University of Khartoum (Sudan), the average IQ of students in the study program for primary education teachers was found to be 65 (Khaleefa , Amer & Lynn, 2014).

4.2. The Ecology of Country-Level Intelligence

Table 2 shows the correlations between measures of cognitive human capital, development indicators, and annual economic growth rates. The *Schooling* variable is based on average years of schooling of the adult population (1995-2010 average) from the Barro-Lee data set (hppt://www.barrolee.com), with missing data points extrapolated from World Bank and United Nations sources. *No Corruption* is a composite of Transparency International's Corruption Perception Index 1998-2003, and the Control of Corruption measure of the World Bank's Governance Indicators 1996-2005 (no earlier data available). *Political freedom* is constructed from the averaged Political Rights and Civil Liberties measures of the Freedom

House Index 1975-2005 and the Voice and Accountability measure of the World Bank's Governance Indicators 1996-2005. Countries with more than 0.1 barrel/day of oil exports per capita are excluded because their economies depend heavily on the oil price, and countries with a population of less than 250,000 are excluded as well.

The first observation is that IQ and school achievement are highly correlated with each other. They also have similar correlations with other variables, including economic growth. Therefore they can be considered alternative measures of the same construct, which we can call cognitive human capital or simply intelligence.

Another observation is that these measures of human capital are closely related to the "development indicators" including log-transformed GDP (1975/2011 average). A difference of 9 IQ points between countries translates into a two-fold difference in per capita GDP. This corroborates the observations of Lynn and Vanhanen (2002, 2006, 2012) of a close relationship between IQ and GDP. We further see that economic growth is related most closely to school achievement and IQ.

Because of their conceptual and correlational similarity, IQ and school achievement were combined into a composite measure of intelligence, with weighting for data quality as described in Meisenberg & Lynn (2011).

Table 2. Correlations of economic growth (1975-2011) with IQ, school achievement, and some development indicators[1)]

	Growth	IQ	School ach.	Schooling	lgGDP	No Corruption
IQ	.458	1				
School achiev.	.517	.902	1			
Schooling[2)]	.239	.770	.741	1		
lgGDP 1975/2011	.146	.817	.782	.850	1	
No Corruption	.172	.677	.659	.683	.775	1
Political Freedom	.083	.627	.537	.641	.709	.761

1) N = 80 countries.
2) Average years in school of the adult population, 1990-2005.

Because the between-country differences, relative to within-country differences, are greater for school achievement than IQ, the averaging was done by bringing the country-level school achievement scores to the same mean and standard deviation as country-level IQ for the 100 countries having both measures. The resulting *Intelligence* variable, which includes only data published before 2011, is available for 168 countries and territories. The averaging of IQ and school achievement enlarges the set of countries for which cognitive test results are available and increases accuracy by averaging out measurement error and weighting data by quality, while sacrificing little in terms of conceptual purity.

5. Determinants of Economic Growth, 1975-2011

5.1. Growth Regressions

In Table 2, log-transformed per capita GDP has high correlations with all other variables except economic growth. Because the direction of causation is indeterminate in every case, it would be futile to "predict" per capita GDP with a combination of its correlates. The endogeneity problem is mitigated when the predicted outcome is not cross-sectional per capita GDP, but change of per capita GDP over time. Although ongoing economic growth can to some extent affect other measures, such as corruption and democratization, such effects are not likely to be large.

The growth regressions of Table 3 include initial log-transformed per capita GDP based on the "advantage of backwardness": the expectation that poorer countries have more unused development potential and are therefore, ceteris paribus, likely to grow faster than countries with higher pre-existing prosperity (Weede & Kämpf, 2002). Intelligence and schooling (average years in school) are included as measures of human capital. Freedom from corruption, as an indicator of non-cognitive human capital, is predicted to promote economic growth independent of cognitive human capital, and political freedom is an indicator of general political and social conditions. A dummy for the ex-communist countries of the former Soviet bloc is included because their growth trajectories were affected by the economic dislocations after the end of communist rule. This variable is omitted for the subsample of poor countries because only one of the ex-communist countries (Mongolia) was classified as poor. The subsamples were formed by a median split, based on the average of their log-transformed per capita GDPs in 1975 and 2011. As in Table 2, small countries and oil exporting countries are excluded.

The striking result is that log-transformed per capita GDP in 1975 is a powerful negative predictor of subsequent growth, and intelligence is an equally powerful positive predictor. In the complete sample, an increase of IQ by 10 points is associated with an increase of the annual economic growth rate

Table 3. Prediction of annual growth rates 1975-2011

Predictor	All countries		Poor countries		Rich countries	
	B[1)]	SE	B[1)]	SE	B[1)]	SE
Constant	-.155	1.230	-2.142	2.297	3.855	2.404
lgGDP 1975	-2.964***	.361	2.709***	.665	-3.729***	.629
Intelligence	.125***	.014	.132***	.020	.126***	.018
Schooling	.158*	.069	.067	.102	.054	.101
No corruption	.146	.074	.499**	.145	.136	.087
Political freedom	-.029	.088	.044	.135	-.040	.105
Ex-communist	-.584	.473			-.460	.467
N	120		60		60	
Adj. R2	.575		.626		.587	

[1)] * p<.05; ** p<.01; *** p<.001, two-tailed t tests

by 1.25%. For example, the 7 East Asian countries in the sample have an average IQ of 104.6 and an average annual growth rate of 5.10%. The 33 countries of sub-Saharan Africa have an average IQ of 70.3 and an annual growth rate of 0.59%. The effect of intelligence is virtually the same in the subsamples of rich and poor countries. This shows that the concept of intelligence has predictive validity cross-culturally, contrary to a frequent claim that intelligence tests and related assessment tools are valid only in the cultures in which they were designed (e.g., Greenfield, 1997). Schooling has only a marginal effect on growth when intelligence is included, consistent with earlier results by Weede & Kämpf (2002) and Ram (2007).

Effects of the other predictors are smaller and more variable. Coefficients are positive for freedom from corruption and negative for (abandonment of) communism. Clearly, the transition from a communist to a capitalist system in the former Soviet bloc has not resulted in the kind of economic boom that China has experienced after the de-facto introduction of a capitalist economy. Political freedom is the only variable that stubbornly refuses to affect economic growth, consistent with the conclusions of Doucouliagos and Ulubaşoğlu (2008).

5.2. Some Caveats about Growth Regressions

The measures used in Table 3 were, as far as possible, taken for the time period between 1975 and 2011, over which growth was observed. In the case of the intelligence measures, we would ideally use a measure of cognitive ability of adolescents in the 1970s, who were economically active in the 1975-2011 period. However, the amount and quality of IQ data has increased steeply over time. The IQ measure is based on studies published from the 1930s to 2011, with a median date of 1990. Most of these studies were performed with children or adolescents. The IQ data set includes a “one size fits all” correction for the Flynn effect. Although the Flynn effect has been a tide that lifted all boats, its strength has been variable across countries and time as shown in Table 1 (see also Flynn, 1987). This invariably introduces errors when using the IQ data set as an approximation of the intelligence of the working-age population between 1975 and 2011. However, these errors are expected to be small.

The school achievement measure is derived mainly from the PISA studies of 2000-2009 and the TIMSS studies of 1995-2007, which were conducted with 15-year-olds (PISA) and 8^{th} graders (TIMSS). Despite some differential trends (Meisenberg and Woodley, 2013), national achievement levels have been quite stable over the time periods covered by these recurrent assessment programs. Therefore it is unlikely that relative achievement has changed very much during the preceding decades.

The alternative explanation, that intelligence is a consequence but not a cause of economic growth, cannot be excluded based on growth regressions alone. However, it is unlikely because the important relationship of the intelligence measure is not with cross-sectional per capita GDP, but with the *change* of per capita GDP over time. Also, earlier studies that took account of earnings and cognitive test scores of migrants in the host country or IQs in wealthy oil countries have concluded that there is a substantial causal effect of IQ on earnings and productivity (Christainsen, 2013; Jones & Schneider, 2010)

6. MEDIATORS OF THE INTELLIGENCE EFFECT

6.1. Use of Path Models

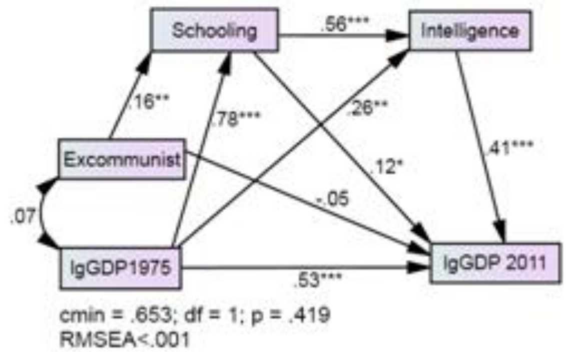
Intelligence is predicted to favor economic growth because it improves job performance, management practices, institutional quality, technological and administrative innovation, ethical conduct, demographic behavior and/or investment decisions—in other words, most of the factors that economists have ever proposed as determinants of economic growth. Anything that is affected by intelligence net of other causes, and that itself affects economic growth, is a bona fide mediator of the intelligence effect. The method for studying mediation effects is path analysis, which models causal effects based on pre-existing theory. It includes fit indices which reject models that do not fit the empiric data.

The models in Figure 3 predict log-transformed per capita GDP in 2011. The only exogenous variables are log-transformed per capita GDP in 1975 and, except for the subsample of poor countries, a dummy for ex-communist. Schooling (average years in school) and intelligence (composite of IQ and school achievement) are assumed to mediate effects of the exogenous variables on lgGDP2011. Each endogenous variable includes an error term with regression weight fixed at 1 (omitted in the figures), to account for unmodeled influences and measurement error. *lgGDP1975* and *Excommunist* are hypothesized to influence *Schooling*, and *Schooling* and *lgGDP1975* are hypothesized to influence *Intelligence*. All variables are allowed to affect *lgGDP2011*. These models do not formally predict a growth rate, but effectively do so by determining effects on log-transformed GDP in 2011 *independent of the effects of log-transformed GDP in 1975*.

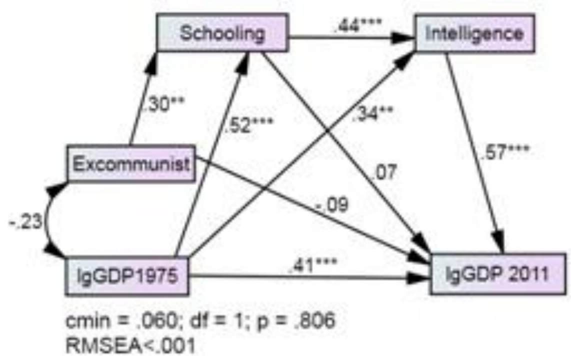
The models deal with the endogeneity problem by modeling intelligence and schooling both as effects of prosperity at an earlier time and as causes of prosperity at a later time. The models have one degree of freedom due to the omitted relationship between *Excommunist* and *Intelligence* (models 3A and 3B) or *lgGDP1975* and *Intelligence* (model 3C). Because these relationships were virtually zero, the model fit is excellent as shown by the fit indices. High p value and RMSEA<.05 indicate good model fit (Hu & Bentler, 1999).

These models replicate the results of the growth regressions in Table 3. Additional relationships are theoretically meaningful. Schooling is raised by high per capita GDP in 1975 and to a lesser extent by communism; and intelligence is raised by schooling and to a lesser extent by per capita GDP in 1975 (except in poor countries). As in the growth regressions, schooling and

A. Complete sample of 120 countries.



B. Subsample of 60 rich countries.



C. Subsample of 60 poor countries.

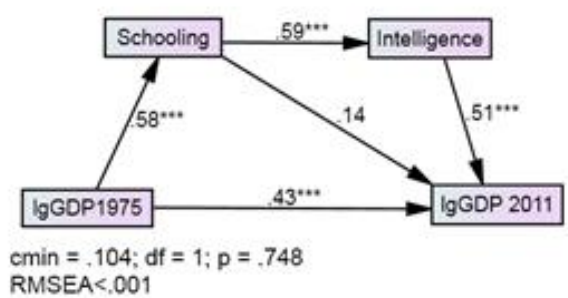


Figure 3. Path model predicting log-transformed per capita GDP in 2011. Standardized regression weights are shown. Error terms are omitted. *p<.05; **p<.01; ***p<.001.

abandonment of communism appear to have marginal positive and negative effects, respectively.

6.2. Mediator Models

The models of Figure 3 were extended by inserting a hypothesized mediator between *Intelligence* and *lgGDP2011*. The mediator was allowed to be influenced not only by *Intelligence*, but by all variables except *lgGDP2011*. Figure 4 shows as an example the model for the complete sample of 120 countries with the total fertility rate (1975-2005 average) as a mediator. The results of this model are included in Table 4.

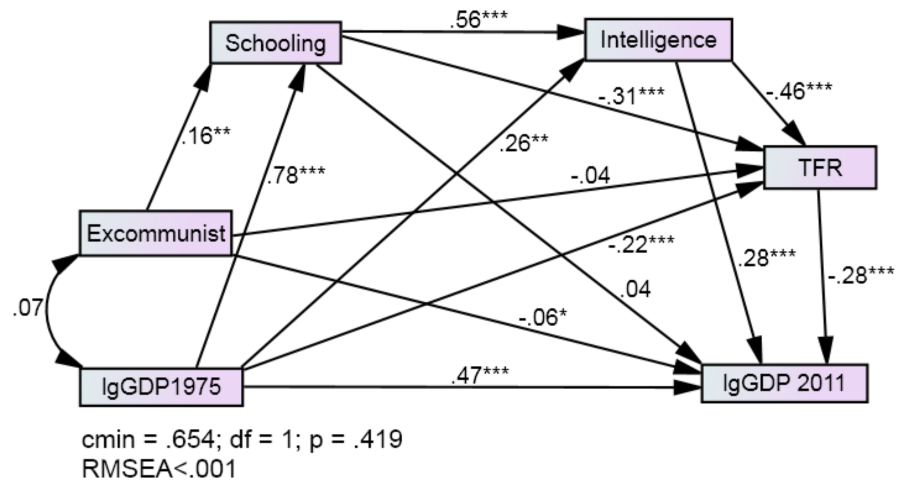


Figure 4. An example of a mediator model. The total fertility rate (TFR, 1975-2005 average) is hypothesized to mediate effects of intelligence (and other variables) on log-transformed per capita GDP in 2011. Error terms of the endogenous variables are not shown. * p<.05; ** p<.01; *** p<.001.

A mediation effect was considered present if both the *Intelligence* → *Mediator* path and the *Mediator* → *lgGDP2011* path were significant at p<.05. For these variables, the indirect effects are highlighted in bold in Table 4. In all, 20 variables were examined as possible mediators of the intelligence effect. The results can be summarized as follows:

Table 4. Mediation of the effects of intelligence (*Intel*) and other variables on log-transformed per capita GDP in 2011 (*GDP11*). These are for models of the structure shown in Figure 4 except models for poor countries, which omit *Excommunist*

	Intel → M	M → GDP11	Intel → GDP11	Indirect	Other
A. Business climate					
1. Economic Freedom					
All	.171	.055	.398***	2.3%	G75++, School+, Excom--
Rich	.367**	.267***	.468***	**17.3%**	G75+, Excom-
Poor	-.203	.060	.524***	-3.2%	School+
2. Big Government					
All	-.098	-.014	.406***	0.3%	Excom+
Rich	-.244	-.064	.550***	2.8%	
Poor	.014	.000	.507***	0.0%	
B. Resource allocation					
1. Consumption share of GDP					
All	-.278*	-.052	.393***	3.5%	G75-
Rich	-.298	-.108*	.533***	5.7%	
Poor	-.313*	-.052	.491***	3.2%	G75-
2. Government share of GDP					
All	-.028	-.022	.407***	0.2%	
Rich	-.193	-.106*	.545***	3.6%	Edu+
Poor	.061	-.006	.508***	-0.1%	
3. Investment share of GDP					
All	.230	.096***	.386***	5.4%	G75-, School-
Rich	.323	.021	.559***	1.2%	
Poor	.171	.238***	.467***	8.0%	School++
4. Gross domestic savings					
All	.469***	.091**	.365***	**10.5%**	
Rich	.432**	.128*	.511***	**9.8%**	
Poor	.460***	.129	.448***	11.7%	G75+
C. Income (re)distribution					
1. Welfare state					

	Intel → M	M → GDP11	Intel → GDP11	Indirect	Other
All	.306***	-.010	.411***	-0.8%	G75++, Excom+
Rich	.260*	.023	.560***	1.1%	G75++
Poor	.458***	-.033	.522***	-3.0%	
2. Gini index					
All	-.680***	-.018	.395***	3.0%	Excom-
Rich	-.447***	-.043	.547***	3.4%	G75--, School-, Excom--
Poor	-.593***	-.119	.437***	13.9%	School+
3. Social pathologies (homicide, theft, teenage pregnancy)					
All	-.822***	-.042	.373***	8.5%	
Rich	-.639***	-.213	.430***	24.0%	G75--
Poor	-.744***	-.045	.474***	6.6%	
D. Technology and trade					
1. Technological competitiveness					
All	.307***	-.049	.423***	-3.7%	G75++, School++, Excom-
Rich	.249**	-.149	.603***	-6.6%	G75++, School++
Poor	.269**	.325**	.420***	**17.2%**	School++
2. Trade openness					
All	.098	.069**	.401***	1.7%	
Rich	.244	.202***	.516***	8.7%	
Poor	-.039	.006	.508***	-0.0%	G75++
E. Good government					
1. Freedom from corruption					
All	.278**	.086*	.384***	**5.9%**	G75++, Excom-
Rich	.228*	.144	.533***	5.8%	School++, Excom-
Poor	.090	.238***	.486***	4.2%	
2. Political freedom					
All	.025	.029	.407***	0.2%	G75++, School++
Rich	.117	.026	.563***	0.5%	G75++, School++

Table 4. Mediation of the effects of intelligence (*Intel*) and other variables on log-transformed per capita GDP in 2011 (*GDP11*). These are for models of the structure shown in Figure 4 except models for poor countries, which omit *Excommunist*
(continued)

	Intel → M	M → GDP11	Intel → GDP11	Indirect	Other
Poor	-.239	.106	.533***	-4.5%	School++
3. Political stability					
All	.239*	.075*	.390***	**4.4%**	
Rich	.363**	.122	.521***	7.8%	G75+
Poor	-.016	.141*	.510***	-0.4%	School+
4. Government effectiveness					
All	.349***	.153***	.354***	**13.1%**	G75++, School+, Exco--
Rich	.313***	.300**	.472***	**16.6%**	G75++, School++, Exco-
Poor	.186	.312***	.449***	11.4%	School++
5. Regulatory quality					
All	.281**	.127**	.372***	**8.7%**	G75++, School+
Rich	.378***	.230**	.479***	**15.4%**	G75++
Poor	-.031	.246***	.515***	-1.5%	School++
6. Rule of law					
All	.353***	.123**	.364***	**10.7%**	G75++, School+, Exco-
Rich	.371***	.250**	.473***	**16.4%**	G75++, School++
Poor	.079	.279***	.485***	4.3%	School++
F. Demography and health					
1. Total fertility rate (TFR) 1975-2005					
All	-.458***	-.275***	.282***	**30.9%**	G75--, School--
Rich	-.571***	-.304***	.392***	**30.7%**	School-
Poor	-.519***	-.323***	.340***	**33.0%**	School--
2. Life expectancy					

	Intel → M	M → GDP11	Intel → GDP11	Indirect	Other
All	.437***	.106	.361***	11.4%	G75++, School++
Rich	.573***	.094	.512***	9.5%	School+
Poor	.500*	.113	.451***	11.1%	School+
3. Under-5 mortality					
All	-.368***	-.138*	.357***	**12.4%**	G75--, School--
Rich	-.411***	-.217*	.476***	**15.8%**	G75-, School--
Poor	-.471***	-.128	.447***	11.9%	School--

M = hypothesized mediator. *Other* refers to significant positive (+) and negative (-) effects (+ and - p<.05, ++ and -- p<.01) of variables other than intelligence on the mediator: *G75* = log-transformed per capita GDP in 1975; *School* = schooling; *Excom* = Excommunist. Standardized regression weights are shown. N is up to 120 countries for the complete sample, and up to 60 each for the subsamples of rich and poor countries. Significant mediation effects are highlighted in bold. *p<.05; **p<.01; ***p<.001.

A. Business climate: Economic freedom is considered a condition for vigorous economic growth (e.g., Justesen, 2008; Weede & Kämpf, 2002). This concept is embodied in two major composite indices, one by the Fraser Institute (www.freetheworld.com) and the other by the Heritage Foundation (http://www.heritage.org/index/Download.aspx). Both indices combine two different kinds of measure. One type describes bureaucracy and red tape, and the other the size of government. These two components are virtually uncorrelated with each other, have different external correlates, and appear to measure different constructs. Therefore two measures were created from the relevant subindices: one for *Economic Freedom* sensu stricto (areas 2-5 of the Fraser index and domains 1, 2, and 5-8 of the Heritage index), and the other named *Big Government* (reversed area 1 of the Fraser index and domains 3-4 of the Heritage index). The correlation (Pearson's *r*) between these two measures is -.144 (N = 164 countries). Data from Fraser are for 1975-2005, and from Heritage for 1995-2005 (no earlier data available).

Table 4 shows that economic freedom does promote economic growth in the subsample of rich countries. Because intelligence favors economic freedom in rich (but not poor) countries, economic freedom qualifies as a mediator of the IQ effect in rich countries. About 17.3% of the intelligence effect in rich countries is mediated by economic freedom. Unlike economic freedom, big government has little or no adverse effect on economic growth even in rich countries, and is not much affected by intelligence either.

B. Resource allocation: Allocation of capital resources has been an element of classical growth theory (Solow, 1956). Human capital theory emphasizes that individuals with higher intelligence tend to have lower impulsivity and lower time preference (Shamosh & Gray, 2008). This is predicted to lead to higher savings rates and greater resource allocation to investment relative to consumption in countries with higher average intelligence.

Table 4 includes results for consumption, government and investment share as % of GDP (1975-2005 average) from the Penn World Tables 7.0 (Heston et al, 2011), and gross domestic savings (1975-2005 average) from the World Bank (http://data.worldbank.org/indicator/NY.GDS.TOTL.ZS?page =4). A higher investment share is related to stronger growth as expected, at least in poor countries, while the effect of consumption tends to be negative. However, the effects of intelligence on investment and consumption, although in the predicted direction, are rather weak and not always statistically significant. Therefore the investment-versus-consumption choice mediates only a small portion of the intelligence effect at best. The savings rate fares slightly better. Here, we do have a robust effect of intelligence independent of other predictors, and higher savings do have a mild association with economic growth in both rich and poor countries. However, reverse causation is possible, since rising prosperity may enable individuals and institutions to save more.

There are only marginal, non-significant associations of higher government expenditure with lower intelligence and slower growth in rich countries. The correlation between the *Government share of GDP* (B2 in Table 4) and *Big Government* (A2) variables is only .177 (N = 162 countries).

C. Income (re)distribution: The welfare state redistributes resources from those who work to pensioners and the unemployed, and from the healthy to the sick. Concerns about possible adverse effects of the welfare state on economic development are voiced at times, but evidence for such an effect is difficult to locate. According to Beraldo, Montolio & Turati (2009), public health expenditures actually promote economic growth.

The *Welfare state* measure used in Table 4 (variable C1) is calculated from ILO (International Labour Organisation) data available at http://www.ilo.org/secsoc/information-resources/WCMS_146566/lang--en/index.htm. It includes measures of pensions, unemployment benefits, health insurance, and social security benefits other than health, mainly from the 1995-2005 period. The results in Table 4 show that the welfare state is favored by high intelligence as well as high prosperity, and that it does not affect economic growth.

The Gini index of income inequality was investigated because of its inverse association with intelligence. Low intelligence and high racial diversity are considered the main predictors of a high Gini index in country-level comparisons (Meisenberg, 2007a, 2008a). The impact of income inequality on economic growth is uncertain, with some studies reporting positive and others reporting negative effects (Forbes, 2000). The Gini index used in Table 4 is based on net income or disposable income, derived mainly from the World Income Inequality Database (WIID2a) of the United Nations University. Results confirm the inverse relationship between Gini index and intelligence, but a high Gini index reduces economic growth only mildly or not at all.

High income inequality is associated with social pathologies in the form of crime, single motherhood and teenage pregnancy (Wilkinson & Pickett, 2009). Therefore a composite measure of social pathologies was created from homicide rate in 2008 (UN Office of Drugs and Crime, http://www.unodc.org/unodc/en/data-and-analysis/homicide.html), crime victimization (stealing, mugging, Gallup World Poll at http://www.gallup.com/ poll/world.aspx), and adolescent fertility rate from the Demographic Yearbook of the United Nations 2009/10 (UN, 2010). These three measures are highly correlated both with each other and the Gini index.

Table 4 shows that social pathologies are indeed powerfully suppressed by higher intelligence, but negative effects on economic growth approach statistical significance only in the subsample of rich countries.

D. Technology and trade: A composite measure of technological competitiveness (variable D1 in Table 4) was computed from (1) 8 topics of the Global Competitiveness Report 2001/02 (World Economic Forum, http://www.cid.harvard.edu/archive/cr/): unique products, sophisticated production processes, sophisticated marketing, quality of research institutions, buyer sophistication, log-transformed patents/capita, company innovation, and company R&D spending; (2) Average of log-transformed royalties/capita, patents/capita, scientific articles/capita, and books published/capita, obtained from the World Development Indicators of the World Bank and the Human Development Reports of the United Nations; and (3) the Arco technology index 1990 (Archibugi & Coco, 2004).

Table 4 shows that technological competitiveness is indeed higher in countries with higher average intelligence, confirming an earlier report by

Gelade (2008). However, a positive effect of technology on economic growth can be demonstrated only for poor but not rich countries. This indicates that diffusion of know-how from the technological frontier to less developed countries is beneficial for these countries. The failure of innovation to stimulate growth in rich countries might be related to the ease with which foreign innovations can be bought or copied, with the result that the countries in which the innovations originate are not always those that profit from them the most. Also, per capita rates of major innovations appear to have been declining throughout the last century (Woodley, 2012), possibly to a point where they are becoming less important for continued economic growth.

The measure of trade openness (1975-2005 average) is from the Penn World Tables 7.0 (Heston et al, 2011). The results show that trade is favored only marginally if at all by higher intelligence, and that its economic benefits can be demonstrated only for rich but not poor countries. Quite possibly, the terms of trade favor the more advanced economies, such that net benefits for less affluent countries are nil.

E. Good government: Most indicators in this category, including *Government Effectiveness*, *Regulatory Quality*, *Rule of Law*, and *Political Stability*, are from the Governance Indicators of the World Bank (www.govindicators.org), each averaged over the 1996-2005 time period. *Political Freedom* and *No Corruption* are the same variables as in Tables 2 and 3.

The only measure in this group that is consistently unrelated with intelligence and economic growth is political freedom, confirming the results of the regression models in Table 3. The others are potent promoters of economic growth in both rich and poor countries. Most of these indicators of "good government" have previously been found to be associated with intelligence (Kalonda Kanyama, 2014). The present results confirm this association for rich countries but not poor countries. The reasons for the latter observation are unknown. Uncertain quality of governance data from some of the poorer countries may be one reason. Another possibility is that higher intelligence in poor countries leads to rent seeking instead of institution building. However, good government promotes economic growth equally in poor and rich countries. The five governance indicators (excluding political freedom) are highly correlated with each other for the 120 countries in the complete sample, with Pearson's *r*'s between .770 (freedom from corruption and political stability) and .965 (government effectiveness and rule of law). Unlike big government, good government is consistently related to intelligence and economic growth in the expected direction and is an important mediator of intelligence effects on growth, at least in the more developed countries.

F. Demography and health: Rampant population growth in developing countries has been a major concern in development economics since the mid-20th century, when populations seemed to grow exponentially in the developing world. Fast population growth, it was assumed, would prevent economic growth by reducing the amount of land and capital per capita. Developing countries were seen as moving into a Malthusian trap (e.g., Ehrlich, 1968). This received wisdom was challenged by the late Julian Simon (1996, 2000), who maintained that growing populations are the most important resource for economic growth (Fitzpatrick & Spohn, 2009; see also Headey & Hodge, 2009). Table 4 and Figure 4 give a decisive answer: High fertility is a powerful correlate of slow growth, even in prosperous countries. It is also evident that high average intelligence in the country, together with extensive schooling and to some extent high prosperity, is a major predictor of low fertility, confirming earlier results (Meisenberg, 2009). Reduced fertility accounts for approximately 30% of the intelligence effect on economic growth, as well as for most or all of the effect of prolonged schooling.

The reason for this is not necessarily a mismatch between population and physical resources, since even the poorest countries today show little signs of being caught in a Malthusian trap (Kenny, 2010). Also, Asian countries with their high population densities and scarcities of land and natural resources have done far better than the sparsely populated, resource-rich Sub-Saharan African countries. A more likely reason is that in both rich and poor countries, excess fertility is contributed mainly by the least educated sections of the population (Meisenberg, 2008b). The challenge of educating large numbers of children from poor family backgrounds and integrating them into the work force is one likely contributor to the adverse effect of high fertility on growth. It is unlikely that high fertility would be an economic liability if the excess births were contributed by the most educated and productive sections of the population. The importance of the quality rather than the quantity of the human population has been emphasized, for example, by Lutz (2009).

Health and longevity are correlates of high intelligence at the individual level (e.g., Wrulich et al, 2013), most likely because more intelligent people tend to have healthier lifestyles and are better able to manage their health problems. At the country level, better health of the working-age population is a plausible contributor to labor productivity (Beraldo, Montolio & Turati, 2009). The last two variables in Table 4 show that better health, indexed by life expectancy and under-5 mortality, is indeed related to higher average intelligence in the country. Better health, in turn, is associated with economic growth, although this effect is statistically significant only for under-5 mortality.

In summary, Table 4 shows that intelligence promotes economic growth through multiple channels. Reduced fertility is a major mechanism, and it appears to mediate the effect of education as well (see Figure 4). "Good government" is another important mediator of the intelligence effect although "small government" is not. Good business management, or "managerial capital" (Bloom et al, 2010; Bruhn, Karlan & Schoar, 2010), may be important as well, but no good indicators of managerial capital are available at the country level. It is reasonable to expect that the quality of business management tends to be high in countries with effective government institutions, because both depend on the competence of managerial personnel. Therefore the governance indicators may, in part, be proxies for good business practices as well.

Another possible mediator of intelligence effects that is difficult to measure at the country level is the willingness and ability to cooperate. A review by Jones (2008) shows that cooperativeness, measured in the Prisoner's dilemma game, is positively related to intelligence. This correlate of intelligence may explain some of the relationship of intelligence with governance. Other likely mediators of the intelligence effect include less red tape and restrictions on economic activities ("economic freedom"), higher savings and/or investment, and technology adoption in developing countries.

7. A General Theory of Economic Growth, 1700-2000

7.1. The Anomaly of Economic Growth

Since the Industrial Revolution of the 18th and 19th centuries, Europe and its overseas clones have experienced more than two centuries of bumpy but sustained economic growth driven by a seemingly inexhaustible stream of innovations. That sustained economic growth is an anomaly that occurred only once in human history is obvious. Through many millennia before the Industrial Revolution, rates of economic growth and contraction were minimal by today's standards, with little change in per capita production and consumption. It is also obvious that the beginning of sustained economic growth was accompanied by rising literacy and the development of a scientifically founded world view. Thus we observe, at the same time or in short succession, phenomena as diverse as the rise of science, the Enlightenment, technological innovations, the Industrial Revolution, humanism, democracy, secularization, birth control and economic growth (Oesterdiekhoff, 2014). The co-occurrence of these disparate phenomena in the same place (northern and western Europe) at the same time (17^{th} to 20^{th} centuries) is unlikely to be the result of chance. Therefore the question: What is their common denominator?

7.2. The Anomaly of the Flynn Effect

The only sensible answer to the riddle of behavioral and economic modernity is that the people changed. They became more intelligent and more rational. For the 20^{th} century, this statement is not mere conjecture but has been proven beyond doubt by psychometric intelligence research. The pervasiveness of rising intelligence in modern societies had not been appreciated until James Flynn's studies in the 1980s (Flynn, 1987), but we do have firm evidence for Flynn effects from the beginning of the 20^{th} century. Tuddenham (1948) compared the IQ test results of white conscripts in the American army during World Wars I and II, finding a difference of 12.9 IQ points favoring the World War II draft (see Table 1). In Britain, standardizations of Raven's Standard Progressive Matrices, the most widely used "culture-reduced" non-verbal intelligence test, in 1942 and 1992 showed an IQ gain of 22 points between the 1890 and 1940 birth cohorts (Raven, Raven & Court, 1998; see Table 1). Thus there is evidence that cohorts born around 1900 were experiencing Flynn effects already.

There is no psychometric evidence for rising intelligence before that time because IQ tests were introduced only during the first decade of the 20^{th} century, but literacy rates were rising steadily after the end of the Middle Age in all European countries for which we have evidence (Mitch, 1992; Stone, 1969), and the number of books printed per capita kept rising (Baten & van Zanden, 2008). These developments indicate that intelligence and intellectual curiosity—an almost inevitable consequence of high intelligence—were rising during these centuries. Mokyr (2005) argues that because rising intellectual development was very much in evidence before the beginnings of the Industrial Revolution, it should be considered a cause or precondition of modern economic growth, rather than only its consequence. Mokyr (2009) also argues that without effective enforcement of intellectual property rights, the technological innovations of the Industrial Revolution were not caused primarily by material incentives. What was rising at that time was the supply of creative individuals, not the demand or incentives for innovation. We also know that two negative correlates of high intelligence, income inequality and violent crime (variables C2 and C3 in Table 4), were declining in Europe since the Middle Age (Eisner, 2003; van Zanden, 2009). Thus we have at least indirect evidence for rising intelligence before, during, and after the Industrial Revolution.

The late phase of this process is the Flynn effect. Its causes have been much debated, but its sheer magnitude – approximately 30 IQ points (2 present-day standard deviations) during the 20th century – virtually excludes genetic changes, which have a major impact only on longer time scales of several centuries to millennia (Meisenberg, 2008c). Therefore massive improvements must have taken place in the environmental determinants of intelligence. Improved nutrition is one candidate (Lynn, 1990), but the extent to which it contributed to the Flynn effect is impossible to estimate. Brain size increased to some extent along with body size during the last century (Miller & Corsellis, 1977), and given the known correlation of about 0.4 between brain size and intelligence (Rushton & Ankney, 2009), this may have made a modest contribution.

More important was almost certainly the massive expansion of educational systems during the 20th century (Schofer & Meyer, 2005). Compulsory public school systems had been introduced during the 19th century in most European countries. Before that time, rising literacy and more extensive schooling had been driven more by rising demand than by rising supply (Mitch, 1992). Today, one stylized fact about formal education is that it raises IQ by 2 to 4 points per year in adolescence (Brinch & Galloway, 2012; Falch & Massih, 2011; Hansen, Heckman & Mullen, 2004). In the United States, for example, the average length of schooling rose from 7.6 years for the 1890 birth cohort to 12.9 years for the 1950 birth cohort (Goldin, 1998). This alone is expected to translate into an IQ gain of 10.5 to 21 points during this 60-year period. Other factors that most likely have contributed to the Flynn effect include better quality of education, urbanization, mass media, and generally the rising complexity of everyday life.

7.3. Feedback between Intelligence and Economic Growth

Whatever the precise causes of the Flynn effect may have been, rising intelligence solves the puzzle of sustained economic growth in the recent past. We only need to accept two propositions: (1) environmental improvements, including a more effective school system and more cognitively stimulating environments outside of school, raise children's intelligence; and (2) intelligent people are more likely than less intelligent people to provide good schools and stimulating environments for their children's intellectual growth.

In this general form, neither of these propositions is controversial. If we accept both, the following prediction emerges: Once the intelligence of a population rises beyond a certain threshold, people will begin raising their living standards through technological and institutional improvements that lead to economic growth. They will also increasingly appreciate the value of intellectual development. Aided by greater prosperity, they will provide a better education for their children, both in and outside of school. In consequence the next generation will grow up to be, on average, more intelligent than their parents. This enables them to innovate even more, raise living standards even more, provide even better education for *their* children, and thereby raise the next generation's intelligence even more. This trans-generational feedback between economic growth and rising intelligence summarizes the dynamic of modern civilization (Meisenberg, 2007b, p. 273-278). It is possible only because of the high (but not infinite) malleability of human intelligence.

7. 4. Why Europe?

Why did this spiral of economic and cognitive growth take off in Europe rather than somewhere else, and why did it not happen earlier, for example in classical Athens or the Roman Empire? One part of the answer is that this process can start only when technologies are already in place to translate rising economic output into rising intelligence. The minimal requirements are a writing system that is simple enough to be learned by everyone without undue effort, and a means to produce and disseminate written materials: paper, and the printing press. The first requirement had been present in Europe and the Middle East (but not China) since antiquity, and the second was in place in Europe from the 15th century. The Arabs had learned both paper-making and printing from the Chinese in the 13th century (Carter, 1955), but showed little interest in books. Their civilization was entering into terminal decline at about that time (Huff, 1993).

A second requirement is the desire of the cognitive elite to use their abilities for technological and institutional improvements rather than philosophical musings or theological debate. This precondition was present in the educated middle classes of early modern Europe, but possibly not in classical antiquity, when many members of the educated classes expressed their disdain for physical labor and the craftsman's work (Mokyr, 1990, pp. 193-208).

Perhaps the most general condition is what we may call aggregate brainpower. A solitary genius is not sufficient to start a scientific or industrial revolution, or a major philosophical movement such as the Enlightenment. Major historical developments like these require a critical mass of interacting minds. The ability to reach this critical mass depends on two factors: the size of the population, and its level of innate talent, or "genotypic intelligence." Classical Athens may have had high genotypic intelligence and a high rate of geniuses per capita, but population size was insufficient for the transition to sustained economic and intellectual growth. Also the 17th and 18th century British had high genotypic intelligence, but they also had a sufficiently large population to bring forth the number of great minds required for the scientific and industrial revolutions.

Demographic behavior was a critical factor for the production of this aggregate brainpower in early modern Europe. In the Malthusian economies of the pre-industrial civilizations, usually greater wealth resulted in a greater number of surviving children. This has been demonstrated for medieval (Razi, 1980) and early modern England (Boberg-Fazlic, Sharp & Weisdorf, 2011; Clark & Hamilton, 2006), where the phenomenon has been dubbed the "survival of the richest." If, as is likely, higher intelligence favored upward social mobility while the excess children of the upper classes moved down the social hierarchy, cultural and genetic selection for higher intelligence was inevitable. Gregory Clark (2007, p. 112-132) proposed precisely this as the reason for the rise of England during the run-up to the Industrial Revolution. Genetic selection for a socially desirable trait such as intelligence is called eugenic fertility, while selection for undesirable traits is called dysgenic fertility.

The survival of the richest persisted into the 19th century in most European countries (Skirbekk, 2008) and to the mid-20th century in China (Lamson, 1935; Moise, 1977; Notestein, 1938; Wolf, 1984), but ended abruptly with the early stages of the demographic transition. Whenever intelligence rises and people become more rational, one invariable consequence is that birth control spreads among the more educated and intelligent sections of the population

(Livi-Bacci, 1986). Fertility differentials reverse in favor of the less educated and intelligent (Skirbekk, 2008), and eugenic fertility gives way to dysgenic fertility.

One detailed study, for example, found that at the time of the French Revolution, the wealthy had more children than the poor in those French townships in which fertility was still high; but the poor had more children than the wealthy in those that were experiencing significant fertility decline already (Cummins, 2013). Importantly, post-transitional fertility differentials are not primarily by wealth, but by education and intelligence: the survival of the richest is replaced not by the survival of the poorest, but the survival of the dumbest. Figure 4 shows that this applies not only to fertility differentials within countries, but also between countries. The reversal of fertility differentials during fertility decline can be considered a general law of demography, since exceptions are extremely rare. A survey of 77 countries showed that at the end of the 20th century, the relationship of educational attainment (years in school and highest degree) with fertility was negative in *all* of them (Meisenberg, 2008b).

This general law of demography explains why the self-reinforcing spiral of Flynn effect and economic growth could take off in Europe but not in classical antiquity or the Muslim Middle East. Usually, the adoption of contraceptive practices by the cognitive elite during the earliest stage of the demographic transition will curtail the supply of highly gifted individuals and thereby prevent further advances that could trigger sustained economic growth. In the Muslim Middle East, in particular, where contraception (mainly by withdrawal) was tolerated by religion and was practiced widely during the heyday of Muslim civilization (Musallam, 1983), we can diagnose protracted cultural and economic decline over the last millennium.

In Europe, by contrast, religious condemnation of contraception was so virulent that much of the earlier knowledge was lost by the time of the Renaissance (McLaren, 1990; Noonan, 1986; Riddle, 1992). In consequence, demographic transition and dysgenic fertility were delayed to a time *after* the Industrial Revolution and the beginnings of the Flynn effect. As late as 1848, John Stuart Mill observed: “That it is possible to delay marriage, and to live in abstinence while unmarried, most people are willing to allow; but when people are once married, the idea, in this country, never seems to enter anyone’s mind that having or not having a family, or the number of which it shall consist, is amenable to their own control. One would imagine that children were rained down on married people, direct from heaven, without their being art or part in the matter, that it was really, as the common phrases have it, God’s will and not their own, which decided the number of their offspring." (Mill, 1976 [1848], p. 155) Because the trans-generational feedback between Flynn effect and economic growth had started already when attitudes to birth control finally changed and fertility differentials became dysgenic in Europe, the Flynn effect could mask the slow genetic decline that resulted from the new demographic regime.

8. PROJECTIONS AND PREDICTIONS OF ECONOMIC GROWTH

8.1. Short-term Projection, 2011-2050

Turning our attention from the past to the future, we must distinguish between short-term *projections* for the next few decades, which directly apply the relationships that were observed in the recent past to the near future, and *predictions* for the more distant future, which are based on the underlying dynamic of long-term economic growth and human development. The projection of short-term economic growth can be achieved with regression equations similar to those in Table 3. Simplifying the model for all countries in Table 3 to include log-transformed initial per capita GDP and intelligence as the only predictors, we obtain the following:

% annual growth = -2.876 – 2.189 x lgGDP 1975 + 0.146 x IQ

If schooling is included, we obtain:

% annual growth = -1.299 - 2.593 x lgGDP 1975 + 0.132 x IQ + 0.144 x Schooling

Substituting lgGDP 2011 for lgGDP 1975, and average length of schooling for 20- to 24-year-olds in 2010 for the earlier schooling variable (based on all adults aged 15+, 1995-2010 average), we obtain the projected annual growth rates of per capita GDP for the near future. We call the projections that are based only on lgGDP 2011 and intelligence version 1, and those based on lgGDP 2011, intelligence and schooling version 2. As expected, growth rates in versions 1 and 2 are highly correlated, with Pearson's *r* of .974 (N = 134 countries). There is moderate continuity between observed past and projected future growth rates, with Pearson's *r* of .496 (version 1) and .484 (version 2), based on 117 countries.

Average annual growth rates are projected to decline from 3.77% in the 1975-2011 period to 1.91% (version 1) or 2.03% (version 2), based on 117 countries for which all three growth rates are available. These averages are weighted for the size of the population in 2010, and cover a total population of nearly 6.01 billion (Table 5). The projected growth rates are lower than the observed past growth rates because one of the main predictor variables, log-transformed per capita GDP, was generally higher in 2011 than in 1975, while intelligence has been assumed to be unchanging. In essence, the projections assume that countries evolve toward a level of prosperity that is commensurate with their level of intelligence. The reason for the slightly higher growth rates in version 2 is that in most countries educational exposure (years in school) is higher for the measure used in the projection (20-24 year olds in 2010) than for the measure used in the 1975-2011 growth regressions. Table 5 shows the past and projected future growth rates for the major world regions, based on the 117 countries for which complete information is available. Table 6 shows growth rates for a selection of individual countries, including most of the

Table 5. Short-term projection of economic growth for different world regions.[1)]

Region	Growth rates			N	
	1975-2011	2011-50 v. 1	2011-50 v. 2	Countries	Population
Prot. Europe	1.77	1.57	1.57	8	132.1
Cath. Europe	1.57	1.51	1.67	11	220.0
English	1.78	1.39	1.52	6	437.5
Excommunist	2.16	1.84	2.08	6	83.2
Latin America	1.34	1.03	1.29	23	572.6
Middle East	1.87	1.21	1.30	15	614.4
South/SE Asia	3.69	1.48	1.59	11	1950.1
Oceania	0.60	1.87	1.79	3	7.8
East Asia	7.81	3.71	3.77	7	1528.7
Africa	0.13	0.63	0.86	27	458.9
World	3.77	1.91	2.03	117	6005.1

[1)] Version 1 of the projected growth rate (2011-50 v. 1) is based only on lgGDP 2011 and IQ; version 2 (2011-50 v. 2) is based on lgGDP 2011, IQ, and average length of schooling. Population is in millions (2010). For definition of the world regions, see legend of Figure 1.

successor states of the former Soviet Union and Yugoslavia, which are not represented in Table 5.

Differences in growth rates between countries are projected to narrow, with a decline in the standard deviation of annual growth rates from 2.86 in the 1975-2011 period to 1.18 (version 1) or 1.15 (version 2) in the 2011-2050 period (all weighted for population size). For example, Table 5 shows that growth rates in Sub-Saharan Africa, which had been the lowest of any major world region, are projected to be somewhat higher in the near future, although still quite low. Conversely, growth in East Asia, which was the world's highest in the 1975-2011 period, is projected to decline to about half of its former value.

Table 6. Short-term projection of economic growth for selected countries

			Version 1		Version 2	
Country	% Growth 1975-2011	GDP 2011	% Growth 2011-2050	GDP 2050	% Growth 2011-2050	GDP 2050
Protestant Europe						
Finland	2.05	32345	1.97	69220	1.93	68169
Germany	1.83	35071	1.57	64387	1.55	63895
Sweden	1.69	34707	1.58	63964	1.74	68013
Catholic Europe & Mediterranean						
France	1.44	29477	1.64	55591	1.80	59108
Greece	1.15	21096	1.25	34246	1.66	40092
Italy	1.47	27239	1.42	47208	1.70	52566
Spain	1.67	25694	1.54	46632	1.57	47172
English-speaking countries						
Australia	1.80	38042	1.58	70111	1.80	76283
Canada	1.54	36335	1.80	72860	1.80	72860
UK	1.89	32080	1.73	62625	1.85	65571
USA	1.77	42244	1.26	68841	1.39	72373
Ex-communist countries						
Armenia		5667	2.55	15130	2.73	16201
Azerbaijan		8801	0.87	12338		
Bosnia		7176	2.28	17287		
Bulgaria	2.66	11738	1.83	23809	2.08	26199
Croatia		15080	2.21	35371	2.37	37596
Czech Rep.		22894	2.01	49750	2.23	54110

			Version 1		Version 2	
Country	% Growth 1975-2011	GDP 2011	% Growth 2011-2050	GDP 2050	% Growth 2011-2050	GDP 2050
Estonia		16741	2.45	43028	2.67	46782
Georgia		6303	1.07	9546		
Hungary	1.60	16315	2.24	38708	2.63	44904
Kazakhstan		11945	0.57	14909	0.90	16941
Kyrgyzstan		2723	0.98	3983	1.36	4612
Latvia		12859	2.15	29478	2.55	34332
Lithuania		15811	1.74	30984	2.18	36663
Romania	1.96	10844	1.55	19756	1.81	21828
Russia		14662	2.09	32850	1.95	31138
Serbia		9323	1.64	17582	1.63	17515
Ukraine		6951	2.48	18071	2.84	20719
Latin America						
Argentina	1.32	13882	1.54	25194	1.78	27624
Bolivia	0.48	3746	2.00	8109	2.74	10750
Brazil	1.46	8911	1.03	13289	1.27	14577
Chile	3.31	13519	1.15	21116	1.62	25301
Colombia	1.78	7765	0.80	10595	0.99	11402
Mexico	1.17	12516	0.96	18167	1.28	20554
Peru	1.01	7891	0.88	11105	1.06	11905
Venezuela	-0.20	9990	0.73	13267	0.75	13370
Muslim Middle East & North Africa						
Egypt	3.98	5171	1.07	7831	1.26	8427
Iran	0.38	12269	0.67	15919	0.95	17740
Iraq	0.59	4160	1.90	8667	1.65	7876
Jordan	2.06	5199	1.65	9843	2.11	11738
Morocco	2.16	3648	1.18	5764	1.17	5742
Pakistan	2.24	2535	1.94	5363	2.06	5615
Sudan	1.86	2253	1.10	3452	0.81	3086
Tunisia	2.57	6808	1.13	10552	1.49	12121
Turkey	2.29	13058	1.12	20161	1.15	20396
South and South-East Asia						
Bangladesh	2.49	1646	1.91	3443	2.29	3980
India	3.91	3598	1.23	5796	1.26	5863
Indonesia	3.91	4208	1.72	8183	1.89	8734
Malaysia	3.62	12268	1.51	22010	1.88	25365
Philippines	1.10	3634	1.68	6959	2.08	8111
Thailand	4.30	8425	1.68	16135	1.93	17756

Table 6. Short-term projection of economic growth for selected countries (continued)

East Asia						
			Version 1		Version 2	
Country	% Growth 1975-2011	GDP 2011	% Growth 2011-2050	GDP 2050	% Growth 2011-2050	GDP 2050
China	8.46	9486	3.87	41706	3.91	42337
Japan	1.99	31587	2.48	82117	2.75	90991
Korea, South	5.85	29618	2.64	81829	2.90	90314
Singapore	4.55	43562	2.58	117639	2.47	112819
Taiwan	5.33	34123	2.48	88710	2.75	98297
Sub-Saharan Africa						
Cameroon	0.26	1829	-0.05	1794	0.24	2008
Cote d'Ivoire	-1.22	1338	0.29	1498	0.21	1452
Ghana	1.17	2349	0.03	2377	0.49	2842
Kenya	0.61	1308	1.25	2123	1.75	2573
Mozambique	2.00	782	1.07	1184	0.80	1067
Nigeria	0.69	2014	0.66	2603		
South Africa	0.50	7918	-0.96	5435	-0.48	6563
Tanzania	1.37	1217	1.15	1901	1.38	2077
Uganda	1.30	1267	0.90	1797	1.22	2033
Zambia	-0.71	1355	0.66	1751	0.95	1959
Zimbabwe	-0.52	4306	-0.15	4061	0.21	4673

8.2 Limitations of short-term growth projections

The projection of economic growth rates based on current prosperity and human capital assumes that the macroeconomic returns to human capital will be the same in the near future as in the recent past. This assumption is reasonable because the strength of the relationship between intelligence and growth rates is similar in rich and poor countries today (Table 3). As many of today's poor countries become more prosperous and more intelligent, they will in all likelihood maintain the intelligence-growth relationship that is seen in rich countries today.

However, the projections ignore country-specific factors. For example, projected growth rates in Table 6 are lower for Iran and Iraq than for other Middle Eastern countries. The reason is that these countries are relatively prosperous already because of their oil wealth, and slow growth is expected because of their combination of relatively high per capita GDP with mediocre

IQ. The projections do not take into account that the presence of natural resources adds to the wealth of the country. These countries evolve to a level of prosperity that is commensurate not only with their intelligence, but also with the profits they obtain from their oil exports.

Another factor is the dispersion of intelligence in the country. For example, South Africa is projected to have negative growth during the coming decades, based on its relatively high prosperity combined with low *average* IQ. One reason is again that South Africa is resource-rich. More important, however, is the strongly skewed distribution of intelligence in the country, with a white minority of approximately 15% that has a European-like IQ average in the 90s, and a large African majority with a typical African IQ near 70 (Lynn, 2006). Unbeknownst to the regression equations, this gives South Africa a higher "equilibrium GDP" because the IQ of individuals at the upper end of the distribution tends to be more important than the IQ in the middle and lower reaches of the distribution for the economic success of countries (Rindermann, Sailer and Thompson, 2009).

8.3. The Future of the Flynn Effect

However, the most important observation is that the projections offer little comfort for developing countries. Although growth in Sub-Saharan Africa is projected to pick up, the regions with the lowest growth rates will still be Africa, Latin America and the Middle East. The reason is that the projections assume unchanging intelligence differentials between countries. Therefore less developed countries are close to the level of prosperity already that matches their generally low IQs.

The assumption of unchanging intelligence differences between countries, or equal Flynn effects everywhere, is a reasonable approximation to reality on time scales of 2, 3, or even 4 decades. Therefore it is justifiable to use the same IQ data set to estimate prevailing IQs during the 1975-2011 and the 2011-2050 periods. However, we cannot realistically predict longer-term trends without making assumptions about the strengths of anticipated Flynn effects in different countries and the resulting changes in average intelligence. For example, the growth trajectories for Sub-Saharan Africa in Tables 5 and 6 are likely to rise above the projection even before 2050 if, as claimed by Wicherts et al (2010), strong Flynn effects are beginning already to raise the average African IQ in the younger generation.

Table 1 shows that Flynn effects on IQ tests averaged about 2 or 3 points per decade during the 20th century, for example in Britain and the United States. Periods with far larger gains invariably coincided with brief periods of rapid economic growth and expanding educational systems. Gains were frequently larger for younger than older ages, as shown in Table 1 for performance on the non-verbal Raven's Progressive Matrices test in Britain: Cohorts born between the late 1960s and the 1990s were gaining 2 points/decade at age 8-12, but lost 0.8 points/decade at ages 13-15. Also, in most cases gains in reasoning ability have been larger than gains in school-related knowledge and skills. In the United States, all age groups have gained about 3 points/decade on the Wechsler tests (Flynn, 2012). However, on the National Assessment of Educational Progress (NAEP, "the nation's report card"), which tests mastery of curricular contents, gains per decade between 1971 and 2008 were the IQ equivalent of 2.02 points at age 9, 1.20 points at age 13, and 0.30 points at age 17 (Rindermann & Thompson, 2013).

Most important is that Flynn effect gains have been decelerating in recent years. Recent losses (anti-Flynn effects) were noted in Britain, Denmark, Norway and Finland. Results for the Scandinavian countries are based on comprehensive IQ testing of military conscripts aged 18-19. Evidence for losses among British teenagers is derived from the Raven test (Flynn, 2009) and Piagetian tests (Shayer & Ginsburg, 2009). These observations suggest that for cohorts born after about 1980, the Flynn effect is ending or has ended in many and perhaps most of the economically most advanced countries. Messages from the United States are mixed, with some studies reporting continuing gains (Flynn, 2012) and others no change (Beaujean & Osterlind, 2008).

Table 1 also shows that reports of Flynn effects in developing countries are becoming more frequent. Studies of international scholastic assessments (TIMSS, PISA) between 1995 and 2011 show a similar picture: little change in the high-scoring, economically developed countries, and gains in lower-scoring, less developed countries (Meisenberg & Woodley, 2013). These assessments are done at age 15 (PISA) or in grade 8 (TIMSS).

Most likely, Flynn effects are ending in the high-IQ countries because we cannot raise intelligence indefinitely with better education for the same reason that we cannot raise height indefinitely with better nutrition, longevity with healthier lifestyles, and corn yields with more fertilizer. The observations suggest that genetic limits to human intelligence are being approached in the most advanced nations, resulting in diminishing returns to additional educational inputs.

In less developed countries, however, educational systems and other aspects of children's intellectual environment are still suboptimal and sometimes awful, and nutritional deficiencies and chronic parasitic diseases are still prevalent in many places. Therefore continued environmental improvements can achieve large intelligence gains until the populations of these countries reach their genetic limits as well. The efforts being invested in the educational systems of developing countries today (Kremer, Brannen & Glennerster, 2013) make it likely that this will be achieved well before the end of the 21st century in virtually all countries, and by about 2050 in most.

We do not know where the genetic limits of cognitive development are for different countries. If each nation has the same genetic capacity for higher intelligence, world-wide differences in intelligence and prosperity will diminish or disappear within two or three generations, much as the gaps between East Asian countries and the West have diminished or disappeared in the last two or three generations. However, there is no theoretical reason to expect equal potential for high intelligence in each nation, and no empiric evidence in its favor. The only molecular genetic studies that speak to this question show that allele frequencies for genetic variants influencing educational attainment and intelligence differ between human populations, and that many of the reported "high-IQ" variants are indeed more common in countries with higher IQ and educational attainment (Piffer, 2013a,b).

8.3. Consequences of Vanishing Flynn Effects

Continuing Flynn effects in less developed countries combined with cognitive stagnation or slow decline in the more developed countries will have important economic consequences. The projected growth rates in Tables 5 and 6 will have to be adjusted downward for high-income, high-IQ countries, and upward for low-income, low-IQ countries. Eventually the empiric relationship between intelligence and economic growth, which has been positive in the recent past (see Table 2), may even reverse. In the long run, it is not high intelligence but *rising* intelligence that leads to economic growth.

Genetic endowments for high intelligence can be described as innate responsiveness to educational efforts and other environmental enhancements. Therefore the two-way interaction between improving environments and rising intelligence outlined in section 7.3 implies that even small differences in genetic endowments can become amplified into far larger actual (phenotypic) differences. At the end of the Flynn effect, nations with lower "genotypic intelligence" will have achieved lower phenotypic intelligence, which leads to lower-quality school systems compared with nations that have slightly higher genotypic intelligence. Therefore phenotypic IQ differences between nations will remain larger than genotypic differences. They may never become quite as small as the differences that we observe today, for example, between racial and ethnic groups in the United States. A single country can maintain equal standards for everyone in its educational system, and socio-economic disparities can be buffered through the welfare state. Such measures are not available to diminish achievement gaps between countries.

9. THE END OF ECONOMIC GROWTH

9.1. Interactions between History and Biological Evolution

Developments on a time scale of centuries are affected not only by Flynn effects and anti-Flynn effects, but also by ongoing genetic changes. Evidence is overwhelming that *within* virtually all countries, fertility differentials have been dysgenic for educational attainment or intelligence since the demographic transition (Meisenberg, 2008b; Skirbekk, 2008). Conservative estimates for the "genotypic" decline that this has caused in western countries since the 19^{th} century have ranged from 0.3 to slightly more than 1 IQ point per generation (reviewed in Lynn, 2011), although higher estimates of up to 1.23 points per decade have been proposed (Woodley, te Nijenhuis & Murphy, 2013). The conservative estimates are only about one tenth as large as the environmentally caused Flynn effect gains that were observed at the same time (see Table 1). Thus the small genetic losses have been swamped by far larger environmentally caused gains.

In addition, nations with lower levels of education and intelligence are growing rapidly while those with higher intelligence are contracting (see Figure 4 and Table 4, variable F1). Differential fertility between countries has been calculated to reduce (phenotypic) intelligence by approximately 0.73 points/decade for the world population between 2000 and 2050 (Lynn & Harvey, 2008) or by 1.34 points/decade for younger cohorts (Meisenberg, 2009), assuming that average intelligence within countries does not change. We do not know what proportion of this decline is genetic, but it implies that Flynn effects of this magnitude are required to offset the predicted decline of the world's IQ that results from fertility differentials between countries.

9.2. "Peak IQ" and the Question of Sustainability

The unsustainability of this situation is obvious. Estimating that one third of the present IQ differences between countries can be attributed to genetics, and adding this to the consequences of dysgenic fertility within countries, leaves us with a *genetic* decline of between 1 and 2 IQ points per generation for the entire world population. This decline is still more than offset by Flynn effects in less developed countries, and the average IQ of the world's population is still rising. This phase of history will end when today's developing countries reach the end of the Flynn effect. "Peak IQ" can reasonably be expected in cohorts born around the mid-21st century. The assumptions of the peak IQ prediction are that (1) Flynn effects are limited by genetic endowments, (2) some countries are approaching their genetic limits already, and others will fiollow, and (3) today's patterns of differential fertility favoring the less intelligent will persist into the foreseeable future.

Exceptionally high intelligence will become less common *before* the average intelligence of the world population begins declining, mainly because the nations that are producing most of the exceptional talent today are contracting. At today's cohort fertility rates, the decline per generation of the young adult population is 20% in Russia, 25% in Germany, and 30% in Italy and Japan (Myrskylä, Goldstein and Cheng, 2013). A similar effect has been achieved by the one-child policy in China. There is no indication that sub-replacement fertility in the economically advanced nations is abating. The intelligence of the "cognitive elite" tends to be more important than average intelligence for patentable inventions, Nobel Prizes, and good government (Rindermann, Sailer & Thompson, 2009). A world-wide depletion of exceptional ability may be occurring already, if the reported decline in the per capita rate of major innovations since the late 19th century (Woodley, 2012) is real. Thus a dearth of innovations in society and technology, leading to a recycling of old ideas and practices, is expected to be the first sign of impending stagnation and terminal decline. The true sustainability issue of the modern world economy is not the depletion of non-renewable resources such as fossil fuels, but the depletion of the mental powers that are required for the maintenance of a functioning economy.

9.3. Brain Drain, Brain Gain and Replacement Migration

Fertility differentials between countries lead to replacement migration: the movement of people from high-fertility countries to low-fertility countries, with gradual replacement of the native populations in the low-fertility countries (Coleman, 2002). The economic consequences depend on the quality of the migrants and their descendants. Educational, cognitive and economic outcomes of migrants are influenced heavily by prevailing educational, cognitive and economic levels in the country of origin (Carabaña, 2011; Kirkegaard, 2013; Levels & Dronkers, 2008), and by the selectivity of migration. Brain drain from poor to prosperous countries is extensive already, for example among scientists (Franzoni, Scellato & Stephan, 2012; Hunter, Oswald & Charlton, 2009).

In the second half of the 21st century, when Flynn effects have ended and dysgenic IQ declines become more visible, in theory the world's most attractive countries can maintain their economic lead by attracting highly intelligent migrants from abroad. However, this parasitic existence may never be realized in most of these countries because native elites may be unwilling to compete with highly capable immigrants. Thus immigration policies may end up favoring low-skilled immigration.

9.3. The Dysgenic Meltdown

Brain drain is one reason why most of the less developed countries will never become nearly as prosperous as the more developed ones. But even the most prosperous and attractive countries will eventually become depleted of the talent that is required to maintain their economic vitality and their institutions. In the educational system, slowly declining intelligence of teachers and school administrators is predicted to reduce the quality of instruction and lead to poorer student outcomes, resulting in even greater deterioration in the following generation. The trans-generational spiral of Flynn effect and economic growth described in section 7.3 will go in reverse, with declining intelligence and deteriorating environments reinforcing each other.

How fast this dysgenic meltdown will unfold and the form it will take are difficult to predict because we have no close historic precedent. There have been "dark ages" of collapse and of cultural and technological regress in the past (Aiyar, Dalgaard & Moav, 2008; Wilkinson, 1995), but never from a level nearly as high as that achieved by the present civilization. It will most likely occur at different times in different countries and world regions. The decline may be slower than the ascent from the 17th to the early 21st centuries because people may be able for a long time to maintain technologies and practices that they no longer fully understand, or it may be faster because the effects of economic and educational deterioration are reinforced by continued dysgenic fertility.

9.4. Alternatives

Can the dysgenic meltdown be prevented with technologies that are under development today or are likely to be developed in the near future? We still experience technological advances that seem to track the Flynn effect, although by most counts (summarized in Woodley, 2012), the per capita rate of *major* innovations has been declining since the late 19th century. Incremental improvements can be achieved by well-trained people with unexceptional native talent, although extraordinary achievement requires high innate ability combined with favorable external conditions. Thus incremental improvements of technologies such as computer science and molecular genetics are likely to continue through the 21st century, although at a slowly decelerating rate.

Using methods of molecular genetics to produce highly talented people is, in theory, possible even with methods that are known today. Knowledge about the genes that contribute to intelligence and educational achievement is accumulating slowly (e.g., Rietveld et al, 2013). We can sequence the genomes of pre-implantation embryos and estimate their developmental potential and disease risks (Hens et al, 2013). In theory, the combination of in vitro fertilization, genome sequencing, and the selective use of embryos with promising genes can raise the prospects for health and intelligence of newborns even today, with potentially profound implications not only for the genetically selected children, but also for future social and economic developments if such techniques come to be employed widely.

Even methods for targeted genome editing are being developed (Gaj, Gersbach & Barbas, 2013). In addition to their medical uses, they can be used to replace genetic variants that lead to lower intelligence with alternative variants that lead to higher intelligence―in the zygote, but not in an adult person. Such methods are likely to become more widely available and even affordable (for some) by the mid-21st century.

Although the 21st century offers a window of opportunity for the use of gene technologies to solve the sustainability problem of human intelligence and civilization, ethical concerns are likely to prevent their use. The major ethical problem is obvious: With the rarest exceptions, people are indifferent about the welfare of future generations. Trans-generational altruism is not part of the innate behavioral repertoire of our species (Meisenberg, 2007b). Being not sufficiently motivated to use genetic selection or engineering even for the benefit of their own children, people are unlikely to tolerate their use by others, whose genetically enhanced children might outcompete their own in the rat race for status and money. Some bioethicists maintain that embryos should be selected for ethical qualities rather than intelligence because higher intelligence without better ethics could be dangerous (Persson & Savulescu, 2013). Today, however, even the use of preimplantation genetic diagnosis for the prevention of serious genetic diseases is illegal in some countries (Pavone, 2012).

This shows that intelligence is not the only form of human capital that is essential for social and economic development. It is an instrument for the pursuit of personal gain and thereby indirectly for the attainment of society-wide prosperity. Sustainable progress, however, requires more than intelligence. It requires a level of ethical development, and a kind of value system, that human societies may not be able to attain during the current bout of civilization. But since the ethical advancement of human societies has tracked cognitive advancement in the past (Flynn, 2014; Oesterdiekhoff, 2014; see also variables C1-C3 in Table 4), it is likely to do so in the future. High intelligence is a necessary but not sufficient condition for the attainment of an ethical consensus that would make modern societies sustainable.

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