Intelligence 69 (2018) 87–93

Contents lists available at ScienceDirect

Intelligence

journal homepage: www.elsevier.com/locate/intell

FLynn-effect and economic growth: Do national increases in intelligence lead to increases in GDP?

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ABSTRACT

According to the cognitive human capital theory, cognitive ability furthers at the individual, institutional and societal level productivity, production, income and wealth. Cross-sectional and longitudinal studies using various indicators (psychometric IQs, student assessment tests, education vs. GDP per capita, growth), different methods (correlations, regressions, path models) and different controls have supported this theory in two research paradigms (psychology, economics). An especially revealing test is, whether historical increases in IQ within countries would lead to later economic growth, i.e. about 10 to 20 years later. This design can exclude national differences being associated with human capital and growth (e.g., in culture, economic freedom and politics) which may bias the results. We used a data set of national IQ changes ("FLynn effect") from Pietschnig and Voracek (2015). For a maximum of 28 nations and 262 periods between 1909 and 2013 IQ development was related to concurrent or lagged GDP per capita development (growth; 5, 10, 15, 20 years). In a second analysis with at least three IQ-GDP periods per country the single within-country correlations for concurrent and later intervals were estimated (13 nations). Finally, we controlled for previous wealth (advantages of backwardness). All analyses show substantial relationships between increases in IQ and GDP, the highest were found for the 5 to 15 years lagged economic growth (r = .25 to .44 resp. .46 to .77). The results back the theory that cognitive ability contributes to wealth.

1. Introduction

Human capital is defined as everything within a person that helps to be productive in economic action. It comprises *physical* and *psychological abilities* as well as *personality* attributes. Adam Smith (*1723, †1790) was one of the first to describe human capital, in his words in the *Wealth of Nations* as "the acquired and useful abilities of all the inhabitants or members of the society" (Smith, 1982/1776, p. 377; Book II, Chapter I). Among human capital, reason and thinking were for Smith the most important characteristics: "The qualities most useful to ourselves are, first of all, superior *reason* and *understanding*, by which we are capable of discerning the remote *consequences of all our actions*, and of *foreseeing* the advantage or detriment which is likely to result from them." (Smith, 2004/1759, p. 248, Part IV, Chapter I) The first, who explicitly introduced the concept of *intelligence* to economics was the economist Friedrich List. In 1841 (published in English in 1909, p. 87) he stated: "Everywhere and at all times has the well-being of the nation been in equal proportion to the intelligence, morality, and industry of its citizens; according to these, wealth has accrued or been diminished."

The *cognitive human capital theory* with its roots in the works of Smith and List claims that cognitive ability (intelligence, knowledge and the intelligent use of knowledge) furthers at the individual, institutional and societal level productivity, production, income and wealth (Rindermann, 2018). Ample evidence at the level of individuals show that cognitive ability predicts and theoretically explains job performance and income (e.g., Irwing & Lynn, 2006; Kramer, 2009; Salgado et al., 2003; Schmidt, 2012). At the societal level, cross-sectional and longitudinal studies using different methods and controls have shown a positive impact of cognitive ability on a nation's wealth: This was found using different cognitive human capital indicators as education (Barro, 1991), student assessment tests (Hanushek & Kimko, 2000) or psychometric IQs (Lynn & Vanhanen, 2002) and different economic criteria as GDP per capita (Meisenberg, 2012), economic growth (Weede & Kämpf, 2002) or national welfare (Hafer, 2017). It was found using cross-sectional (Lynn & Vanhanen, 2002) or longitudinal designs (Rindermann, 2008) and different methods as correlations (Lynn & Vanhanen, 2002), complex regressions with many controls (Jones & Schneider, 2006) or path models using intervening variables shedding light on possible causal factors in politics,

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https://doi.org/10.1016/j.intell.2018.05.001
Received 7 September 2017; Received in revised form 27 March 2018; Accepted 7 May 2018

institutions, science and the economy (Rindermann, Kodila-Tedika, & Christainsen, 2015). Such analyses show that cognitive ability also works via political and institutional mechanisms (e.g., increasing economic liberty, improving government effectiveness) leading to cognitive capitalism. Finally, research in different paradigms, in economics (e.g., Hanushek & Woessmann, 2015; Jones, 2016) or in psychology (e.g., Coyle, Rindermann, & Hancock, 2016; overview of Hunt, 2012) have supported the cognitive human capital theory.

However, one crucial proof is missing: In 20th century there was observed a steep increase in IQ results across decades (e.g., Flynn, 1984, 2012). According to the meta-analysis of Pietschnig and Voracek (2015) the increase was on average per decade *dec* = 2.83 IQ points. It was found first in western countries (e.g., the US; Flynn, 1984; Rindermann & Thompson, 2013), later also in developing and emerging countries (e.g., Kenya; Daley, Whaley, Sigman, Espinosa, & Neumann, 2003). Initially, James Flynn took the view that these increases were mere test result changes, no real cognitive ability increases (but altered this opinion later on; Flynn, 2007). Other researchers saw no gains in the relevant general factor of intelligence (te Nijenhuis & van der Flier, 2013).

Nevertheless, there is ample evidence that the FLynn effect is not a kind of “IQ inflation”, but a real world increase in thinking ability: The best predictor at the individual level and one of the determinants of cognitive ability, *amount of education*, has increased in 20th century too (Meyer, Ramirez, & Soysal, 1992). Much more people than in the past work today as *academics*, as physicians, lawyers, teachers, scientists, engineers or economists. *Brain size* (and as an indicator head circumference) has also increased, equivalent to $d = .20$ (or *dec* = 3.00 “IQ points”, Lynn, 1990; 4.69 g per decade, Miller & Corsellis, 1977). Within professions the *cognitive demands* have risen, as described for the example of farmers by Seymour Itzkoff (1994, p. 97). Real cognitive ability has to be elevated to deal with all these intellectual challenges.

From a historical perspective, the 20th century intelligence increase is the continuation of a much longer cognitive development process being indicated, for example, by the decline of magical thinking (Oesterdiekhoff, 2012, 2014a, 2014b): Up to 17th century, people in Europe believed that witches exist. Less people today believe in magic and superstition. Up to 16th century, there were trials against animals, e.g. rats were ordered to appear in court for having eaten major parts of the harvest. In premodern societies, death was generally seen as being caused by other persons using witchcraft. Ordeals and oracle showed the truth, their results also overrode empirical evidence. Magic procedures could cure sickness (see also Hallpike, 1980; LePan, 1989).

If this all were true – that there was an increase in real world thinking abilities and that higher intelligence leads to higher productivity, innovation, income and wealth – then the IQ increases in the last century should have led to GDP increases too. We want to test this hypothesis by using international data sets. A first analysis in this direction was conducted by Pietschnig and Voracek (2015, p. 289) showing positive associations between concurrent changes in IQ and changes in GDP per capita. However, since intelligence increases will not have immediate effects, either because innovation, administrative improvement and productivity increases need some time to be developed and implemented, or because intelligence increases were measured among children samples who decades later will work as adults, a delayed impact on economic growth was expected. Thus, we focused on delayed GDP increases. Because high initial wealth decreases growth (and vice versa) we also controlled in a regression for GDP.

2. Method

2.1. Data

Data on annual IQ increases (FLynn effects; “FLynn”, a combination of the names of James Flynn and Richard Lynn, the two rediscoverers of IQ increases in late 20th century; Flynn, 1984; Lynn, 1982) in different countries and periods of time were taken from a meta-analysis of Pietschnig and Voracek (2015). Their meta-analysis (Table S1 of their appendix) includes 551 records from 271 independent samples and 34 “countries”. We did not take summary or regional entries (as termed “45 countries”, “German speaking countries” or “North America”) but only country level data. We also averaged or dropped different IQ scores if several came from the same sample and time of measurement (averaged: if only subscales were given, dropped: subscales). For example, results from Wechsler tests were often broken down into full-scale (FSIQ), verbal (VIQ) and performance IQ (PIQ). In such a case, VIQ and PIQ were excluded and only the FSIQ was used or VIQ and PIQ were averaged to FSIQ if this was not already given and then VIQ and PIQ were dropped. Five indeterminate signs (“ > ” or “ < ”) were ignored. Thus, 271 records for 31 countries remained. Further necessary exclusions and missing data (missing GDPs, see Section 2.2) reduced the number of observations to a maximum of 262 records for 28 countries. FLynn effect periods reach from 1909 to 2013 and differ from record to record in their begin, end and length.

GDP per capita (GDP/c, “International Dollar Geary-Khamis Defined”) was taken from the Maddison Project (Bolt & van Zanden, 2014; Maddison Project, 2013). The Maddison source includes data for long time periods, including the early 20th century, fitting to the information on IQ increases collected by Pietschnig and Voracek (2015).

2.2. Data matching

The periods of FLynn effects given by Pietschnig and Voracek (2015) vary from measurement to measurement and across countries. For example, the first period for France goes from 1938 to 1947 and the second from 1944 to 1984, the first period for the Netherlands goes from 1952 to 1982 and the second from 1966 to 1978. We calculated for each period the average IQ change per year (e.g., if 3 IQ points in 10 years, then 0.30 IQ points per year). Next the fitting changes in GDP/c for these periods and countries were assigned. A conventional method to estimate these changes would be to calculate the percentage change in GDP/c from the first year to the last year of a period. However, this formula does not pay attention to annual fluctuations. Therefore, an alternative approach has been adapted: the annual percentage increase (growth) in GDP of a certain period. E.g., if there was a three years covering period from 1951 to 1953, the GDP/c of 1951 was divided by the GDP/c 1950, then subtracted by 1 and multiplied with 100; the GDP/c of 1952 was divided by the GDP/c 1951, then subtracted by 1 and multiplied with 100; the GDP/c of 1953 was divided by the GDP/c 1952, then subtracted by 1 and multiplied with 100. Finally the average growth was calculated by taking the arithmetic mean from the results of the given years. As a side effect, a correction for compound interest effects was not necessary. Compound interest should be considered if intervals longer than one year were analyzed (the longer the interval the more important to consider compound interest).

The calculations of increase differ somewhat between IQ and GDP: For annual IQ, differences were calculated. Different to GDP for IQ there is no absolute zero point, IQ is a standardized measure of deviation. Differences are the established measure of IQ increases. For annual GDP differences, economic growth rates were calculated. By this method (percentages instead of differences), production and income increases at lower levels are more stressed than at higher levels: E.g., if GDP/c increased from 5000$ to 10,000$ (+5000$ = +100.00%) and from 30,000$ to 35,000$ (+5000$ = +16.67%) the difference is equal in $ but growth was much higher in the case of the less rich country. Economic growth rates are the established measure of production, income and wealth increases.

Further country-specific information: Dominica (no GDP information from Maddison) and Estonia (GDP information from 1990 onward but only one estimate of FLynn effect between 1935 and 2006) had to be excluded. For Bulgaria the GDP information is missing from 1946 to 1949, the annual increases were estimated based on the information given for 1945 and 1950.

2.3. Analysis

2.3.1. Concurrent and lagged comparisons

In usual analyses of cognitive human capital effects, cognitive ability and economic measures of the same time period are compared. Cognitive ability levels, or more precisely, national cognitive ability patterns are seen to be stable. However, we analyze the effects of changes here. To take full effect of changes some time is necessary, such as for developing innovations in technology, improvements in productions processes or increasing efficiency in administration. Thus, not only IQ and GDP/c increases for the same periods but also for 5, 10, 15 and 20 years later were compared. One example: For Israel Pietschnig and Voracek (2015, their Table S1) presented an IQ gain of 2.87 IQ points (mean of Otis-typed) for the years 1976 to 1984. This is a difference of eight years, thus the annual gain is 0.36 IQ points. We looked for GDP/c for 1976 to 1984, $10,071 and $11,483. This a difference of $1412 or per annually a gain of $176. Based on the average yearly increase this is an average economic growth rate of 1.75%. For the 5-years lag the GDP/c of 1981 and 1989, for 10-years lag of 1986 and 1994, for the 15-years lag of 1991 and 1999 and for the 20-years lag the GDPs per capita of 1996 and 2004 were taken and the annual growth rates calculated (always based on the average annual growth rates).

Lagged comparisons caused further exclusions by shifting the observed GDP/c periods more than five years behind the latest year (2010) for which GDP data were given by the Maddison Project. The number of exclusions increased from 5 to 20 years lagged.

2.3.2. Approach 1: calculations at the level of periods and countries – Overall comparison

For $N = 262$ (concurrent, lagged = 245; 223; 202; 184) periods we have both intelligence and fitting GDP/c measures. Data are given in this sample from 28 countries (data are documented in Table S1 of the Online Supplement). On average, for each country around 9 FLynn effect measurements are given. However, only for the United States $N = 137$ measurements exist and together with Great Britain ($N = 22$) these are > 60% of all measurements. Thus, the analyzes should be done in two versions, first using measurements from all nations and second excluding the measurements from the United States and Great Britain: Are the results stable including and excluding these two countries with their many measurement points?

Additionally, two variance components are mixed: Differences across time (in which we are interested here) and differences across countries (the usual approach, however, in which we are not interested here). Thus, we have also done an analysis using a second approach:

2.3.3. Approach 2: calculations at the level of periods within countries

For $N = 13$ countries (see Table 2, column 1; data are documented in Table S1 of the Online Supplement) we had at least the minimum necessary quantity of different periods and appropriate GDP measures. For each country we want to include, we need at least three different time periods, which was not given for Argentina, Belgium, Bulgaria, China, Denmark, Finland, Ireland, Kenya, Norway, Switzerland, Sudan and Turkey. In this analysis, we implemented a tolerance level if countries' given IQ periods go beyond the given GDP information to avoid a loss of too many periods and countries. We decided that differences equal or less to 5% in time span were rated as appropriate. For example, if the IQ measures were given for 1920 and 1950 (30y) but the GDP data only for 1921 to 1950 (1y/30y = 3% < 5%), we decided to use the data; if GDPs were given only for 1922 to 1950 (2y/30y = 7% > 5%), the data were excluded. 5% can be seen as arbitrary. We checked the robustness of results using 0, 10, 15 and 20% levels of tolerance.

To come to a final result it was necessary to average the 13 correlations found across time in 13 countries. The traditional approach is to use *n*-weighted Fishers-*z*-transformation to calculate a mean (see Table 2, first mean). However, this (*n*-weighted) would imply again, that US measures dominate the final result. To come to a more meaningful global outcome, we chose a simple (not *n*-weighted) arithmetic mean (Table 2, second mean) and means using Fishers-*z*-transformation (Table 2, third resp. last mean). Fishers-*z*-transformation has the advantage measuring the steeper increase in correlation (in similarity, in relationship) of two variables at the higher levels of correlations (e.g., the relationship of two variables increases more from $r = .80$ to .90 than from $r = .10$ to .20 albeit for both the numerical increase is with 0.10 identical).

As results we present correlations (r) and standardized regression coefficients (β). The latter were calculated in a linear regression with GDP/c of the first year of each period as a control for growth in GDP/c. Here negative effects are expected (poorer countries can catch up, advantages of backwardness or beta convergence). Although significance tests are reported in tables, such tests have limitations in country-level analyses (Pollet, 2013) and, of course, for the assessment of numerical results in general (e.g. Gigerenzer, 2004). More important is to check the robustness of effects across different methods, statistical analyses and country samples.

3. Results

In the first approach across all periods and countries (see Table 1), the correlations between IQ and GDP/c increases were in all periods positive, from concurrent to a 20 years delay. The largest correlations were found for a lag of 10 years ($r = .34$) followed by a lag of 5 years ($r = .25$). When controlling in regressions for GDP/c of the first year of each period, effects showed the same pattern; the largest effects were for a lag of 10 years ($\beta_{\text{IQGr}\rightarrow\text{EcGr}} = .32$) followed by a lag of 5 years ($\beta_{\text{IQGr}\rightarrow\text{EcGr}} = .22$). GDP/c of the first year of each period was

Table 1
Bivariate correlations between annual increases in IQ and GDP per capita at the level of countries and periods for concurrent or lagged intervals, and β-coefficients from regressions with GDP per capita of first year as second predictor (approach 1).

Countries	Interval	Concurrent	5 years lagged	10 years lagged	15 years lagged	20 years lagged
All	r	.21*	.25*	.34*	.18*	.05
	$\beta_{\text{IQGr}\rightarrow\text{EcGr}}$	.18	.22*	.32*	.17	.04
	$\beta_{\text{GDP1}\rightarrow\text{EcGr}}$	−.25*	−.23*	−.22*	−.19	−.30
	N	262	245	223	202	184
UK and USA excluded	r	.30*	.22	.38*	.44*	.23
	$\beta_{\text{IQGr}\rightarrow\text{EcGr}}$	.27	.22	.37*	.45*	.24
	$\beta_{\text{GDP1}\rightarrow\text{EcGr}}$	−.41*	−.31	−.20	−.15	−.14
	N	103	91	77	63	48

Notes: Pearson's correlations and β-coefficients with $^*p < .001$ (two tailed). No tolerance level in case selection. Same countries have several periods. Example: 10 years lagged means e.g. IQ change 1950–54 and GDP change 1960–64 correlated. $\beta_{\text{IQGr}\rightarrow\text{EcGr}}$: standardized beta-coefficient of FLynn-effect (IQ growth) on dependent economic growth (%); $\beta_{\text{GDP1}\rightarrow\text{EcGr}}$: standardized beta-coefficient of GDP per capita of the first year of a period on dependent economic growth (%).

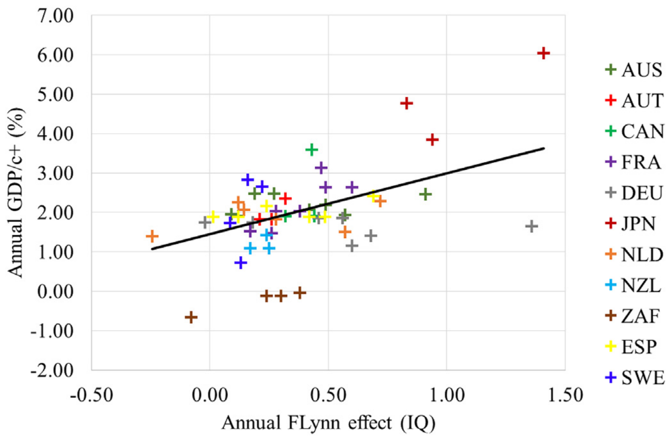

Fig. 1. Scatterplot between annual increases in IQ and GDP per capita at the level of countries, 15 years lagged for 63 measurements and 11 countries separately (approach 1; GBR and USA excluded); regression line represents all comparisons across 16 countries of FE and GDP/c + ($r = .44$; $N = 63$; $p < .001$).

consistently negatively associated with growth (advantages of backwardness). According to these results, intelligence increases need some time to result in GDP/c increases. However, as mentioned, the US and GBR dominate the sample (about 60% of all observations). After exclusion of both countries, a similar pattern was found but with the largest correlations for a lag of 15 years ($r = .44$, displayed in Fig. 1; $\beta_{IQGr \rightarrow EcGr} = .45$) followed by a lag of 10 years ($r = .38$; $\beta_{IQGr \rightarrow EcGr} = .37$).

In this first approach, time effects are confounded with cross-country differences.

Thus, we conducted a second analysis with time effect correlations within 13 countries and then averaged the correlations (approach 2; see Table 2 and Fig. 2). Among three averaging methods, using Fishers-*z*-transformation but not weighted for number of observations is the best approach: It does not overstate the influence of one single country and it appropriately averages correlations of notably different correlations (last row of Table 2, bold line in Fig. 2). According to the country based time analysis there is a positive relationship between intelligence increases and concurrent GDP/c development ($r = .30$). For a five-year time lag the correlation between intelligence increases and economic growth goes up to $r = .46$. The correlation even goes up to its peak of $r = .77$ for a lag of 10 years, and decreases first to $r = .59$ for a lag of 15 years and finally to $r = .31$ for a lag of 20. The pattern itself is largely stable across the three averaging methods, i.e. it does not depend on the specific country composition. However, the means vary due to lower correlations in larger samples and due to some high correlations (being even higher after Fishers-*z*-transformations).

Regression analyses showed several suppressor effects ($\beta > 1$ or < -1), especially in countries with low *N*. Analyses of relationships in the same period revealed no positive effect of cognitive increases on economic growth: Using Fishers-*z*-transformation without weighting for the number of observations (last row of Table 2) resulted in $\beta = -.03/-.16$. The first number ($\beta = -.03$) is the result without corrections of suppressor effects (Fishers-*z*-transformation is not possible for values $\geq |1|$, such results are set to missing values), the second number ($\beta = -.16$) is the result correcting for suppressor effects (values $> .95$ or $< -.95$ were set to .95 or $-.95$). As expected, the largest effects were observed for lagged effects, for 5 and 10 years (5 years, $\beta = .42/.36$; 10 years: $\beta = .29/.59$).

The use of the 5% level of tolerance (see Methods) can be seen as arbitrary. Therefore, the correlations from Table 2 (second row from below) were additionally calculated by using varying tolerance levels. Correlations are very similar for a level of tolerance of 0% (.25; .29; .45; .51; .31), 5% (.18; .27; .56; .42; .21), 10% (.25; .30; .43; .50; .31), 15% (.25; .30; .43; .50; .30) and 20% (.20; .30; .44; .48; .30). This makes changes due to the tolerance level negligible. Chosen statistical specifications do not significantly alter results.

4. Discussion

Past cross-sectional and longitudinal research, which had chosen different designs and controls, came to the robust result that cognitive ability has an impact on economic wellbeing. All this research used a countries comparing approach: Human capital differences between countries were compared with economic differences between countries (GDP/c or other and more global variables describing economic and societal states or variables describing processes as growth rates) (e.g. Coyle, Rindermann, Hancock, & Freeman, 2018; Dickerson, 2006; Hafer, 2017; Hanushek & Woessmann, 2015; Jones, 2016; Lynn & Vanhanen, 2002; Meisenberg, 2012; Rindermann, 2008; Weede & Kämpf, 2002). By contrast, in our design we looked at development: Does development in psychometric intelligence test results across time within a country go along with development in economic per capita production and income? If the *cognitive human capital theory* and the results of country comparisons were true then increases in intelligence (or broader conceived increases in cognitive ability including knowledge) should stimulate economic growth leading to higher GDPs per capita. This is exactly what the study has found: Within a time lag of 5 to 15 years increased intelligence led to increased production and income, the correlation was $r = .34$ (approach 1 across countries, 10 years lag, all countries included, see Table 1). Controlling for GDP (because poorer countries can catch up, advantages of backwardness may distort the effects) resulted in a similar effect of cognitive increases on growth ($\beta_{IQGr \rightarrow EcGr} = .32$). The advantages of backwardness effect was as expected negative (around $\beta_{GDP1 \rightarrow EcGr} = -.24$) – richer countries usually grow less fast, poorer countries faster.

In a pure within-country approach reducing the impact of cross country differences in culture, politics and institutions the correlation even reached $r = .77$ (approach 2 within countries, 10 years lag, Fishers-*z* not weighted, $\beta_{IQGr \rightarrow EcGr} = .29/.59$; see Table 2). Time lags were to be expected. The effects of growing cognitive ability have to go through multiple economic mechanisms, e.g. vocational training, talent allocation, scientific and technological innovation, before they express in productivity and income increases.

The presented results have several implications: First, they back the cognitive human capital theory. Longitudinal national cognitive development and independent from country differences a within country development in intelligence modify countries' wealth development. Country differences are seen to depend on rather stable factors (Rindermann, Becker, & Coyle, 2016). Countries differ in many correlated and possibly relevant variables (e.g., economic freedom, commodities, political conditions). All those possible biases are excluded in a within-country comparison. The cognitive human capital theory is corroborated by a purer, less blurred approach.

Second, if former IQ changes are related to later GDP changes, changes in psychometric IQ test results do not represent mere “IQ inflation” but a real historical cognitive development – “hollow” test changes would show no effect at all. Third, the purer approach allows an assessment of the mid-term (one to two decades) direct effects of intelligence on economic development. A correlation of $r = .77$ (41% of variance remains unexplained; Table 2) and even more a correlation of $r = .34$ (Table 1) make clear that further factors are relevant for growth, e.g., economic freedom and especially important in a such a time-referenced approach specific business cycles. The economy goes up and down and human capital is one factor among others in such trends.

This also points to some weaknesses of this approach: An analysis of mid-term development tends to *underestimate* the total impact of cognitive ability on economy, administration, politics, society and culture and all together on wealth. Cognitive ability helps to create an

Table 2
Bivariate correlations between annual increases in IQ and GDP per capita at the level of periods separately for 13 countries for concurrent or lagged intervals and β-coefficients from regressions with GDP per capita of first year as second predictor (approach 2).

		Concurrent		5 years lagged		10 years lagged		15 years lagged		20 years lagged	
Country ISO	Coefficient	Coefficient	N	Coefficient	N	Coefficient	N	Coefficient	N	Coefficient	N
AUS	***r***	−.75	8	−.07	8	.45	8	.29	8	.01	6
	$\beta_{IQ\to Ec}$	−.33		.18		.27		.41		.38	
	$\beta_{GDP1\to Ec}$	−.74		−.44		.38		−.22		−.67	
AUT	***r***	.55	5	.84	5	.95	5	–	–	–	–
	$\beta_{IQ\to Ec}$	.11		.52		.85					
	$\beta_{GDP1\to Ec}$	−.94		−.61		−.20					
BRA	***r***	−.07	11	–	–	–	–	–	–	–	–
	$\beta_{IQ\to Ec}$	−.01									
	$\beta_{GDP1\to Ec}$	−.56									
CAN	***r***	.81	4	−.12	4	.98	4	–	–	–	–
	$\beta_{IQ\to Ec}$	3.14		3.05		1.42					
	$\beta_{GDP1\to Ec}$	2.34		3.19		.45					
DEU	***r***	.11	13	−.02	12	.08	9	−.25	7	−.64	6
	$\beta_{IQ\to Ec}$	.17		.06		.17		−.20		−.53	
	$\beta_{GDP1\to Ec}$	−.96		−.97		−.96		−.94		−.91	
ESP	***r***	.59	9	.34	9	.35	9	.60	6	–	–
	$\beta_{IQ\to Ec}$	.09		.29		.53		.20			
	$\beta_{GDP1\to Ec}$	−.93		−.08		.33		−.87			
FRA	***r***	.86	7	.74	7	.75	7	.85	7	.80	6
	$\beta_{IQ\to Ec}$	−.33		−.40		−.52		−.33		−.45	
	$\beta_{GDP1\to Ec}$	−1.27		−1.31		−1.42		−1.36		−1.39	
GBR	***r***	−.29	22	.15	22	.48	16	.31	16	.13	15
	$\beta_{IQ\to Ec}$	−.21		.24		.61		.38		.16	
	$\beta_{GDP1\to Ec}$	.44		.4		.74		.43		.23	
JPN	***r***	.98	3	.99	3	.98	3	.82	3	−.42	3
	$\beta_{IQ\to Ec}$	−1.07		.95		1.03		1.01		.73	
	$\beta_{GDP1\to Ec}$	.79		.15		−.20		−.61		−1.46	
NLD	***r***	.59	9	−.17	9	−.31	8	.37	6	.45	3
	$\beta_{IQ\to Ec}$	.01		−.36		−.83		.20		.70	
	$\beta_{GDP1\to Ec}$	−.79		−.26		−.77		−.22		.32	
SWE	***r***	−.08−	5	.91	5	.84	4	.59	4	.79	3
	$\beta_{IQ\to Ec}$	.30		.95		1.00		1.00		1.48	
	$\beta_{GDP1\to Ec}$	.80		−.11		−.85		−.85		−1.61	
USA	***r***	−.07	137	.28	137	.33	132	−.11	123	−.15	121
	$\beta_{IQ\to Ec}$	−.07		.26		.29		−.13		−.17	
	$\beta_{GDP1\to Ec}$	−.04		−.28		−.49		−.48		−.58	
ZAF	***r***	−.84	4	−.65	4	.97	4	.98	4	.90	4
	$\beta_{IQ\to Ec}$	−1.20		−1.16		.81		1.06		1.18	
	$\beta_{GDP1\to Ec}$	−.63		−.91		−.28		.14		−.51	
M weight F-*z* (*r*)		.03		.29		.46		.12		−.03	
M arithmetic (*r*)		.18		.27		.57		.45		.21	
M Fishers-*z* (*r*)		**.30**		**.46**		**.77**		**.59**		**.31**	
M weight F-*z* (β_{IQ}) (max |.95|)		−.06 (−.08)		.26 (.25)		.28 (.35)		−.04 (−.04)		−.11 (−.03)	
M arithmetic (β_{IQ}) (max |.95|)		.05 (−.09)		.38 (.22)		.47 (.42)		.36 (.36)		.39 (.30)	
M Fishers-*z* (β_{IQ}) (max |.95|)		**−.03 (−.16)**		**.42 (.36)**		**.29 (.59)**		**.08 (.08)**		**.16 (.49)**	

Notes: Pearson's correlations and β-coefficients. Tolerance level of 5% in case selection. Number of periods (*N*) vary between countries, e.g., the USA has for more times IQ measurements than Canada. "Weight": mean correlations/betas averaged using Fishers-z-transformation and weighted for *N*. "Arithmetic": simple arithmetic mean. "Fishers-*z*": mean correlations averaged using Fishers-z-transformation (results of this most appropriate averaging method are set in bold). Mean calculations for $\beta_{IQ\to Ec}$ effects. Suppressor effects ($\beta > |.95|$) are set on max .95/−.95 in second row in parentheses. Fishers-*z*-transformation does not function with values $\geq |1|$ (values set to missing values). β_{IQ} or $\beta_{IQ\to Ec}$: standardized beta-coefficient of FLynn-effect (IQ growth) on dependent economic growth (%); $\beta_{GDP1\to Ec}$: standardized beta-coefficient of GDP per capita of the first year of a period on dependent economic growth (%).

environment being globally supportive for national development. This can be shown in studies analyzing such relationships in cross-country comparisons (e.g., Rindermann et al., 2015). Mid-term changes as changes and not as levels do not unveil these effects. Related, the *ways* in which cognitive ability may work cannot be analyzed by the presented approach. Either necessary are cross-country studies as mentioned before or single country case studies which analyze in close-ups the relation between changes in ability, e.g., due to education, and changes in performance as in technology, administration and economy. Of course, we have not applied an experimental approach (to artificially alter the IQ level of randomly chosen countries and then look for the outcomes) but we applied a design analyzing effects of a natural "experiment": For what reason ever cognitive ability levels grew more or less varying between countries and time (approach 1) or only varying between time (approach 2) and then being followed by higher productivity and income. As mentioned, we did not control for further important causal factors as economic freedom or government effectiveness. Further studies should integrate them. We were the first to analyze time delayed economic effects of secular increases in cognitive ability. A correlation of $r = .77$ seems to be rather high. We encourage colleagues to reassess the data or to apply further approaches. One approach can be based on the study of Hamilton and Monteagudo (1998) who analyzed the effects of changes in education (as a proxy for human capital) on changes in GDP growth (not GDP growth itself). Similarly, growth changes could be related to IQ changes.

Finally, the approach allows to give an outlook: If cognitive ability can increase then future economic growth is more probable. The first tentative predictions in this direction (Meisenberg, 2014; Rindermann & Pichelmann, 2015) showed a mixed picture: In developed countries only minor increases of cognitive ability are expected, but the increases

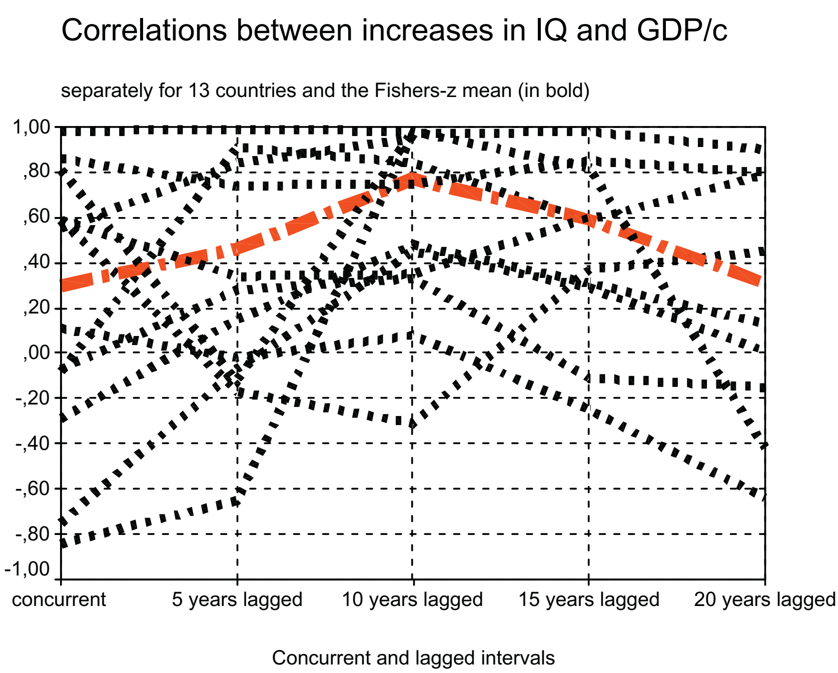

Fig. 2. Correlations between development in IQ and GDP/c (approach 2).

could still lead to further economic growth. However, the rising complexity in technology, science and the work world and other headwinds as demographic and social change will make future growth more difficult (e.g., Gordon, 2016). If there would even come cognitive declines (e.g. Woodley of Menie, Figueredo, Sarraf, Hertler, & Fernandes, 2017) such predicted challenges could be hardly met. Nevertheless, especially for countries which are currently at low cognitive ability levels stronger future FLynn effects are expected (Rindermann, 2013; Rindermann, Becker, & Coyle, 2017). For many countries in Africa (Rindermann, 2013, 2018) such cognitive human capital increases may lead to higher growth rates resulting in higher standards of living.

Acknowledgements

The authors are grateful to Fanrui Shao (Mount Holyoke College) for her help in preparing the manuscript. Additionally, we want to express our gratitude to Steven Pinker (Harvard University) who gave us hints for conducting this study.

Author contributions

Both authors contributed equally to this work.

Conflict of interest

The authors declare no competing financial interests. Correspondence and requests should be addressed to David Becker (david.becker@s2009.tu-chemnitz.de).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.intell.2018.05.001.

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