The mathematics skills of school children: How does the UK compare to the high performing East Asian nations?

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Abstract

The Programme for International Student Assessment (PISA) and Trends in Mathematics and Science Study (TIMSS) are two highly respected studies of school pupils' academic achievement. British policymakers have been disappointed with UK school children's performance on these tests, particularly in comparison to the strong results of young people from East Asia. In this paper we provide new insight into the UK – East Asia gap in school children's mathematics skills. We do so by considering how cross-national differences in math test scores change between ages 10 and 16. Our results suggest that, although average math test scores are higher in East Asian countries, this achievement gap does not increase between ages 10 and 16. We thus conclude that reforming the secondary school system may not be the most effective way for the UK to "catch up" with the East Asian nations in the PISA math rankings. Rather earlier intervention, during pre-school and primary school, may be needed instead.

Key Words: PISA, TIMSS, educational policy, primary education, secondary education

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1. Introduction

One of the major developments in educational research over the last twenty years has been the widespread implementation of cross-national studies of pupil achievement, including the Programme for International Student Assessment (PISA), Trends in Mathematics and Science Study (TIMSS) and Progress in International Reading Literacy Study (PIRLS). These aim to produce cross-nationally comparable information on children's abilities at a particular age in at least one of three areas (reading, math and science). Regular reports are then published by the survey organisers where countries are ranked in terms of school children's test performance. This has had a major impact upon policymakers from a number of countries, with many treating these international "league tables" as an evaluation of their school system's success. British policymakers have shown particular concern over the UK's position of 28th, out of 65 countries, in the most recent PISA mathematics assessment. Although a few northern European countries have fared rather better (e.g. Finland), it is the consistently strong performance of East Asian nations that has really caught policymakers attention[1]. For instance, in the most recent PISA mathematics study, Shanghai was ranked top, Singapore 2rd, Hong Kong 3rd, Korea 4th, Taiwan 5th and Japan 9th. Given the important role of human capital in economic productivity and growth (OECD 2010; Hanushek and Woessmann 2008; Barro 2001) the UK has looked towards the strong performance of these countries with an envious glare. Indeed, it is now widely believed that if Britain does not raise the academic skill of its school children, then its long-run prosperity will suffer as a result.

This has led policymakers to consider what can be learnt from the East Asian nations to help British educational standards improve. For instance, the Secretary of State for Education Michael Gove recently stated that[2]:

"These regions and nations – from Alberta to ***Singapore****, Finland to* ***Hong Kong****, Harlem to* ***South Korea*** *- should be our inspiration"* [Emphasis our own]

[1] Finland has only routinely taken part in the PISA study and not the other international assessments (e.g. PIRLS or TIMSS). On the other hand, a number of leading Asian economies (e.g. Hong Kong, Singapore) have participated in PISA, PIRLS and TIMSS for a number of years. It is the East Asian countries consistently strong performance (throughout various studies and numerous survey waves) that is perhaps most impressive.

[2] See http://www.education.gov.uk/inthenews/inthenews/a0070008/secretary-of-state-comments-on-pisa-study-of-school-systems

With agreement from the shadow Education minister Stephen Twigg[3]:

"we must learn from high-performing nations like Japan"

Similarly, the East Asian nations have been highlighted as strong education systems in the on-going review of British mathematics curricula (Department for Education 2011), with an implicit suggestion that at least some of their school practises and policies hold the key to Britain's future educational success. Table 1 illustrates this point still further, where educational and economic inputs are compared to educational outputs across the UK and four comparator countries (Japan, Hong Kong, Singapore and Taiwan). Despite similar levels of GDP per capita, public expenditure on education and school enrolment rates, educational outcomes towards the end of secondary school (as measured by PISA test scores) are significantly lower in the UK.

<<Table 1>>

It is therefore surprising that we do not know more about the achievement gap between Britain and the high performing East Asian nations. Although insightful, studies such as PISA are often considered in isolation, providing a limited snapshot of children's abilities at one particular point in time. It would perhaps be more useful for academics and policymakers to understand the specific point(s) in the education system that the UK falls behind these world leaders, and whether this is being driven by the experiences of certain sub-groups. For instance, the math skills of British and East Asian children could be roughly equal at the end of primary school, but then markedly diverge during secondary school. In this situation, reform of secondary education would perhaps be the most obvious policy response. On the other hand, it could be that most of the UK – East Asia achievement gap emerges early in children's life (e.g. differences are apparent even by age 10) and that cross-national differentials do not grow much further beyond this point. Indeed, as the evidence base currently stands, one cannot rule out the possibility that British children actually catch up with their East Asian peers during secondary school. In this situation resources and efforts for reform might be better concentrated at earlier points in children's life (e.g. before their 10th birthday). It would also suggest that analysis of studies such as PISA, which focuses upon the latter stages of secondary school, would be of little use in revealing why young people in East Asia are so much better at math than young people in the UK.

[3] See http://www.bbc.co.uk/news/education-18057883

The aim of this paper is to thus develop a better understanding of how children's performance on internationally standardised math tests changes between ages 10 and 16, comparing the experiences of British children to those from the four aforementioned East Asian jurisdictions (Japan, Singapore, Taiwan and Hong Kong). This is, in our opinion, a vital first step towards identifying why children in East Asian countries outperform their British peers. Within this broad topic, we consider the following three specific issues.

Firstly, we illustrate how mean math test scores change with age. This is important for identifying the point(s) in the education system that British children fall behind young people in other countries (on average) and thus where efforts for school reform should be concentrated. Secondly, we investigate inequality in educational *outcomes*, and how the *distribution* of math skill changes between ages 10 and 16. Our initial focus will be upon the spread of achievement, and whether this widens or narrows in the UK relative to the four East Asian countries. This is followed by an assessment of whether the gap between the most able young mathematicians in Britain and the most able young mathematicians in East Asia widens (or declines) during secondary school. This is a particularly prominent policy issue, as having a pool of very highly skilled individuals is vital for technological innovation and long-run economic growth (Bean and Brown 2005, Toner 2011). Finally, we consider an output-based measure of equality of educational *opportunity*, focusing upon math test score differentials between socio-economically advantaged and disadvantaged groups (a topic of much recent academic and political debate). Previous research has found that the socio-economic achievement gradient widens in England between the end of primary school and the end of secondary school (Goodman et al 2009, Ermisch and Del Bono 2012), but that the same is not true in other English-speaking countries (Ermisch et al 2012). However, there has been little work considering this issue using the TIMSS and PISA datasets, and how Britain compares with the high performing East Asian jurisdictions in this respect. We make this important contribution to the existing literature.

Our results suggest that, although average math test scores are higher in East Asian countries than the UK, differences do not seem to increase between the end of primary and the end of secondary school. However, high achieving school children in East Asia do further extend their lead over high achieving pupils in Britain between ages 10 and 16. We also find that the vast majority of the socio-economic achievement gradient in mathematics skills in the UK is already apparent by age 10. This leads to the following policy recommendations:

- To narrow the mathematics achievement gap with the leading East Asian nations, British policymakers should concentrate on educational reforms in primary and pre-school.

- Yet there is also a need to ensure that the best young mathematicians in Britain manage to keep pace with the most highly skilled pupils in other countries during secondary school via, for instance, gifted and talented schemes.

- Further efforts are needed to raise the basic skills of disadvantaged groups, again with a focus on the primary and pre-school years.

- Over the longer-term, a cultural shift in Britain may be needed, where the importance of education is recognised and promoted by all.

The paper now proceeds as follows. In section 2 we describe our empirical methodology and the TIMSS and PISA datasets. Section 3 provides estimates of change in test scores between ages 10 and 16 for the UK and a series of comparator countries. This is followed in section 4 by a discussion of our findings and a series of policy recommendations.

2. Data

The aim of this paper is to examine the variation in children's math skills across countries, and how this changes between the end of primary school and the end of secondary school. Ideally, longitudinal data would be available, enabling one to track the progress of exactly the same children over time. Unfortunately cross-nationally comparative data of this type does not exist. The next best alternative is to use repeated cross-sectional data, where samples have been collected from the same, or very similar, cohorts of school children at various points in time. From such data one can draw inferences about the distribution of children's math skill at several ages, and thus how key points on the achievement distribution (e.g. mean, standard deviation, 10^{th} percentile, 90^{th} percentile) change during the primary to secondary school transition. The approach we take in this paper is to compare how these key statistics change across countries.

To do so, we draw upon data from the following rounds of the PISA and TIMSS studies:

- The 4th grade (age 9/10) TIMSS wave from 2003
- The 8th grade (age 13/14) TIMSS wave from 2007
- The PISA (age 15/16) wave from 2009

Each of these resources collects nationally representative data and has been explicitly designed to facilitate comparisons of children's cognitive skills across countries (OECD 2011a and Olson et al 2008 provide further information). They also have similar sample designs, with schools firstly selected as the primary sampling unit and then either one or two classes (TIMSS) or 35 pupils (PISA) randomly chosen to participate (from within each school). Response rates for the countries included in our analysis can be found in Appendix Table 1. In most of the countries considered, school response was around 80 and 90%, while pupil response typically stood at over 90%[4]. In all three studies the survey organisers have produced a set of weights which attempt to correct for bias induced by non-response, while also scaling the sample up to the size of the national population. These weights are applied throughout the analysis.

A notable feature of the three studies is that they collect data for children who were born at approximately the same time[5]. For instance, the two TIMSS studies for Britain refer to children who were born between September 1992 and August 1993, while those who took part in PISA 2009 were in the school year below (born between September 1993 and August 1994). Consequently, one can track the performance of a very similar cohort of children at three different ages (9/10, 13/14 and 15/16). This is important if one wishes to interpret the changes observed as "age" rather than "cohort" effects. Although discussion shall focus on the performance of the UK relative to a set of leading East Asian nations, we include twelve countries that took part in each of these three studies into our analysis. This includes five from the rich western world (Australia, UK, Italy, USA, Norway), four Asian "tiger" economies (Hong Kong, Japan, Singapore, Taiwan), and three with middle incomes (Lithuania, Russia, Slovenia)[6]. Some additional commentary shall be presented regarding the UK's performance relative to this broader set of countries.

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[4] The school response rate we refer to is after replacement schools have been included.

[5] The TIMSS studies collect information from children within the same school "grade" (i.e. the same school year group), while in PISA children are all the same age (i.e. between 15 years 3 months and 16 years and 2 months old).

[6] In TIMSS "England" and "Scotland" are treated as separate countries in the international database while in PISA they are combined into a sample for the whole UK. In this paper we combine the England and Scotland samples in TIMSS and label this as the UK.

It is important to recognize that there are some limitations with this empirical strategy. Firstly, although each study examines children's ability in mathematics, there are some conceptual differences in the skills being measured. For instance, whereas TIMSS focuses upon children's ability to meet internationally agreed curricula, PISA examines functional ability – how well young people can use the skills in "real life" situations. Whether this slight difference in focus is of substantive importance is, however, questionable. For example, the correlation between children's PISA math test scores and a curricula based measure in the UK (key stage 3 scores) is high at over 0.80 (Micklewright and Schnepf 2006). Nevertheless, one cannot rule out the possibility that there are at least some subtle differences in the precise skills being measured.

Secondly, there are some differences between the surveys in the test score metric generated. In all three studies children's responses to the test questions are combined into a set of possible overall test scores via an item-response model[7]. Five "plausible values" are then created for each child; these are five separate estimates of children's ability in mathematics. The intuition behind this process is that children's true ability cannot be observed, and must be estimated from their answers on the test. This results in a measure of children's achievement that has a mean of 500 and standard deviation of 100 in all three studies. However each of the surveys contains a different pool of countries upon which these achievement scores are based. For instance, while PISA includes all members of the OECD the two TIMSS studies do not. Consequently, although the test metric across the three surveys appears to be on the same scale, figures are not actually directly comparable (e.g. a mean score of 500 in PISA is not the same as a mean score of 500 in TIMSS).

To overcome this problem, all data are transformed (within each survey) into international z-scores. That is, each country's mean test score (for each wave of the survey) is adjusted by subtracting the mean score achieved amongst all children in the twelve countries for that particular survey and dividing by the standard deviation. This is a standard method for obtaining comparable units of measurement for variables that are on different scales and is similar to the approach taken by Brown et al (2007) in their comparison of the PISA and TIMSS datasets. One implication of this is that estimates refer to British pupils' test performance <u>relative</u> to that of children in the twelve other countries. Thus our focus is upon how the UK's performance relative to other countries changes between primary and

[7] A one parameter Rasch model PISA is used to generate test scores in PISA while a three-parameter item scaling procedure is used in TIMSS.

secondary school. Terms like "relative decline" shall therefore be used as international z-scores are comparative measures.

Similar difficulties arise when one considers the availability and comparability of children's background characteristics. For instance, the TIMSS studies contain very little information on pupils' socio-economic status. This poses a problem for estimating the socio-economic gradient in mathematics achievement, and whether this gradient steepens as children age. We therefore turn to what many consider to be the best available proxy for family background that is contained within each of the three datasets and measured in a comparable way – the number of books in the family home[8]. Sociologists (e.g. Evans et al 2010) have argued that this reflects the scholarly culture of a household, and is thus a measure of the educational environment in which a child is being raised. On the other hand, various economists have argued that books in the home are "the single most important predictor of student performance in most countries" (Woessmann 2008) and that there is evidence that this is a cross-nationally comparable proxy for socio-economic position (Hanushek and Woessmann 2010, Schuetz et al 2008)[9]. It has been widely used in this manner by various academics in analyses of the PISA, PIRLS and TIMSS datasets (Woessman 2008, Waldinger 2007, Schütz et al. 2008, Ammermueller and Pischke 2009, Machin 2009, Evans et al 2010, Jakubowski 2010, Ermish and Del Bono 2010, Hermann and Horn 2011, Brunello et al 2012) including investigations of how the socio-economic gradient changes with age across countries (Jerrim and Micklewright 2012a, Ammermueller 2006). Nevertheless, Jerrim and Micklewright (2012a, 2012b) discuss some of the limitations with using books as an indicator of family background, focusing upon difficulties with measurement. We thus proceed with caution, acknowledging this to be an imperfect proxy for socio-economic status, though one which has been widely used in the data sources under our investigation.

In each dataset we use this variable in a series of OLS regression models to estimate how inequality of educational opportunity varies across countries. This takes the form:

[8] In a background questionnaire, children in PISA and TIMSS are asked about the number of books there are in their household, and instructed to tick the corresponding category.

[9] For instance, Hanushek and Woessmann (2010) state "Schuetz, Ursprung, and Woessmann (2008) corroborate the cross-country validity of the books-at-home variable by showing that the association between household income and books at home does not vary significantly between the six countries for which both income and books measures are available in the PIRLS dataset".

$$A_{ijk} = \alpha + \beta_1.SES_i + \beta_2.Sex_i + \beta_3.I_i + \beta_4.SES_i * I_i + \varepsilon_{ij} \quad \forall k \qquad (1)$$

Where:

A = Children's score on the TIMSS or PISA math test

Sex = A binary indicator of the child's gender (0 = female, 1 =male).

I= Whether the child is a first or second generation immigrant (0 = Native , 1 = Immigrant)

SES = A set of four dummy variables reflecting the number of books in the family home (Reference: Less than 25 books)

i= child i

j = child j

k = country k

This specification follows the existing literature on international comparisons of socio-economic achievement gradients (e.g. Schütz et al 2008, Wößmann 2008, Jerrim and Micklewright 2011, Jerrim 2012). Socio-economic status (as measured by books in the home) is the covariate of interest, with controls included for gender and whether the child was a first or second generation immigrant. As argued by Wößmann (2008) other characteristics (e.g. type of school attended) are intentionally not controlled, so that the SES parameter captures all the channels by which family background influences children's test performance (through both nature and nurture). The estimated coefficients will thus capture the *cumulative* impact of family background on children's test performance, including their experiences during the first years of life (which Cunha et al 2006, amongst others, have stressed are extremely important). During this paper we focus upon test score differences between the most advantaged (more than 200 books) and least advantaged (less than 25 books) groups. Our primary interest is: (a) how does this socio-economic achievement gradient vary across countries and (b) how does the gradient change as children move from the end of primary school to the end of secondary school[10].

Given the data difficulties described above, our analysis shall proceed with some caution. Specifically, our strategy is to treat the TIMSS 4th grade survey as a broad indicator of children's math skills towards the end of primary school (when children are aged 9/10) with

[10] In Appendix 1 we also consider gender and immigrant/native differences in math test scores.

the TIMSS 8th grade and PISA 2009 studies as two separate indicators of math skills towards the end of secondary school. Our intention is thus to look for evidence of robust changes in math achievement (at the country level) that hold whether either TIMSS 2007 (8th grade) or PISA 2009 is used as the secondary school follow-up survey.

3. Results

3.1 Average test scores

In Table 2 countries are ranked by mean test scores at ages 9/10, 13/14 and 15/16. The countries of interest are highlighted in shades of light (UK) or dark (East Asia) grey. At each point the UK sits in the middle of the cross-country ranking, with average test scores roughly in-line with those achieved by children from the United States. Indeed, on no occasion can one reject the null hypothesis that average test scores in the UK are significantly different from zero at the 5% level. In other words, the UK's performance is always roughly in-line with the cross-national average (within this pool of 12 countries). A particularly notable feature of Table 2 is that the East Asian nations are consistently at the top of the international rankings, with a sizeable gap between this group and all other countries included in the analysis. For instance, even when children are in primary school (age 9/10) there is a big difference (almost 0.4 of an international standard deviation) between the lowest performing East Asian country (Taiwan) and the highest performing other country included in the sample (Lithuania). Thus a substantial and statistically significant cross-national achievement gap has emerged long before the start of secondary school.

<< Table 2 >>

The UK is clearly quite some distance behind the leading East Asian nations (in terms of pupils' average math achievement) before children reach their tenth birthday. But do British children fall further behind during secondary school? The answer to this question can be found in Table 3. This provides the change in average test scores between ages 10 and 14 (left hand columns) and 10 and 16 (right hand columns) across the 12 countries. The column labelled "Sig Diff to 0" indicates whether there is a statistically significant change in a country's performance relative to the cross-national average between the two ages. On the other hand, the column labelled "Sig Diff to UK" illustrates whether there is a significant improvement or decline in average test scores relative to the change observed within the UK.

This has similarities to a classic difference – in – difference test, where change in one "treatment group" over time (e.g. UK secondary schooling and culture) is compared to the change in other "treatment groups" (e.g. various form of East Asian secondary schooling and culture).

<< Table 3 >>

Starting with the UK, notice that the change in mean test scores between both ages 10 and 14 (-0.092) and 10 and 16 (-0.013) are small and statistically indistinguishable from 0 at conventional thresholds. Thus there is little evidence that the math skills of British children either improve or deteriorate (relative to young people in our pool of 12 countries) between the end of primary school and the end of secondary school (on average). This is in contrast to some countries (Norway and Slovenia) where average test scores clearly increase, while in others (Lithuania and Russia) there is a marked decline. Yet there is also little to suggest that British pupils fall further behind children in the leading East Asian nations. For instance, notice that the change in mean test scores between ages 10 and 16 in the UK is not significantly different to that in any of the East Asian countries. This point is further emphasised in Figure 1, which plots mean test scores for the countries of interest at the three ages. Although the gap between the UK and the four East Asian countries is always large (often half an international standard deviation or more) there is no consistent evidence that the gap widens or declines during the primary (age 9/10) to secondary (age 13/14 or 15/16) transition.

<<Figure 1>>

A clear implication for policymakers is that it is not during secondary school that the leading East Asian countries pull away from the UK in terms of school pupils' math skills. Rather, the causal factor(s) behind these countries strong performance seemingly occurs much earlier in life (i.e. before the age of 9/10) and this relative advantage is then maintained. Consequently, reforming the secondary school system may not be the most effective way for the UK to "catch up" with such countries in the PISA rankings. Earlier intervention (e.g. during pre-school and primary school) may be needed instead. Moreover, it seems unlikely that analysis of datasets that focus upon the latter stages of secondary school (like PISA) will be able to explain why average math performance is so much higher in East Asia than the UK.

3.2 Inequality in educational outcomes

Although the UK's relative performance in terms of pupils' average math test scores may not change significantly between primary and secondary school, it is possible that the distribution of achievement could alter as children age. Evidence on this matter can be found in Figure 2. This plots the standard deviation of children's math test scores at ages 9/10, 13/14 and 15/16[11]. The UK is highlighted using a light grey line with square markers.

<< Figure 2 >>

At age 9/10, inequality in mathematics achievement stands at roughly 1.1 international standard deviations in the UK. This is notably higher than in the East Asian nations, with the standard deviation being only 0.9 in Japan and less than 0.8 in Hong Kong and Taiwan. Yet this situation seems to reverse towards the end of secondary school; whereas inequality in mathematics achievement falls in the UK (to 0.93 of an international standard deviation by age 16) it increases in a number of East Asian countries (e.g. it is up from 0.80 at age 10 to 1.02 at age 16 in Hong Kong). Thus, although there is little change in average test scores between ages 10 and 16, the same does not appear to be true with regards educational inequality. In particular, whereas mathematics achievement seems to become more equal in the UK during secondary school, in the East Asian countries it becomes more dispersed[12].

What is behind this apparent change in educational inequality? Table 4 panel A presents the 10th percentile of the achievement distribution at the three ages. This reflects the math skills of the least able pupils within each of the 12 nations. Figure 3 illustrates how the 10th percentile changes between primary and secondary school for the UK and East Asian nations. The left hand side refers to the age 10-14 comparison and the right hand side the age 10-16 comparison. The thin black line running through the centre of the bars represents the estimated 99% confidence interval[13]. Interestingly, there is some evidence of an increase in P10 within the UK, particularly for the age 10 to age 16 comparison. In other words, the lowest achievers in the UK manage to improve relative to low achievers in other countries. The opposite is true, however, in Singapore, Hong Kong and Taiwan, where P10 declines

[11] Ferreira and Gignoux (2011) consider several possible measures of inequality in educational outcomes and conclude that the standard deviation is the most appropriate when analysing the international achievement datasets.

[12] Here we refer to inequality in educational outcomes (the spread of achievement) and not equality of opportunity (how achievement differs between socio-economic groups). The latter shall be the focus of the following sub-section.

[13] Standard errors have not taken into account the clustering of children within school, and thus are likely to be underestimated. For this reason we present 99% (rather than more conventional 95%) confidence intervals.

(e.g. in Hong Kong P10 declines from -0.48 at age 10 to -0.66 at age 14 and -0.72 at age 16). Consequently, one can see that between primary school and the end of secondary school, low achieving children in the UK seem to “catch up” (to a certain extent) with low achievers in at least some of the East Asian countries. This is consistent with government policy in Britain during this period, when a number of initiatives attempted to raise the basic skills of low achieving groups. However, it should be noted that, despite this progress, a significant gap remains between the lowest achievers in the UK and the lowest achievers in East Asia, even at age 16[14].

<< Table 4 >>

<< Figure 3 >>

Does the same hold true for the highest achieving children? In Table 4 panel b we provide analogous results for the 90th percentile of the math achievement distribution (i.e. the test performance of the most able young mathematicians within each of the countries). Figure 4 then compares the change in the 90th percentile between the end of primary school and the end of secondary school. Worryingly, it seems that the UK does lose some ground relative to its international competitors (and particularly the East Asian nations) in this respect. The bars in both the left and right hand panel of Figure 4 are negative for the UK, with the estimated 99% confidence interval not crossing zero. The implication is that the math skills of the most able children in the UK decline relative to the most able children within the pool of 12 countries included in our analysis. On the other hand, the opposite is true in several of the East Asian countries – the most able pupils tend to further extend their lead. For instance, Table 4 reveals that the 90th percentile in Hong Kong moves from 1.13 standard deviations above the cross-country mean at age 10 to 1.37 standard deviations at age 16. Pulling these results together, Figure 4 provides clear evidence of a substantial and statistically significant difference between the UK and East Asian countries in terms of skill development of the most able young mathematicians during secondary school.

<< Figure 4 >>

[14] This can be seen in the right hand column of Table 4 panel A.

3.3 Inequality of educational opportunity

Finally, we turn to the issue of inequality of educational opportunity, defined as the difference in math test scores between high (more than 200 books) and low (25 or fewer books) socio-economic groups. Table 5 provides estimates at the three ages. It becomes immediately apparent that the UK has a particularly large socio-economic achievement gradient when measured in this way. For instance, at age 9/10 children from advantaged backgrounds score (on average) 0.93 standard deviations more on the TIMSS math test than children from disadvantaged backgrounds. This is bigger than any other country included in the analysis, with cross-national differences statistically significant at the 5% level in 10 of the 11 comparisons made (the exception is Singapore). Moreover, no country has a significantly bigger socio-economic achievement gap than the UK at either age 13/14 or age 15/16. It is also interesting to note that there is no common pattern across the East Asian countries, with quite large socio-economic differences occurring regularly in some (e.g. Singapore, Taiwan) but not in others (e.g. Hong Kong).

<< Table 5>>

Does the socio-economic test score gradient increase between ages 10 and 16 in the UK? Evidence on this issue can be found in Figure 5. This plots the socio-economic test score gap at the three ages. Children from advantaged backgrounds do indeed extend their lead over their disadvantaged peers in the UK, as has been found in previous research (Goodman et al 2009, Ermisch et al 2012). Although this increase of 0.18 of a standard deviation (from 0.93 at age 10 to 1.11 at age 16) is on the boundary of statistical significance (t= 1.92, p = 0.05) and of reasonable magnitude, the vast majority of socio-economic inequality in educational achievement is nevertheless apparent by age 10. Moreover, Figure 5 would seem to suggest that the socio-economic gradient also increases in the four East Asian countries by roughly the same (Singapore, Japan) or even greater (Hong Kong, Taiwan) amounts.

<< Figure 5 >>

Thus although we have replicated previous findings of an increasing socio-economic achievement gradient between ages 10 and 16 in the UK, we have also presented evidence that suggests the same holds true in the leading East Asian nations. As inequality in educational achievement is already large before children finish primary school, this further suggests that public investment into increasing opportunities for young people from disadvantaged homes may be best placed in the early years (Cunha et al 2006).

4. Discussion, policy recommendations and conclusions

The programme for International Student Assessment (PISA) and Trends in Mathematics and Science Study (TIMSS) are two highly respected studies of school pupils' academic achievement. Policymakers have shown great interest in their findings – particularly the dominance of East Asian countries towards the top of the PISA and TIMSS rankings. The Secretary of State for Education, Michael Gove, and his shadow, Stephen Twigg, have both suggested that Britain must learn lessons from these high performing jurisdictions, including policies that could be successfully implemented in this country. We have provided some guidance on this issue by attempting to identify the age at which children in the UK are overtaken by their peers in East Asia (in terms of average mathematics test scores), and thus where efforts to reform the schooling system should be concentrated. This leads us to the following three policy recommendations.

Firstly, policymakers should concentrate on reforming mathematics education in the early primary and pre-school years. This paper has shown how there is a large gap in math achievement between the UK and leading East Asian nations even at age 10, but also that this gap does not appreciably widen during secondary school. Thus, despite major policy focus on secondary schools, there is little evidence that these institutions are responsible for the UK's disappointing position in the PISA and TIMSS rankings. What policies from East Asian countries could the UK adopt to boost math skills before the end of primary school? Unfortunately, the answer does not seem to be straightforward. One might suggest that there is a need for government to provide more (and higher quality) pre-school care, as there is evidence that this has a positive impact upon children's later academic achievement (Cunha et al 2006). However, pre-school enrolment rates are already higher in the UK than Japan, Singapore, Taiwan and Hong Kong (recall Table 1). Moreover, although we are unable to compare pre-school quality, it is interesting to note that the OECD has recently suggested that certain East Asian nations should learn lessons from the UK in this respect (Taguma et al., 2012). Investment in education also seems unlikely to be the cause, as the percentage of GDP per capita spent on education has been consistently lower in the East Asian countries than the UK during the 1999-2009 period (World Bank 2012). Primary school class sizes also tend to be larger in East Asia and instructional hours lower (OECD 2011a). However, one factor that does notably differ is the quality and status of teachers. For instance, teachers in East Asia tend to be high academic performers (OECD 2011a), and have a duty to study and research, aswell as teach (Jensen et al. 2012). Moreover, they receive high earnings both in comparative international terms and relative to other professional groups. Although establishing the causal impact of this higher pay and status is beyond the scope of this paper, we do suggest that raising the prestige of teaching (particularly at the primary school level) could be an important lever upon which British policymakers may draw.

Our second recommendation calls for further investment in the skills of children from disadvantaged backgrounds, again with a focus on the primary and pre-school years. Section 3.3 illustrates that the socio-economic gradient in math test scores seem to be steeper in the UK than East Asian countries. While this gap may widening slightly in the UK during secondary school, socio-economic differences in academic achievement are largely in place by age 10. Although some caution is required when interpreting this result, given the limitations of the data available, we note that our findings (and subsequent policy recommendation) are consistent with a host of other academic research (e.g. Schutz et al 2008, Jerrim and Micklewright 2011, Cunha et al 2006, Heckman 2007). As primary education is free or nearly free in the UK and most East Asian countries, alternative explanations for the large socio-economic achievement gradient in Britain must be sought. One possibility is that ability grouping in primary school mathematics classes is relatively common in Britain, but not East Asia (Boaler et al. 2011, OECD 2012)[15]. As Gamoran (2004) and OECD (2012) note, there is little evidence that such streaming improves average performance, but may exacerbate test score differences between advantaged and disadvantaged groups. Similarly, between school selection processes are weaker in East Asian countries than the UK (OECD 2012), meaning that disadvantaged children are likely to have better access to quality educational resources. Reducing the segregation of pupils in Britain, both within and between primary schools, may thus make an important contribution to narrowing the socio-economic achievement gap in mathematics.

Finally, although we maintain that policymakers should focus on the earlier stages of young people's educational career, some important changes are needed to improve aspects of mathematics provision during secondary school. The most pressing issue is to ensure that the curriculum stretches the best young mathematicians enough, and that they are motivated (and

[15] Hallam and Parsons (2012) show that one in six UK children are being taught in ability streams at age 7.

incentivised) to fully develop their already accumulated academic skill. Evidence presented in this paper has shown how the best young mathematicians in Britain fall further behind those in East Asia between ages 10 and 16. This is something that needs to be corrected as such highly skilled individuals are likely to be important for the continuing success of certain major British industries (e.g. financial services) and to foster the technological innovation needed for long-run economic growth (Bean and Brown 2005, Toner 2011). One possible explanation for this finding is the widespread use of private tuition by East Asian families for both remedial and enrichment purposes (Ono, 2007; Sohn et al., 2010). This helps to boost the performance of all pupils, including those already performing well at school. In comparison, private tutoring in the UK is mainly undertaken by a relatively small selection of children from affluent backgrounds, often for remedial purposes. While a large proportion of East Asian families are willing to personally finance such activities through the private sector, the same is unlikely to hold true in the foreseeable future within the UK. Consequently, the state may need to intervene. Gifted and talented schemes, a shift of school and pupil incentives away from reaching floor targets (e.g. a C grade in GCSE mathematics) and enhanced tuition for children who excel in school are all possible policy responses.

These recommendations do, however, come with important caveats. Firstly, although it is true that most of East Asia's modern educational systems "*were strongly and deliberately modelled after the Western educational rubric* (Jeynes, 2008: 900)" the identification of successful policies in some countries does not necessarily ensure the success of their implementation in others. Even when policies and teaching methods have been proven to be effective in East Asia, culture and context potentially limits the extent to which such initiatives can be successfully transferred to other countries (Cowen, 2006). Secondly, it is worth underlining that cultural and social factors might be behind these countries strong PISA and TIMSS test performance. In East Asian cultures, education has historically been considered a highly valued good and the main legitimate method for social mobility. This can be seen not only in the East Asian teachers' high salaries, but also by the heavy investment of families in private tutoring services. Family and social commitment to education is also reflected in the large number of weekly hours East Asian students spend in self-study activities and, as Zhu and Leung (2011) argue, the great impact extrinsic motivation has on their mathematics test performance (much more so than their Western peers). Consequently, the implementation of some of the characteristics of the East Asian educational model may imply the need for a cultural shift towards greater belief in the value of education amongst all and the importance of a hard work ethic. Indeed, it is important for academics and policymakers to recognise that East Asian children vastly out-perform their British peers even when they have been through the British schooling system[16]. This is perhaps the clearest indication that it is actually what happens outside of school that is driving these countries superior PISA and TIMSS math test performance. We recognise, of course, that such cultural shifts cannot be expected to take place in the UK in the short run, as it is notoriously difficult to modify people's attitudes and beliefs. Similarly, although such policies can lead to higher academic performance, they have well known side effects, such as the pressure which students (physical and psychological) and parents (financial) must put up with (Bray 2003). Yet, in an increasingly competitive world, such a cultural shift may be necessary to ensure Britain's future prosperity and long-run economic success.

[16] In 2011, 78.5% of Chinese children achieved 5 or more A* - C grades including math and English. This compares to a national average of 58.2%. See http://www.education.gov.uk/rsgateway/DB/SFR/s001057/index.shtml

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Table 1. Key characteristics of the UK, Japan, Singapore, Hong Kong and Taiwan

	Japan	Hong Kong	Singapore	Taiwan	United Kingdom
1. GDP per capita (PPP 2005 US $000)	32.0	36.3	47.3	28.7	33.4
2. % GDP spent on education (2009)	3.8	4.8	3.1	4.1	5.4
3. Enrolment rates in pre-primary education (%)	90	97	-	29	81
4. Enrolment rate: primary education (%)	100	92	-	98	100
5. Enrolment rates: secondary education (%)	99	76	-	95	96
6. Enrolment rate: higher education (%)	59	57	-	82	59
7. Mean PISA math score (2009)	529	555	562	543	492
8. Mean PISA reading score (2009)	520	533	526	495	494
9. Mean PISA science score (2009)	539	549	542	520	514

Sources:

1 Pennworld Tables.

2 to 6 World Development Indicators and Taiwan, from Ministry of Education. Data refers to 2009.

7 to 9 PISA survey website

Table 2. Average math test scores at ages 9/10, 13/14 and 15/16 (international z-scores)

	Age 9/10			Age 13/14			Age 15/16	
	Mean	**SE**		**Mean**	**SE**		**Mean**	**SE**
Singapore	0.820*	0.062	Taiwan	0.904*	0.050	Singapore	0.729*	0.056
Hong Kong	0.570*	0.037	Singapore	0.844*	0.062	Hong Kong	0.644*	0.053
Japan	0.446*	0.023	Hong Kong	0.599*	0.078	Taiwan	0.521*	0.059
Taiwan	0.435*	0.026	Japan	0.571*	0.040	Japan	0.371*	0.057
Lithuania	0.064	0.041	UK	-0.101	0.059	Australia	0.215*	0.032
Russia	0.037	0.051	Russia	-0.103*	0.041	Slovenia	0.070	0.060
UK	-0.009	0.049	USA	-0.130*	0.035	Norway	0.032	0.025
USA	-0.128*	0.034	Lithuania	-0.166*	0.038	UK	-0.021	0.034
Italy	-0.326*	0.047	Slovenia	-0.219*	0.025	USA	-0.077	0.046
Australia	-0.375*	0.052	Australia	-0.278*	0.057	Italy	-0.121*	0.029
Slovenia	-0.623*	0.033	Italy	-0.477*	0.035	Lithuania	-0.193*	0.042
Norway	-0.959*	0.031	Norway	-0.596*	0.023	Russia	-0.285*	0.038

Notes:

1 * indicates where average test scores are statistically different from 0 at the 5% level. This illustrates whether average math test scores are significantly different from the 12 country cross-national average.

2 Age 9/10 refers to TIMSS 2003 4th grade data, age 13/14 is TIMSS 2007 8th grade and age 15/16 PISA 2009.

3 All figures presented are international z-scores.

Table 3. Change in average math test scores between primary and secondary school

	Change 10 – 14				Change 10 – 16			
	Change	SE	Sig Diff to 0	Sig Diff UK	Change	SE	Sig Diff to 0	Sig Diff UK
Norway	0.363	0.038	***	***	0.991	0.039	***	***
Slovenia	0.404	0.042	***	***	0.693	0.068	***	***
Australia	0.097	0.078	-	*	0.590	0.062	***	***
Italy	-0.151	0.058	***	-	0.205	0.055	***	***
Taiwan	0.469	0.056	***	***	0.086	0.064	-	-
Hong Kong	0.030	0.086	-	-	0.074	0.065	-	-
USA	-0.002	0.049	-	-	0.051	0.058	-	-
UK	-0.092	0.076	-	-	-0.013	0.059	-	-
Japan	0.125	0.046	***	**	-0.075	0.061	-	-
Singapore	0.024	0.088	-	-	-0.091	0.084	-	-
Lithuania	-0.230	0.056	***	-	-0.257	0.058	***	***
Russia	-0.140	0.066	**	-	-0.322	0.063	***	***

Notes:

1 *, ** and *** indicate statistical significance at the 10%, 5% and 1% level. “Sig Diff to 0” illustrates whether the change in average math test scores are significantly different from the change for 12 country cross-national average. “Sig Diff UK” illustrates whether the change in average math test scores are significantly different from the change seen in the UK.

2 The left hand columns refer to the change in average math test scores between age 10 (TIMSS 2003 data) and age 14 (TIMSS 2007 data). The right hand columns refer to the change in average math test scores between age 10 (TIMSS 2003 data) and age 16 (PISA 2009 data)

3 All figures presented are international z-scores.

Table 4. The estimated 10th and 90th percentile of the math test score distribution at ages 9/10, 13/14 and 15/16 (international z-scores)

(a) Test scores at the 10th Percentile

	Age 9/10			Age 13/14			Age 15/16	
	P10	SE		P10	SE		P10	SE
Hong Kong	-0.48	0.03	Singapore	-0.66	0.03	Hong Kong	-0.72	0.03
Singapore	-0.56	0.03	Japan	-0.70	0.03	Singapore	-0.79	0.03
Taiwan	-0.57	0.02	Taiwan	-0.84	0.04	Japan	-0.92	0.02
Japan	-0.76	0.02	Hong Kong	-0.93	0.05	Taiwan	-0.94	0.03
Lithuania	-1.21	0.04	USA	-1.28	0.02	Australia	-1.08	0.02
Russia	-1.22	0.03	Slovenia	-1.32	0.02	Norway	-1.14	0.02
USA	-1.39	0.02	Lithuania	-1.36	0.03	UK	-1.23	0.02
UK	-1.45	0.03	Russia	-1.39	0.03	Slovenia	-1.24	0.02
Italy	-1.69	0.03	UK	-1.41	0.03	USA	-1.33	0.03
Australia	-1.73	0.04	Australia	-1.48	0.04	Italy	-1.40	0.02
Slovenia	-1.93	0.03	Italy	-1.61	0.03	Lithuania	-1.41	0.02
Norway	-2.30	0.04	Norway	-1.61	0.03	Russia	-1.44	0.02

(b) Test scores at the 90th Percentile (international z-scores)

	Age 9/10			Age 13/14			Age 15/16	
	P10	SE		P10	SE		P10	SE
Singapore	1.551	0.016	Taiwan	1.763	0.022	Singapore	1.536	0.020
Hong Kong	1.129	0.016	Singapore	1.638	0.020	Hong Kong	1.368	0.018
Japan	1.065	0.018	Hong Kong	1.359	0.020	Taiwan	1.318	0.021
Taiwan	0.952	0.016	Japan	1.241	0.022	Japan	1.075	0.020
UK	0.747	0.029	UK	0.599	0.023	Australia	0.900	0.013
Russia	0.714	0.023	Russia	0.565	0.020	Slovenia	0.795	0.023
Lithuania	0.711	0.020	USA	0.483	0.015	Norway	0.662	0.018
USA	0.541	0.015	Lithuania	0.475	0.022	UK	0.595	0.016
Italy	0.378	0.023	Slovenia	0.354	0.019	USA	0.592	0.020
Australia	0.294	0.019	Australia	0.323	0.025	Italy	0.591	0.010
Slovenia	0.039	0.026	Italy	0.123	0.019	Lithuania	0.450	0.020
Norway	-0.242	0.027	Norway	-0.052	0.015	Russia	0.308	0.017

Notes:

1 Age 9/10 refers to TIMSS 2003 4th grade data, age 13/14 is TIMSS 2007 8th grade and age 15/16 PISA 2009.

2 All figures presented are international z-scores.

Table 5. Socio-economic differences in children’s math test scores at age 10, 14 and 16 (international z-scores)

	Age 9/10		Age 13/14		Age 15/16	
	Difference	**SE**	**Difference**	**SE**	**Difference**	**SE**
UK	0.933	0.082	1.113	0.074	1.109	0.041
Singapore	0.898	0.073	0.946	0.089	0.994	0.076
USA	0.721*	0.042	0.841*	0.043	1.059	0.054
Australia	0.648*	0.071	0.901	0.086	1.011	0.036
Norway	0.619*	0.064	0.670*	0.034	1.038	0.042
Japan	0.602*	0.063	0.736*	0.068	0.707*	0.057
Taiwan	0.556*	0.040	1.115	0.065	1.060	0.068
Lithuania	0.529*	0.072	0.788*	0.064	0.930*	0.057
Russia	0.405*	0.083	0.672*	0.071	0.735*	0.056
Slovenia	0.301*	0.076	0.729*	0.048	1.161	0.095
Hong Kong	0.235*	0.063	0.643*	0.099	0.800*	0.067
Italy	0.142*	0.072	0.630*	0.054	0.928*	0.041

Notes:

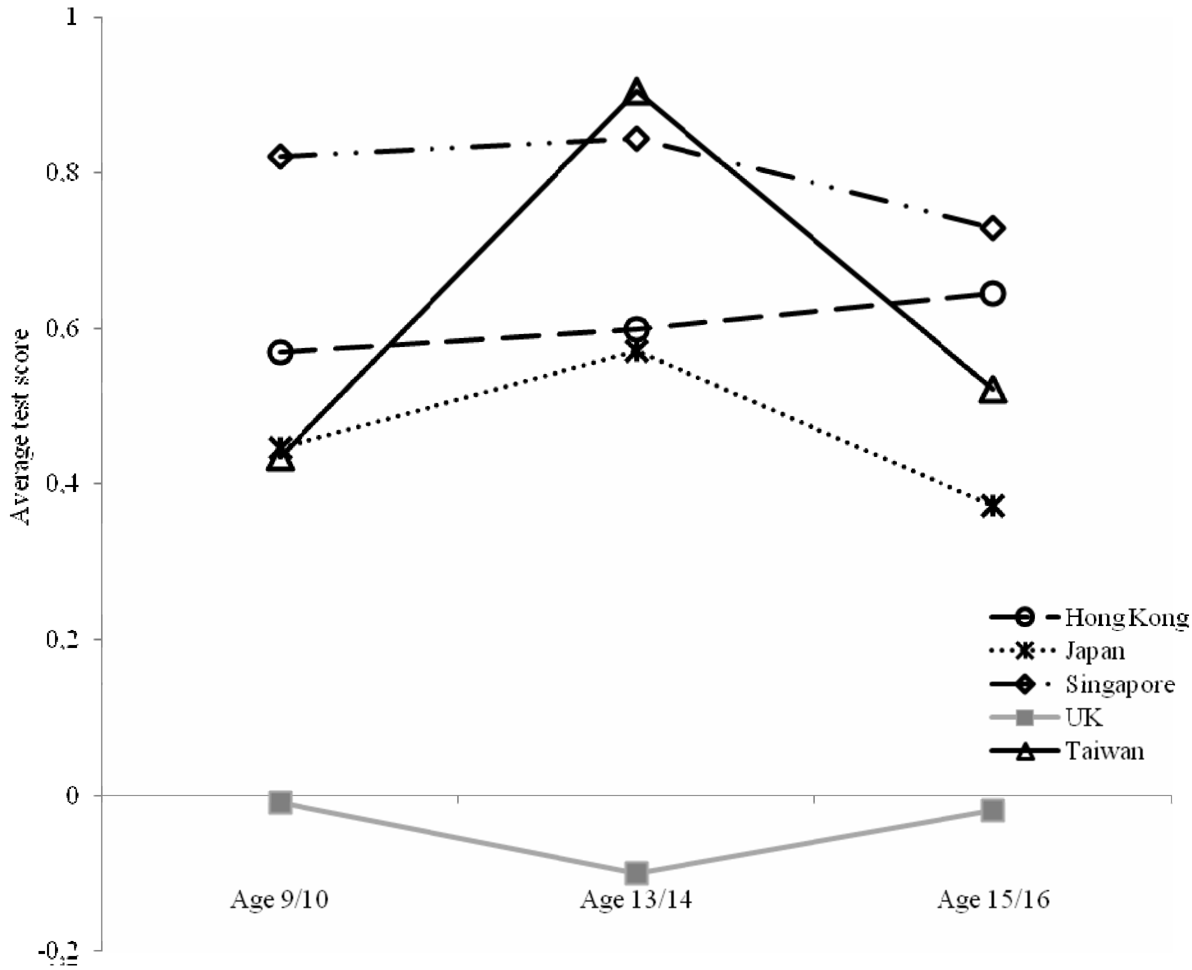
1 Authors’ calculations based upon the regression model presented in section 2.

2 Figures refer to the difference in average test scores between children with few (0 – 25) versus children with many (more than 200) books.

3 All figures presented in terms of international z-scores

4 * indicates where socio-economic gradient significantly different to the UK at the 5% level

Figure 1. Average math test scores at ages 9/10, 13/14 and 15/16 – the UK compared to a selection of East Asian countries

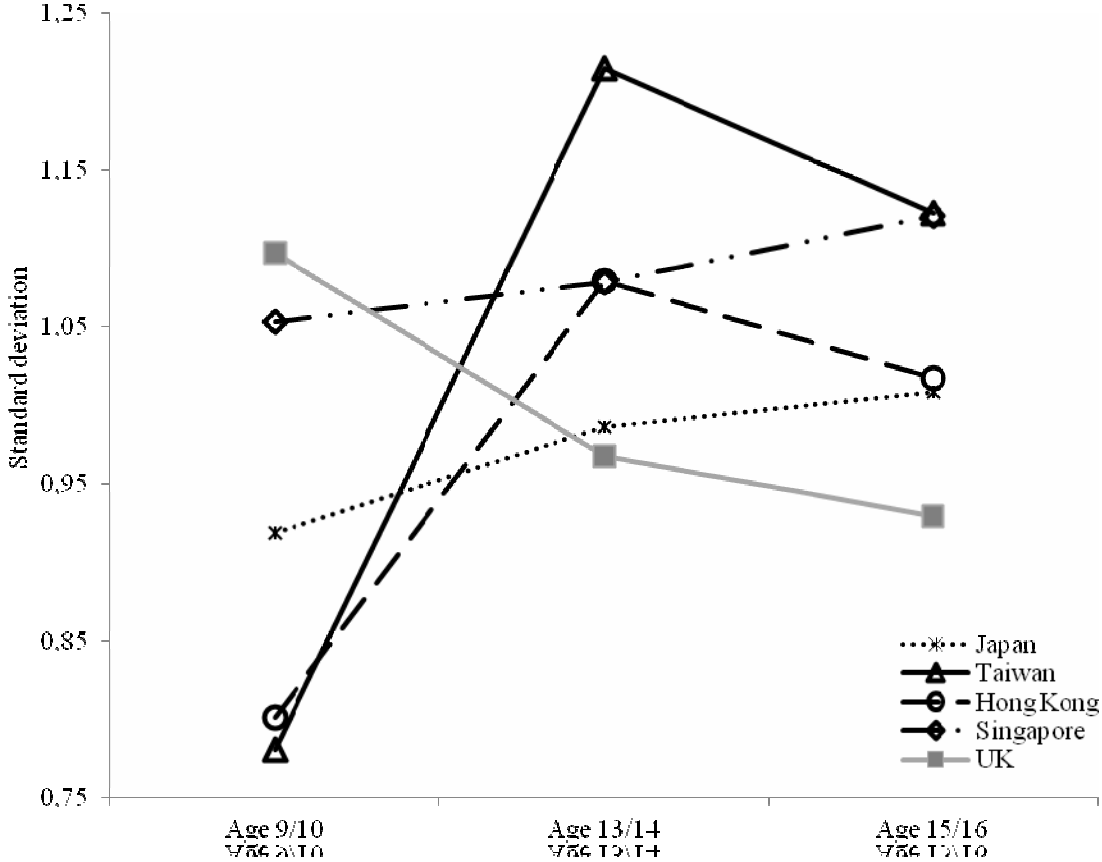


Notes:

1 Age 9/10 refers to TIMSS 2003 4th grade data, age 13/14 refers to TIMSS 2007 8th grade data and age 15/16 refers to PISA 2009.

2 All figures presented in terms of international z-scores.

Figure 2. Standard deviation of mathematics test scores (inequality in math outcomes)



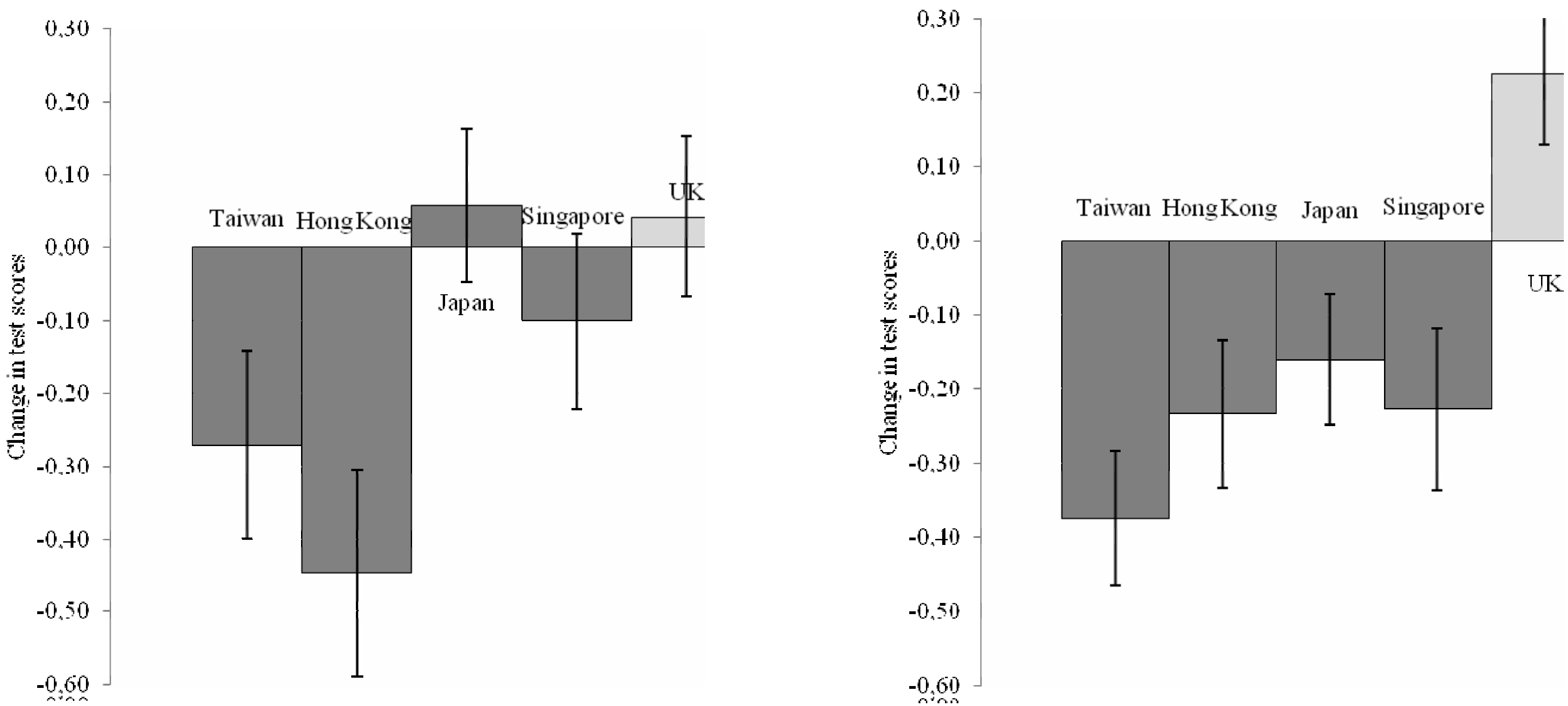
Notes:

1 Age 9/10 refers to TIMSS 2003 4th grade data, age 13/14 refers to TIMSS 2007 8th grade data and age 15/16 refers to PISA 2009.

2 All figures presented in terms of international z-scores.

Figure 3. Change in the 10th percentile of the math test distribution between the end of primary school and secondary school

(a) Age 9/10 to 13 / 14 **(b) Age 9/10 to 15 / 16**



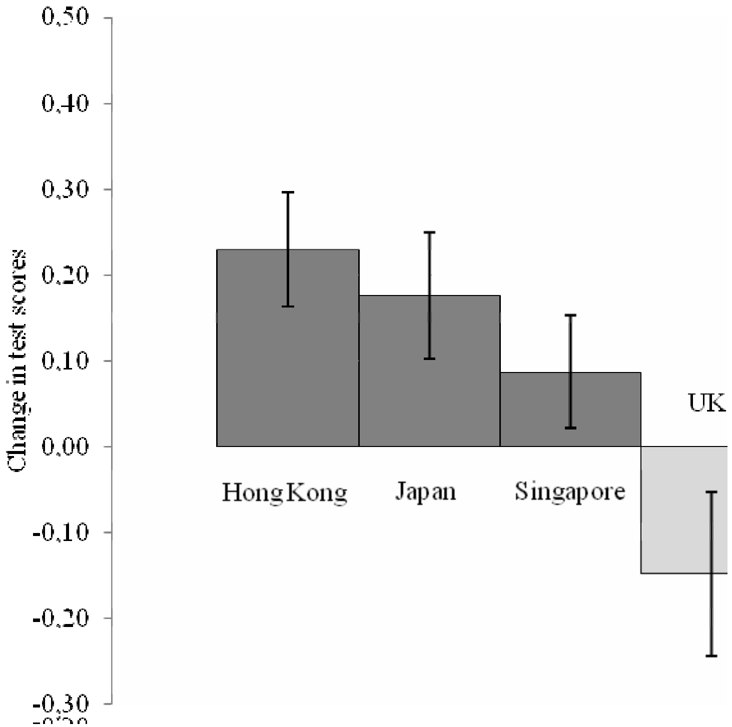
Notes: 1 The left hand panel refers to the change in the 10th percentile of math achievement between age 9/10 (TIMSS 2003 4th grade) and age 13/14 (TIMSS 2007 8th grade). The right hand panel provides analogous figures for the change between age 9/10 (TIMSS 2003 4th grade) and age 15/16 (PISA 2009) .

2 All figures presented in terms of international z-scores.

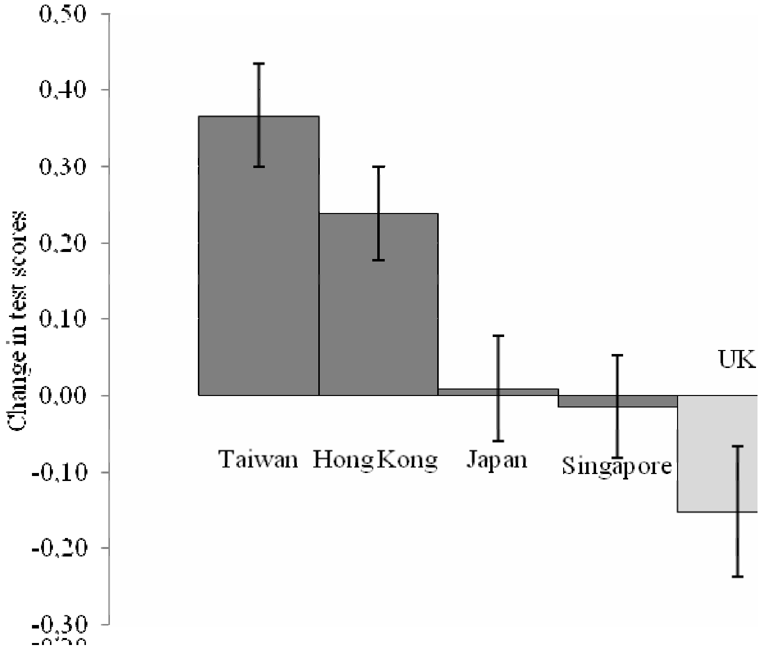
3 The thin black line running through the centre of each bar is the estimated 99% confidence interval.

Figure 4. Change in the 90th percentile of the math test distribution between the end of primary school and secondary school

(b) Age 9/10 to 13 / 14



(b) Age 9/10 to 15 / 16



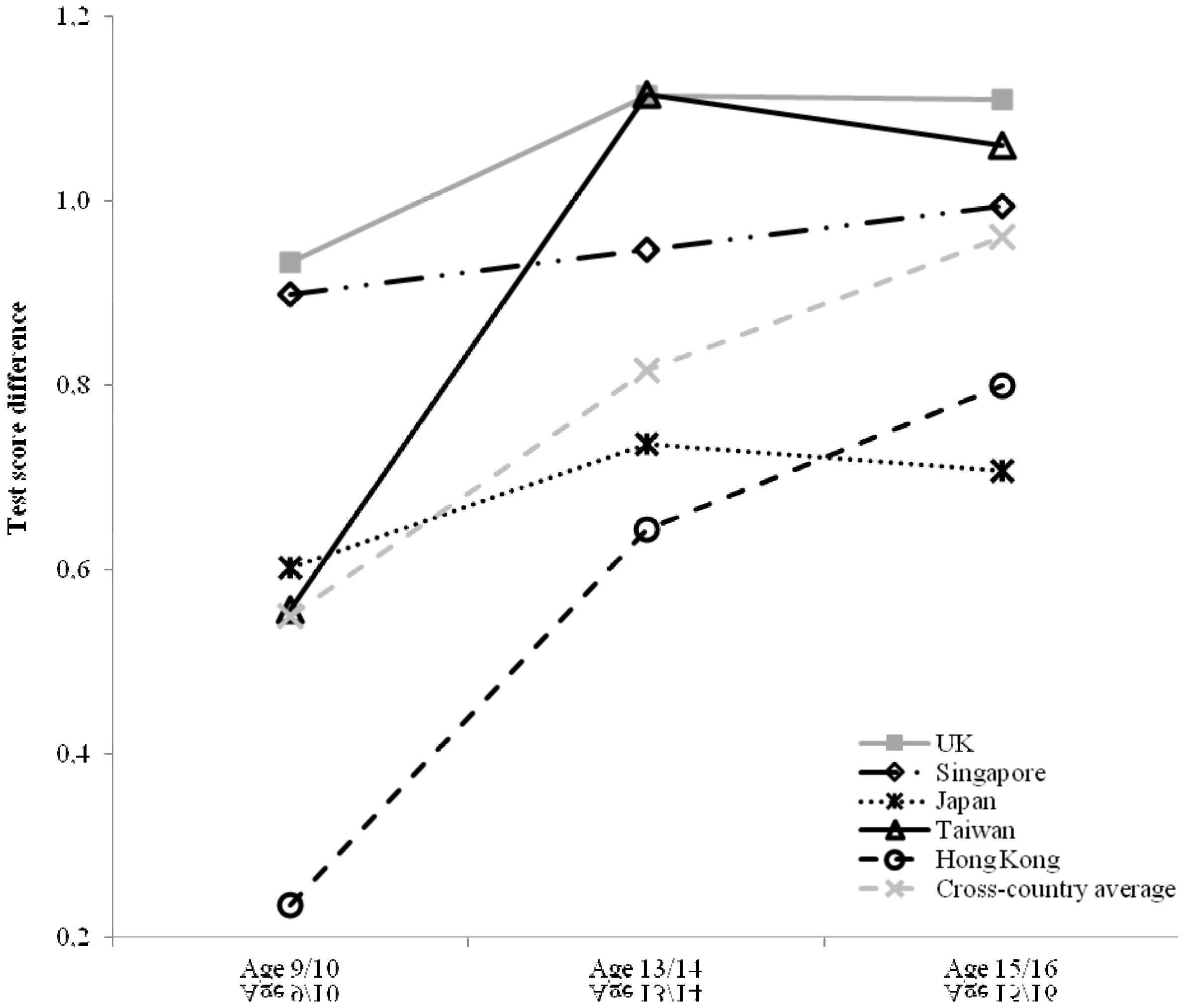
Notes: 1 The left hand panel refers to the change in the 90th percentile of math achievement between age 9/10 (TIMSS 2003 4th grade) and age 13/14 (TIMSS 2007 8th grade). The right hand panel provides analogous figures for the change between age 9/10 (TIMSS 2003 4th grade) and age 15/16 (PISA 2009) .

2 All figures presented in terms of international z-scores.

3 The thin black line running through the centre of each bar is the estimated 99% confidence interval.

4 Results for Taiwan have been excluded from the left hand panel for clarity of presentation. The 90th percentile is estimated to increase by 0.8 of a standard deviation between age 10 and age 14 in this country (see Table 4 panel b for further details).

Figure 5. Socio-economic inequality in math test scores at ages 9/10, 13/14 and 15/16



Notes:

1 Estimates refer to differences between children from households with few books (0 – 25) to those with many books (more than 200 books

2 Age 9/10 refers to TIMSS 2003 4th grade data, age 13/14 refers to TIMSS 2007 8th grade data and age 15/16 refers to PISA 2009.

3 All figures presented in terms of international z-scores.

Appendix Table 1. Response rates across countries and surveys

	4th grade TIMSS (2003)		8th grade TIMSS (2007)		PISA (2009)	
	School	Pupil	School	Pupil	School	Pupil
Singapore	100	98	100	96	98	91
Japan	100	97	97	97	95	95
Taiwan	100	99	100	100	100	95
Italy	100	97	100	97	99	92
Russia	100	97	100	98	100	97
Slovenia	99	92	99	95	98	91
Lithuania	96	92	99	94	100	93
Norway	93	95	93	95	97	90
Australia	90	94	100	95	99	86
Hong Kong	88	95	79	96	97	93
UK	82	93	86	93	87	87
United States	82	96	83	95	78	87

Notes:

1 School response rates refer to after replacement schools have been included.