Taking Productivity in Education Seriously II:
Insights from Primary & Secondary Education

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Where we were, at the end of yesterday's lecture

- People who begin higher education with much greater cognitive skill appear to be able to absorb many more dollars of educational resources and still be as/more productive with each dollar.
- In fact, people with extremely high cognitive skills appear to be able to interact with an order of magnitude more educational resources and achieve the same (or slightly greater) per dollar average productivity with those resources.

These results (strong single crossing) have important economic implications

- If people make optimal investments in higher education, they will end up with very different levels of human capital.
- This is growth maximizing.
- If cognitive skills are fixed or determined by biology, we are in a bind: what is good for growth will raise income inequality and, therefore, the need for redistribution.
- But nothing in the economics of human capital prohibits high cognitive skill *for everyone*. So understanding whether everyone could have it is important.

Cognitive Skill –What's in a Word?

Economists have traditionally been fairly free and loose with their terminology:

- Cognitive skill
- Aptitude
- Ability
- Mental readiness
- College readiness
- Productivity, etc.

when what they meant was "the expected treatment effect of margin-pushing education, in terms of skills."

Slippery word choices: good or bad?

- Good: Economists' willingness to use any number of words for the same concept turns out to be somewhat justified by neuroscience, which argues that "ability" is plastic, multidimensional, modified by experience, and improved by exercises that push the brain to develop skills at the margin.
- Bad: The use of the word "ability" (and the letter "a") in seminal models of human capital encouraged economists to think of the parameter as fixed.

“Ability” = “Cognitive Skill”

- In these lectures, I am forced to use “ability” and “cognitive skill” somewhat interchangeably owing to existing research.
- What is ruled in: the capacity for higher order cognitive functioning in which the brain’s frontal lobe plays a disproportionate role:
  - Reasoning
  - Planning
  - Integration
  - Self-regulation
- These capacities are intertwined with emotional and social and even bodily skills, but they are also somewhat distinct and especially valuable in formal education.

Reminder: Becker's model of human capital formation

$$y_i = f(s_i, a_i)$$

where:

y = the outcome (human capital or some function of it like lifetime earnings)

s = schooling

a = ability

Education production was assumed to obey **Single-Crossing** in schooling & ability.

- Single-Crossing: a higher ability student always derives more benefit from any marginal unit of educational resources than a lower ability student:

$$\frac{\partial^2 f}{\partial s \partial a} > 0 \quad \forall\ s \geq 0$$

- Yesterday's lecture suggests that single-crossing holds strongly among people of university age.

Taking the model seriously

- Becker's model of human capital was not based on neuroscience.
- Rather, it was based on the empirical observation that people who were commonly regarded as more able tended to acquire more education.
- So, ought we to take seriously the assumption that ability is fixed or predetermined?
- Should *a* be a function of previous educational experience?
- In the last lecture, the answer did not matter but it matters in this one.

This lecture's argument proceeds in 4 steps

1. Recent neuroscience suggests that ability is plastic, especially in early adolescence.
2. Descriptive evidence supports the hypothesis that early adolescence is a time when ability changes to a unusual extent, with long-lasting effects.
3. Causal evidence on successful educational interventions suggest that they have greater and longer-lasting effects on early adolescents.
4. Ironically, we invest the fewest educational resources in early adolescents.

Neuroscience & the Economics of Education

(a little intellectual history)

I am not the first to suggest we look to neuroscience for guidance on education production

One could argue that the entire early childhood education "industry" was motivated by neuroscientific arguments.

It relied on 3 arguments which—I agree—are crucial:

1. Plasticity of ability at certain ages.
2. Path determination or long-lastingness of effects generated at certain ages.
3. Susceptibility of ability to age-suitable educational interventions.

Where early childhood went right and wrong

- Early childhood (age 0 to 3) *is* a period of great brain plasticity with effects that are long-lasting.
- However, the brain areas affected are not the ones that control ability in the sense of the higher order cognitive skills that are so valuable in formal education.
- Moreover, successful interventions that suit early childhood seem not be primarily *educative* in nature.
  - Breastfeeding, nutrition, pollution, play, parental nurturing…
- At some point the focus switched to non-cognitive skills (which may affect adult outcomes but seem to have little effect on cognitive skill-building in schools) yet the prescription remained: <u>early childhood education</u>.

Part I: Recent neuroscience identifies adolescence as the period when ability is plastic.

After this part, we will treat what neuroscience suggests as an <u>hypothesis</u> to test.

As explained later, neuroscience does not provide the *causal* evidence we need.

Recent neuroscience

- Rapid advances are due to large-scale MRI-based and other non-invasive brain-based studies. These complement forensic studies, animal studies, etc.
- Knowledge that was state of the art in, say, the mid-1990s is now outdated.

- I borrow from many recent reviews:
  - Steinberg, *Age of Opportunity*, 2014.
  - Reyna et al, *The Adoloscent Brain*, 2012.
  - Special issue of *Brain Cognition* on advances in child and adolescent neuroscience (2010).
  - Spear, *The Behavioral Neuroscience of Adolescence*, 2010
  - Sylwester, *The Adolescent Brain*, 2007.
  - Giedd, "The Teen Brain: Insights from Neuroimaging," 2007.
  - Lenroot & Giedd, "Brain Development in Children and Adolescents: Insights from Anatomical Magnetic Resonance Imaging," 2006

Periods of brain plasticity have high rates of:

- Synaptic pruning

Developmental plasticity involves eliminating unnecessary connections, a process called pruning. A 1-year-old has about twice as many connections between neurons as there are in the adult brain. “Pruning makes the brain function more effectively, the way that thinning a tree allows the remaining branches to grow stronger.”

- Myelination

Myelination, in which white matter grows around a connection to make electrical impulses travel faster, makes a circuit not only more efficient but more durable or hardened.

These processes fulfil the conditions for disproportionate influence

- Pruning makes a brain plastic at certain ages.
- Myelination makes changes that occur in key pruning periods unusually durable –hard to change once the path is set.

There are 2 periods of unusual pruning and myelination: early childhood, early adolescence

- Early childhood: development related to sensory functioning (vision, hearing, social & spatial awareness, speech recognition), not much in the frontal lobe.
- Adolescence: development related to cognition (reasoning, planning, self-regulation), disproportionately in the frontal lobe.

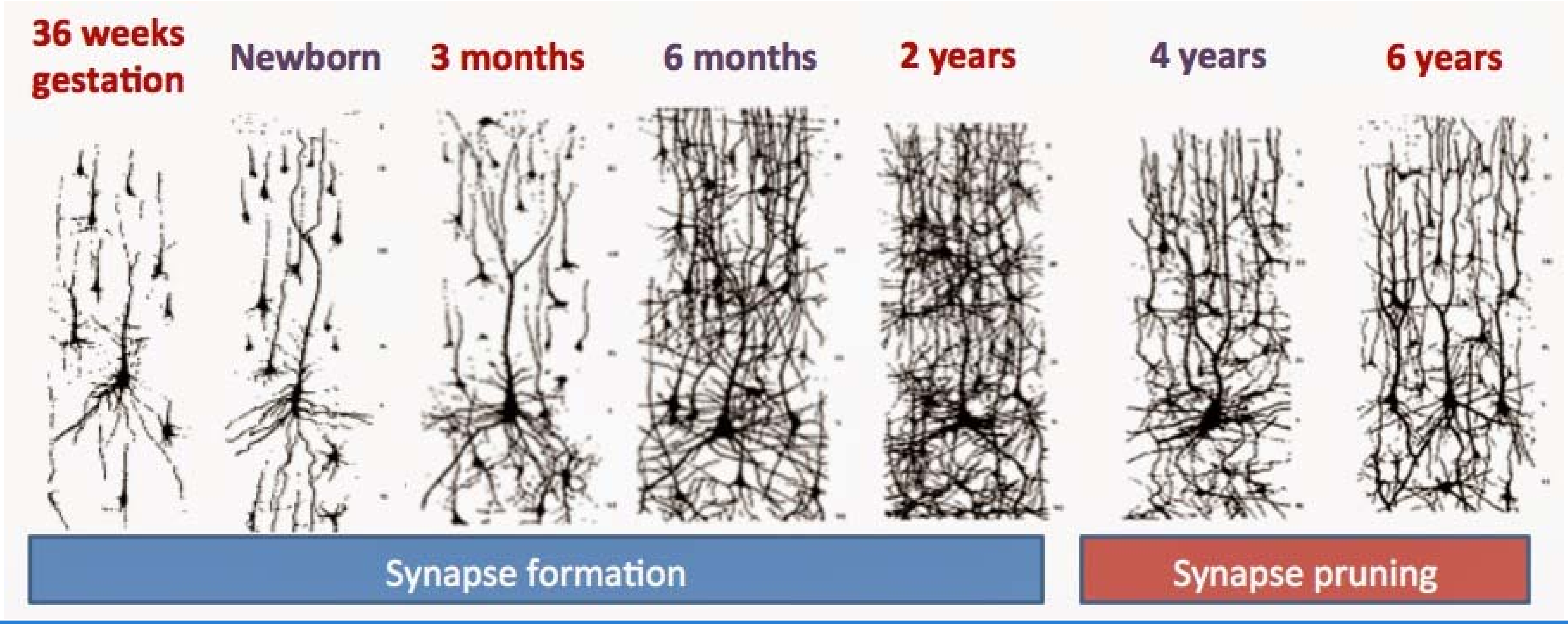
"The childhood developmental period from birth to about age 10 focuses on learning how to be *a human being*—learning to move, to communicate, and to master basic cultural knowledge and social skills. The adolescent developmental period… focuses on learning how to be *a productive… human being*…."

Early childhood vs. early adolescence

"Until recently, it was believed that no period of development came close to the early years in terms of the potential impact of experience on the brain. Because the brain approaches its ultimate adult size by the age of ten or so, many had assumed that brain development was more or less complete before adolescence began. We now know, however, that internal transformations in brain anatomy and activity are not always reflected in the organ's outward appearance.... [A]dolescence is... a period of brain growth that is far more sensitive to experience than anyone previously imagined."

Between 36 weeks and age 2, the brain engages in exuberant neuron and synapse creation—not so much in the frontal lobe.

Pruning of this growth begins at ~2 and is rapid through ~3 or 4.

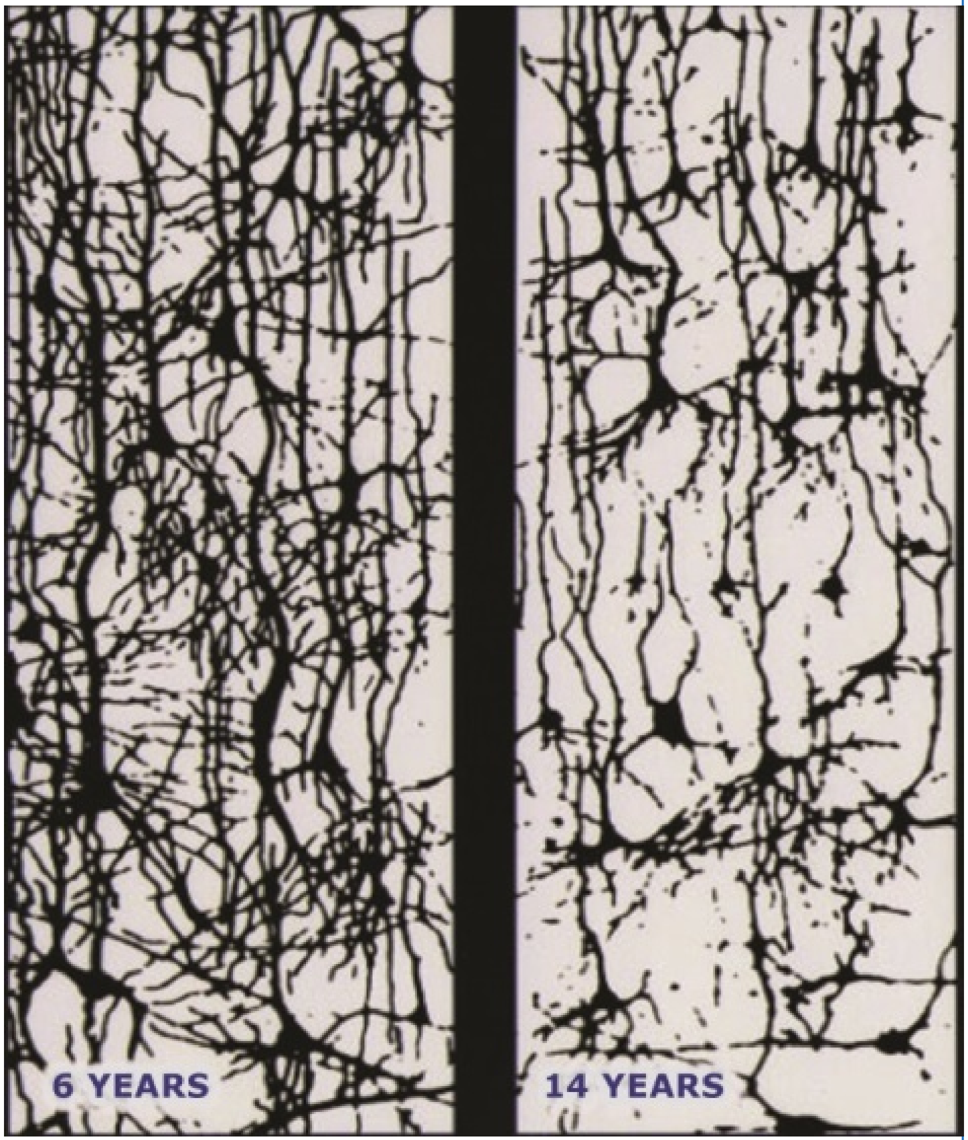


Between 6 and 10, myelination reinforces the sensory circuits pruned up to age 6.

Towards the end of this period, the brain engages in exuberant creation in the <u>frontal</u> lobe.

<u>Frontal</u> lobe pruning begins at ~10.5 (females) or 11.5 (males) and is rapid through ~13 or 14.

After that, pruning is less important & myelination is more important.



Early childhood vs. early adolescence

"the sensory lobes… mature during childhood, and the frontal lobes… mature during adolescence…. Since our frontal lobes provide the solutions we need to survive, one might think that they would mature first--but then we would be solving problems that we don't understand."

Early childhood vs. early adolescence

"We must... revisit our steadfast belief in the unique importance of the first years of life. The brain *is* especially malleable during the first few years and, yes, it does lose some of this malleability after infancy. But new evidence shows that brain plasticity increases during adolescence.... Whether the brain is as plastic in adolescence as it is early in life isn't really the right question because... the brain is plastic in different places during these time periods."

Plasticity cuts both ways

"You're likely familiar with the idea that the early years—`0 to 3' is the popular shorthand--are a time during which children's experiences make a major, lasting difference in how their brains develop and the lives unfold.... But most people don't realize that adolescence is a second period of heightened malleability.

The fact that the adolescent brain is malleable is both good and bad news, though. As neuroscientists are fond of saying, plasticity cuts both ways. By this they mean that the brain's malleability makes adolescence a period of tremendous opportunity--and great risk."

Early adolescence: opportunities & risk

"The abilities that develop in adolescence… are not as necessary for survival as are those that develop early in life. You can live without being able to reason logically, plan ahead, or control your emotions (the plenitude of illogical, impetuous, and short-tempered adults attests to this)….

Unlike elementary skills, whose development is tightly regulated by pre-programmed biology, evolution left more room for variation in the development of complex abilities. That's why there's so much variation in how well different people reason, plan for the future, and control their emotions, but far less variation in how well people see, hear, and walk.

In the past, not all environments demanded… advanced cognitive abilities…. In today's world, though, where formal education is increasingly important for success, people who are bad at reasoning, planning, and self-regulation are at a serious disadvantage, and the fact that the development of these abilities is highly sensitive to environmental influence is a mixed blessing…. For people… in favorable circumstances [during early adolescence], the plasticity of these brain systems is wonderful. For those who [aren't], this same plasticity can be disastrous."

Adolescence is the last major period of plasticity

"Not only is the brain more plastic during [early] adolescence than in the years that immediately precede it, but it is also more plastic… than in the years that follow it. The drop in plasticity as we mature into adulthood is just as significant as the increase in plasticity as we enter adolescence. In fact, adolescence is the brain's <u>last</u> period of especially heightened malleability."

Part 2:
Descriptive evidence suggests that early adolescence is key

1. Cognitive skill trajectories diverge especially in early adolescence.

2. After early adolescence, cognitive skill trajectories "harden:" students transition among them less often.

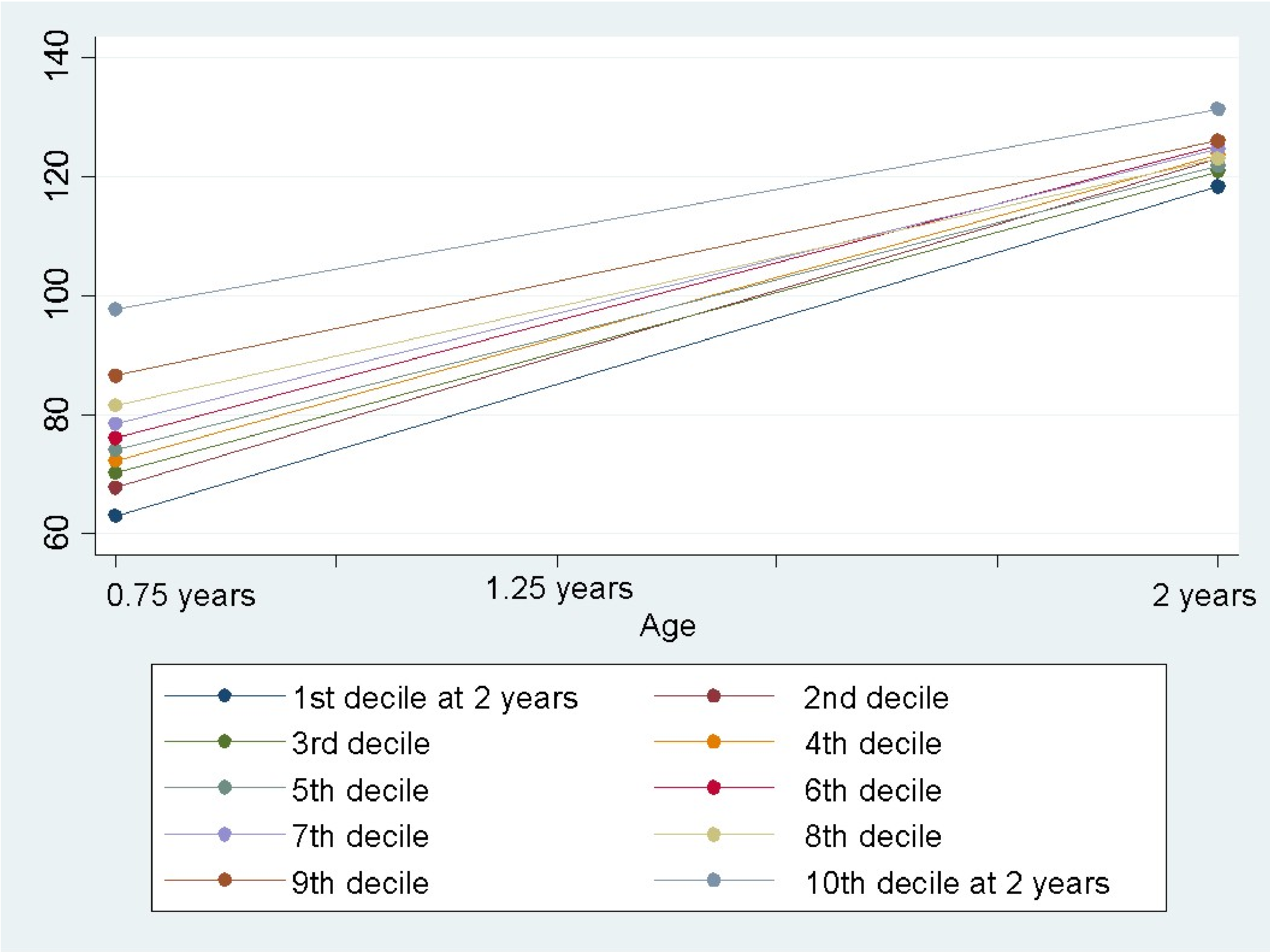
Data I use to create cognitive trajectories

- Longitudinal data from the U.S. Dept. of Education:
  - Early Childhood Longitudinal Study—Birth to Kindergarten
  - Early Childhood Longitudinal Study—Kindergarten to Grade 8
  - Early Childhood Longitudinal Study—Kindergarten to Grade 4
  - National Educational Longitudinal Study—8th Grade onwards
- Administrative data on the students in public (government-controlled) schools from a large state.
  - They are tested in grades 3 through 8 and in grades 10 and 11.

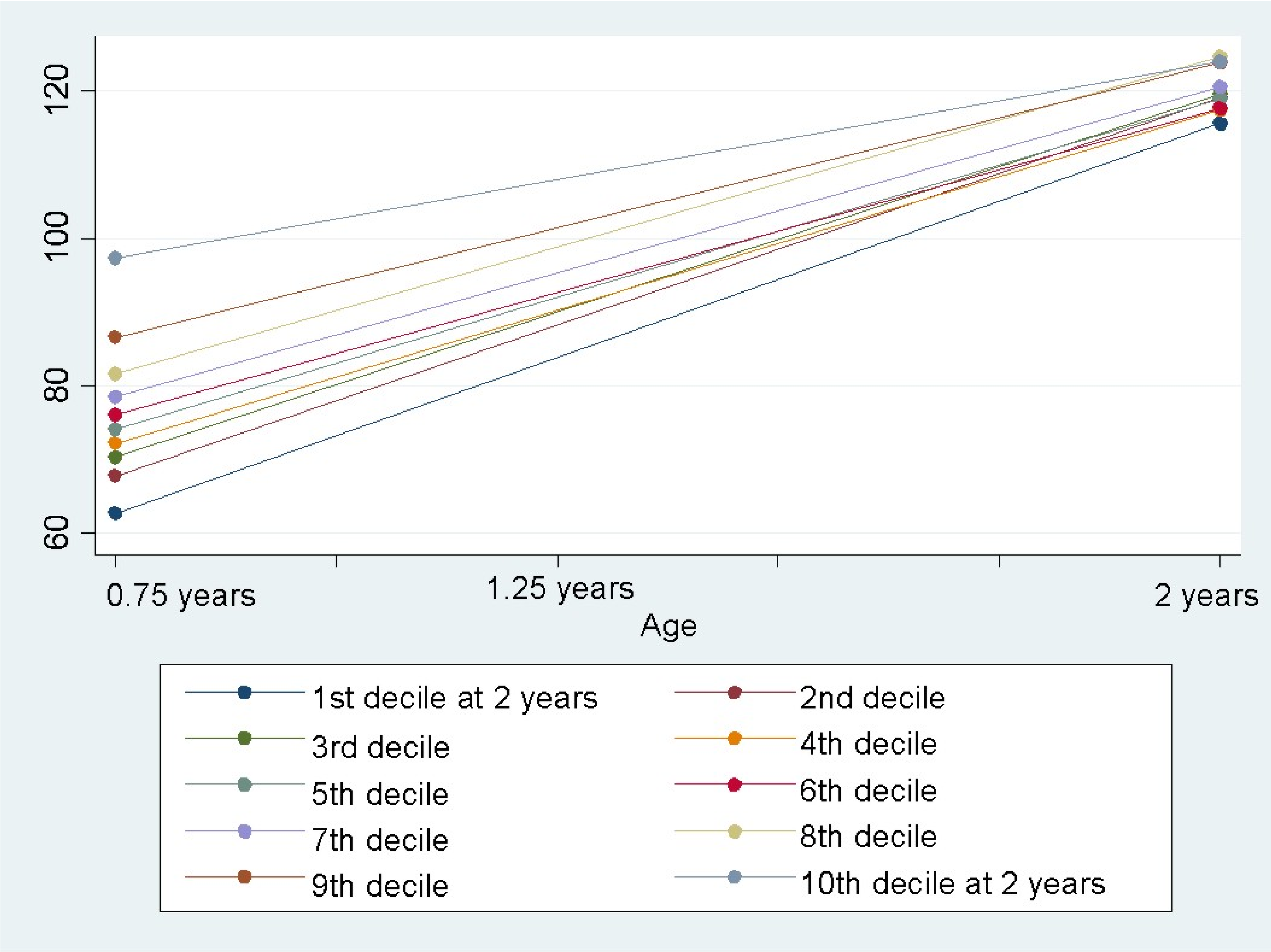
Notes to aid interpretation

- All of the data are in IRT-based vertical scales that should show absolute measures of cognitive skill. Take the trajectories as reasonable measures of change.
- Do not compare the *scales* across the studies.
- I show figures based on math because it is more affected by successful educational interventions than is reading. (This fact is useful later.) However, reading figures do not convey different messages.

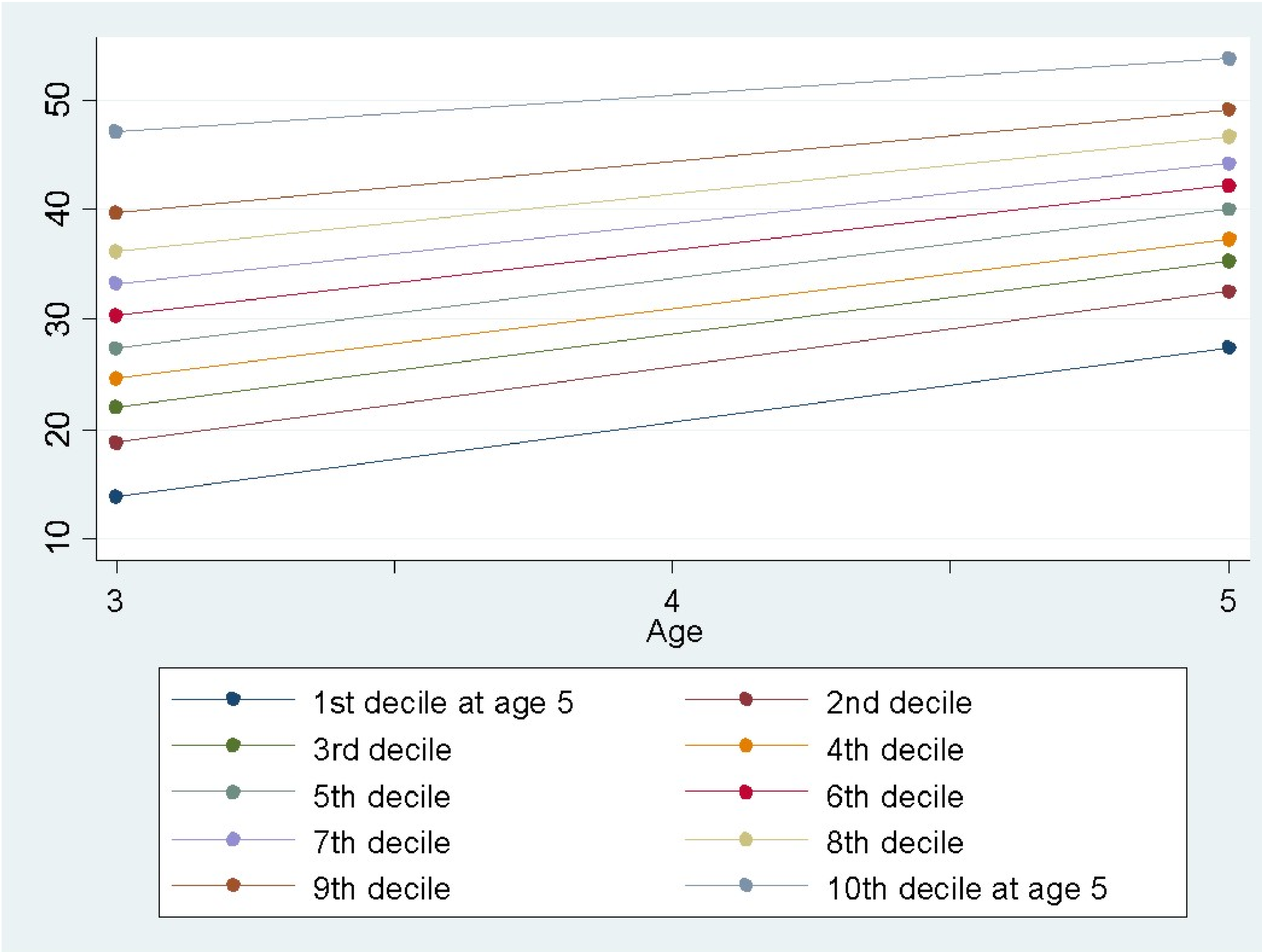
Female mental score, 9 months to 2 years



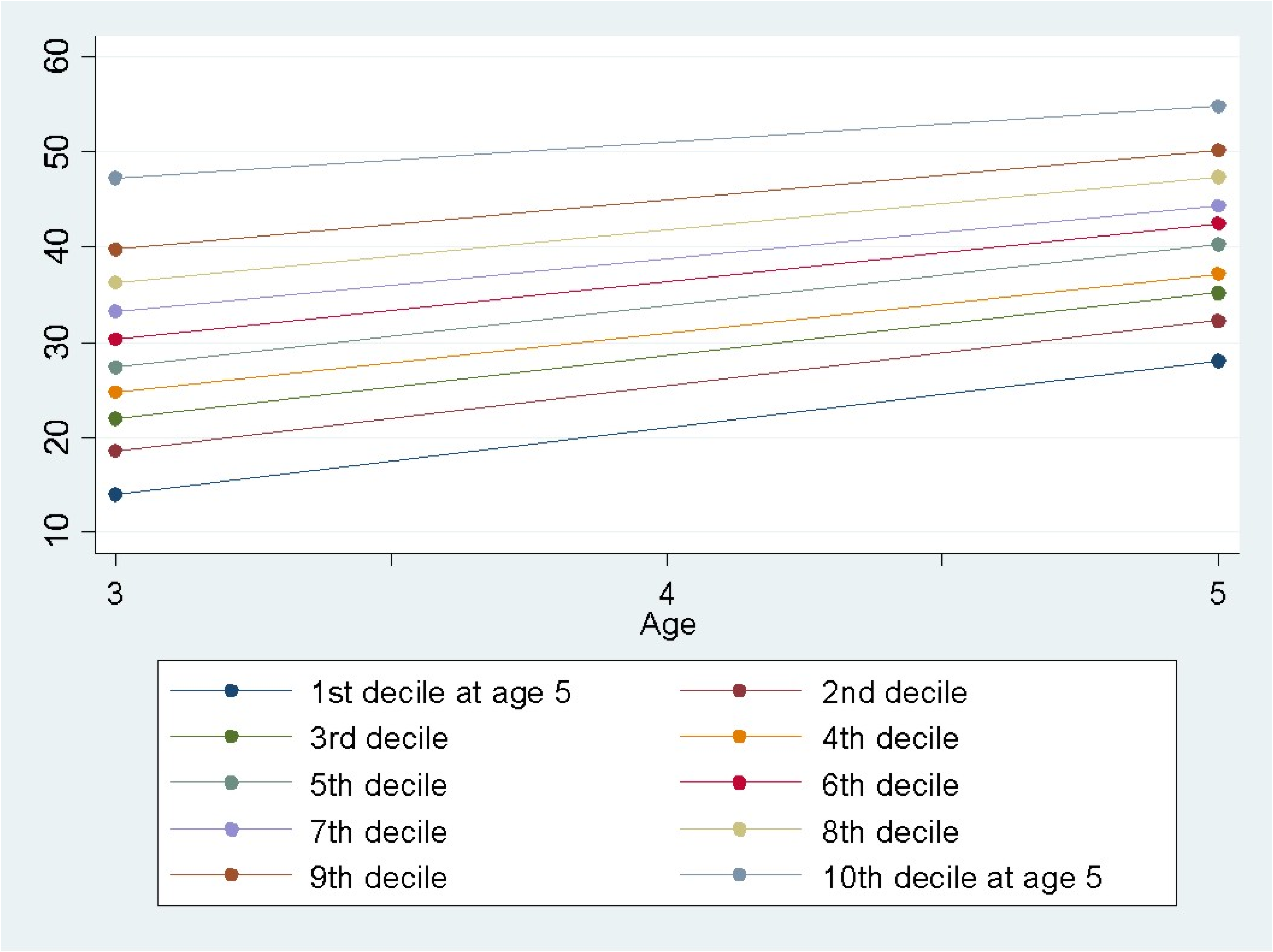
Male mental score, 9 months to 2 years



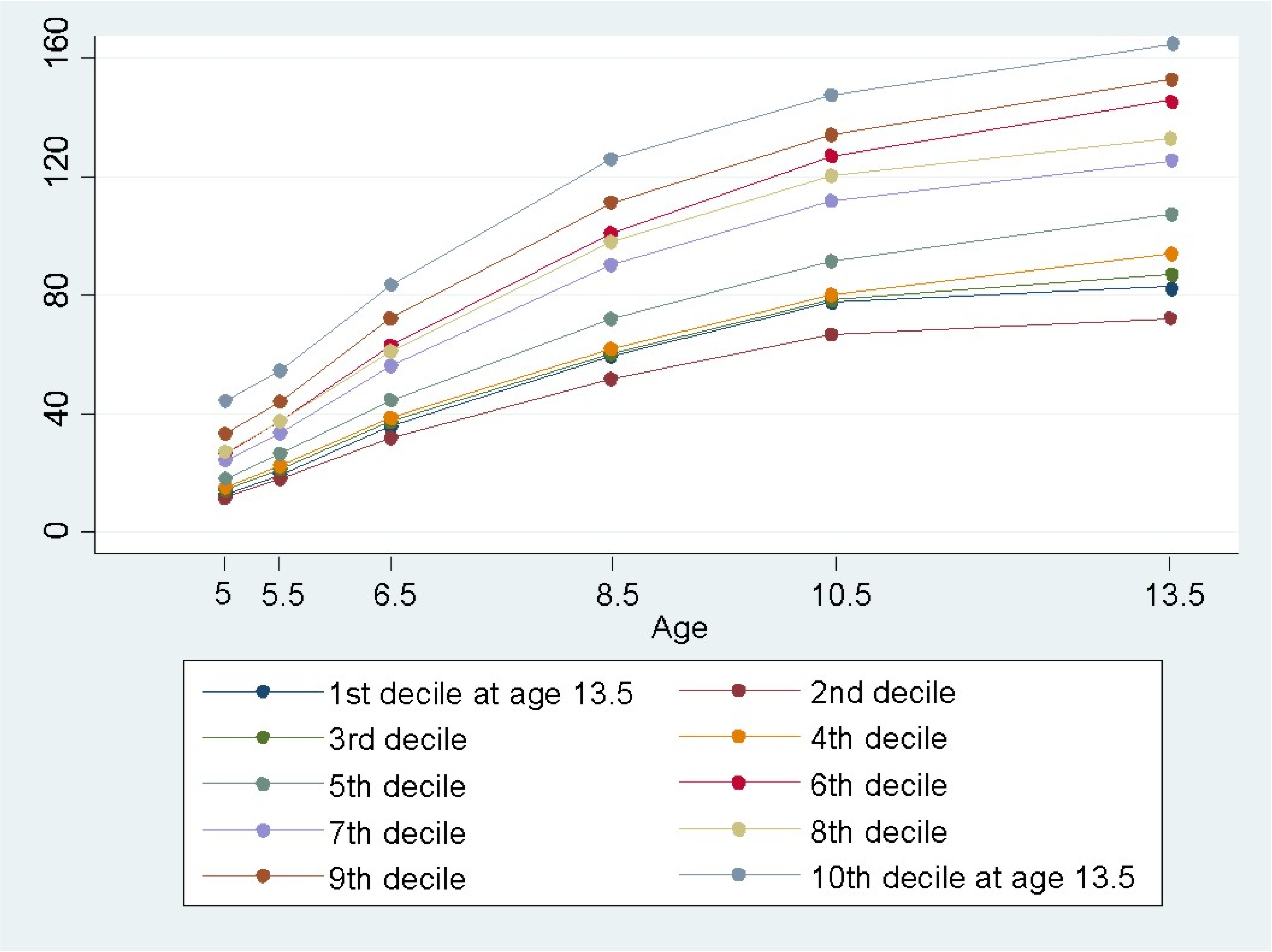
Female math score, age 3 to 5



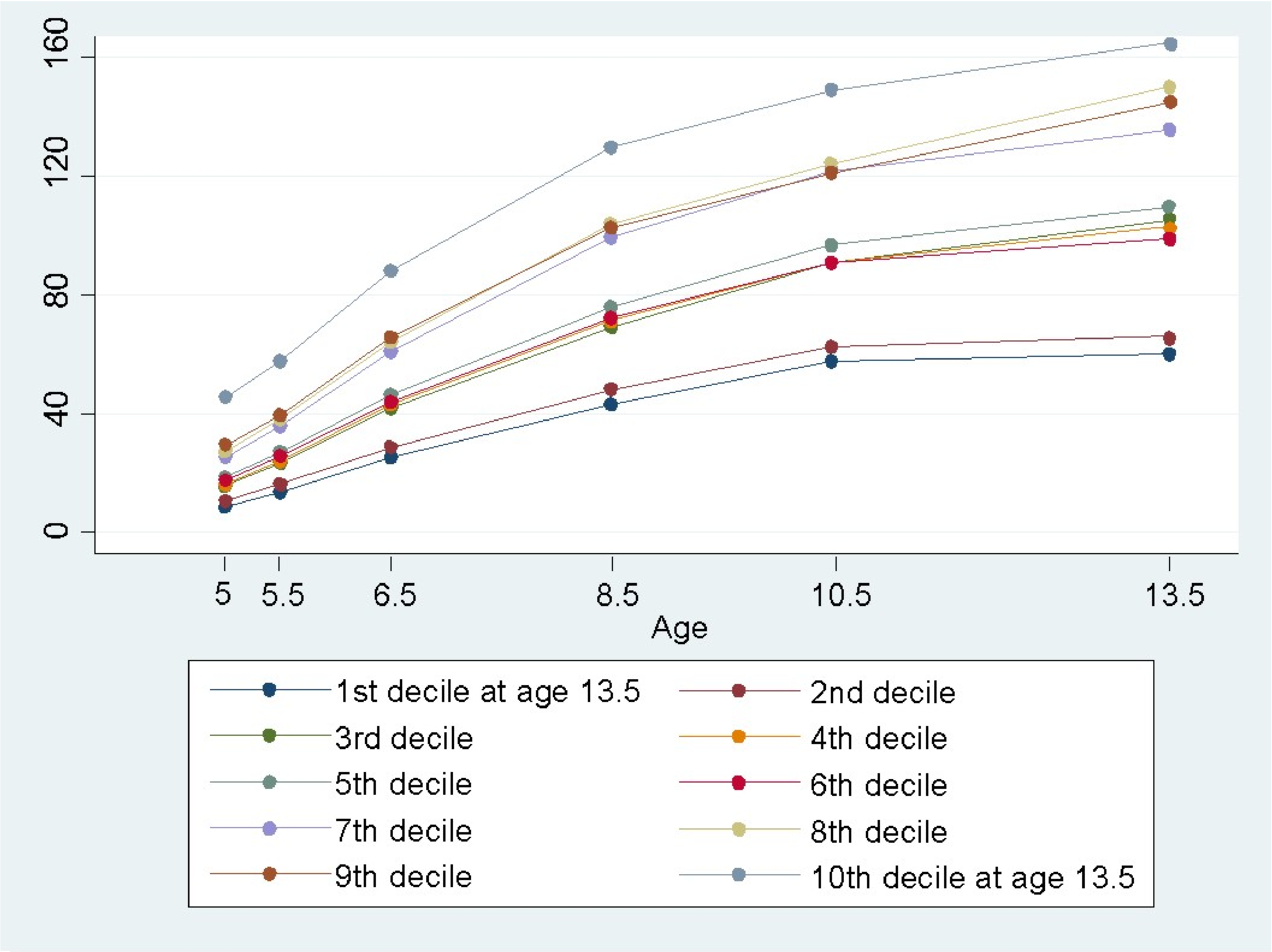
Male math score, age 3 to 5



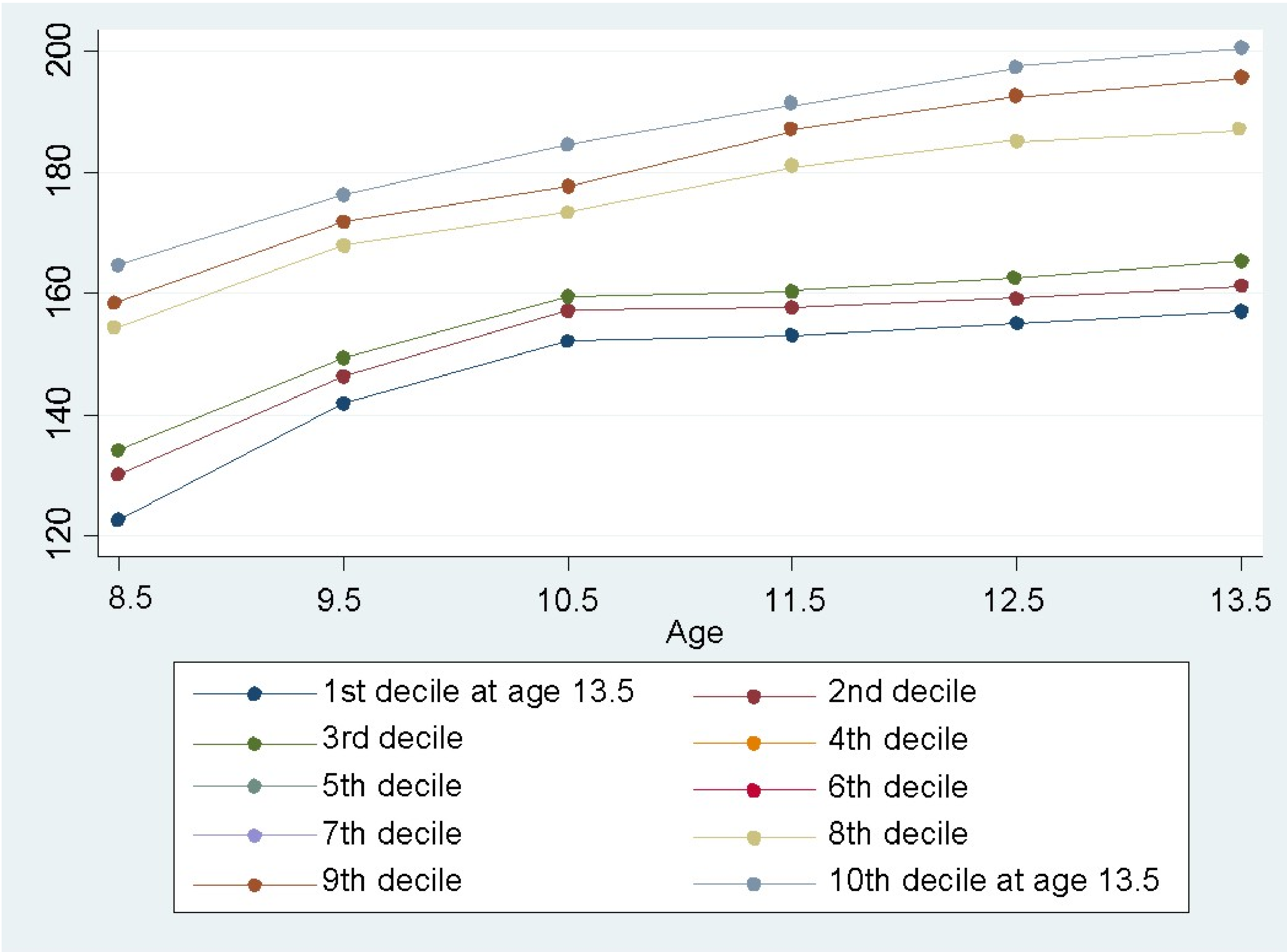
Female math score, age 5 to 13.5



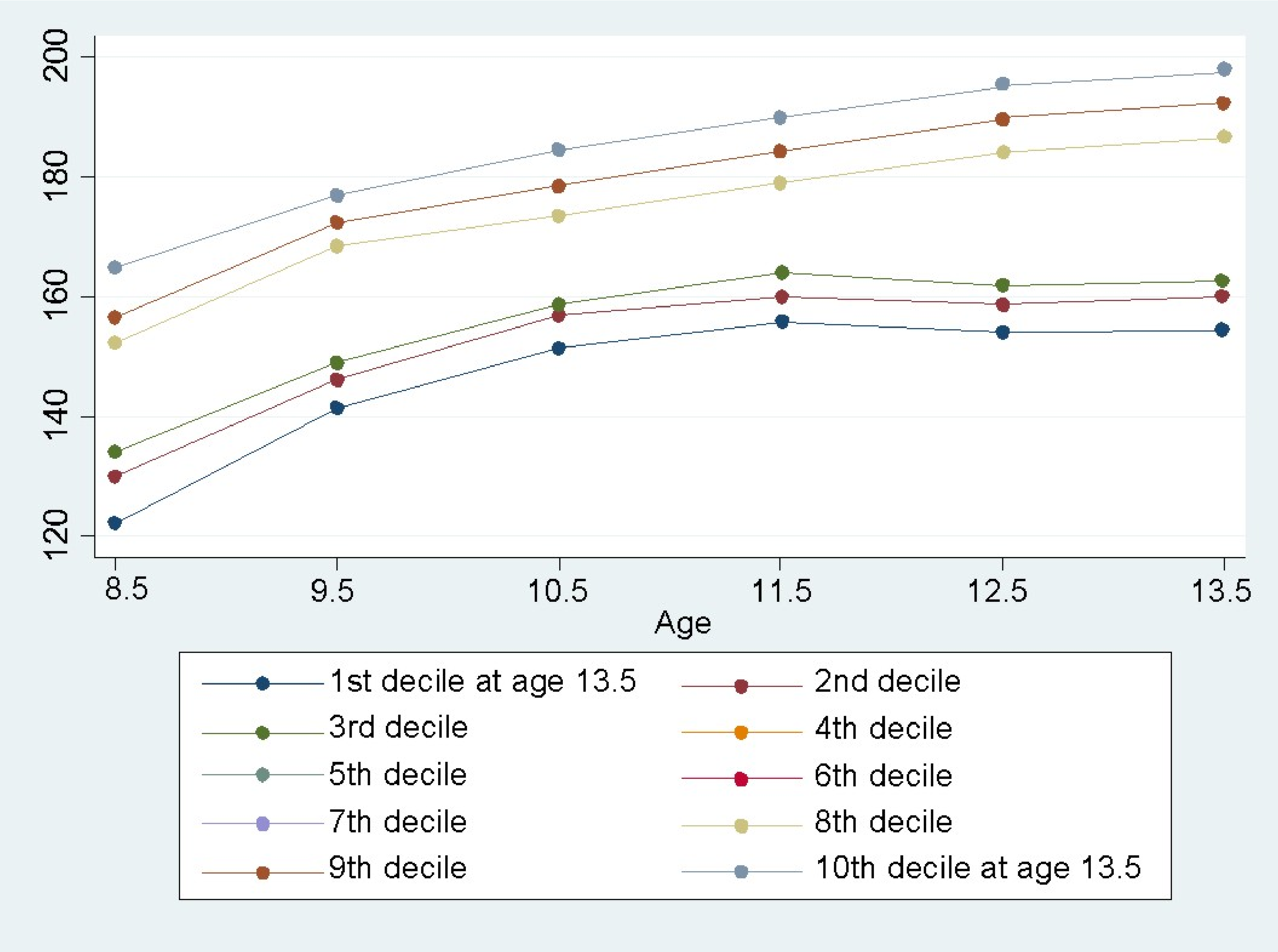
Male math score, age 5 to 13.5



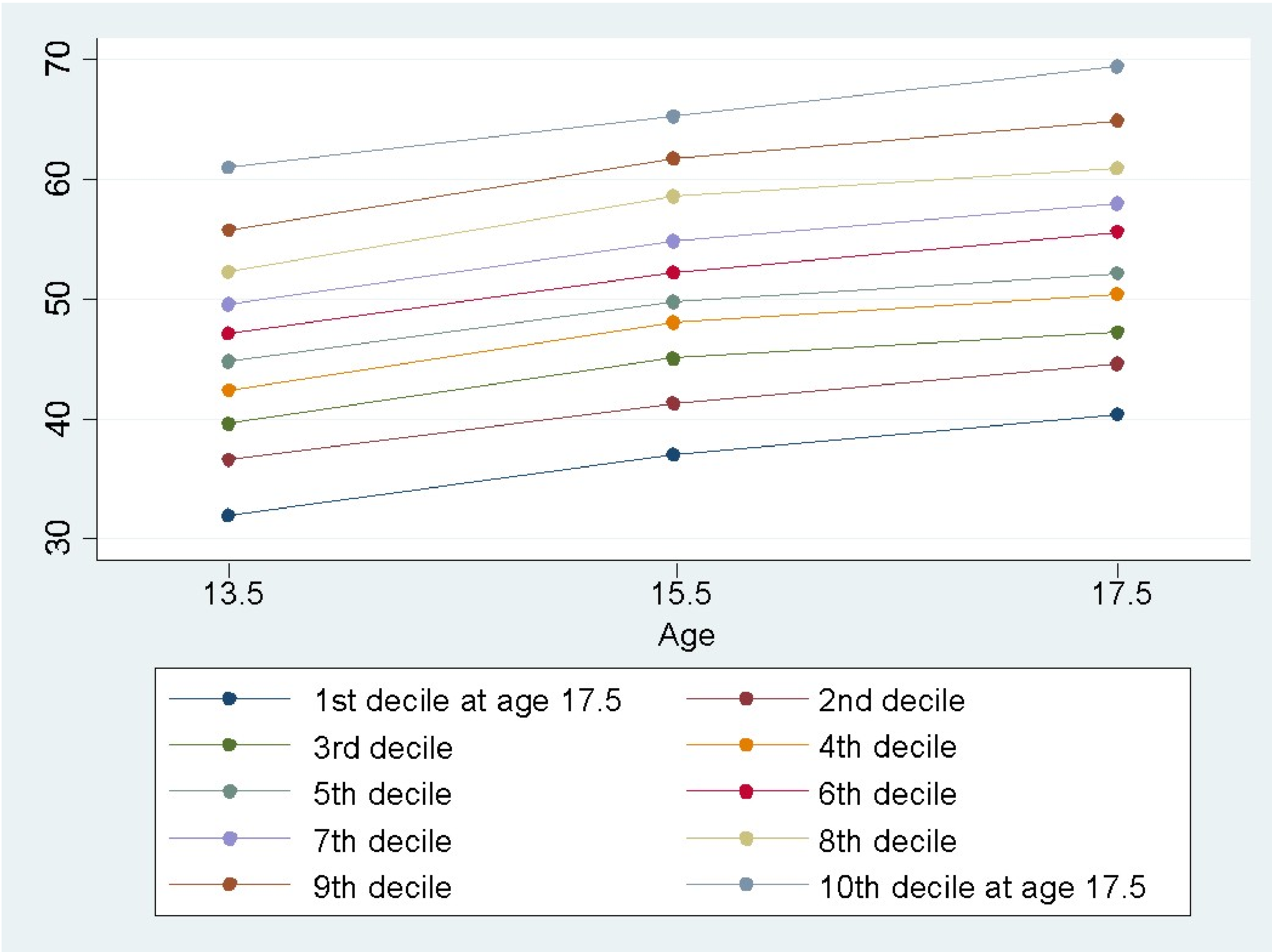
Female math score, age 8.5 to 13.5
A "close-up" on adolescence



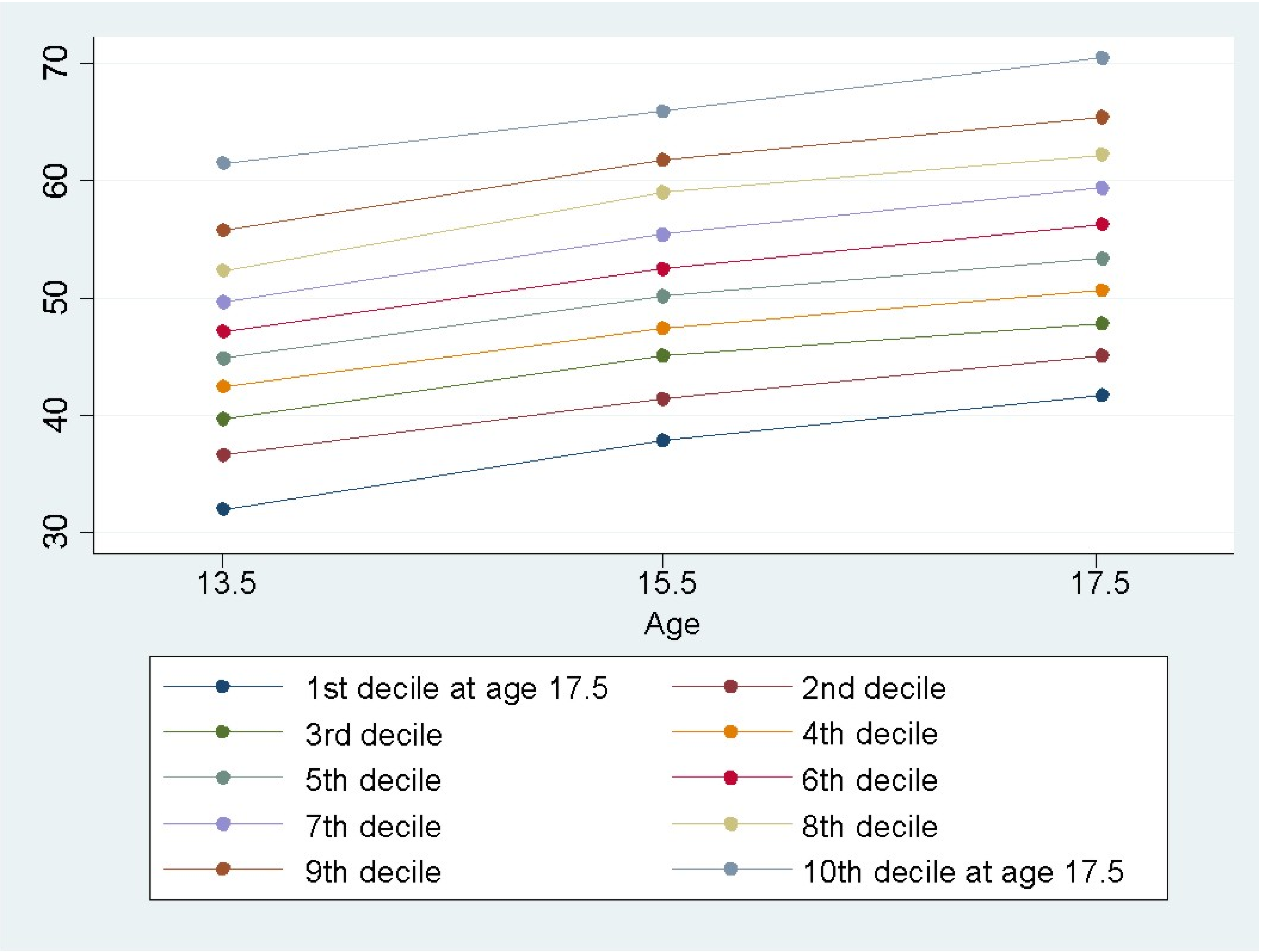
Male math score, age 8.5 to 13.5
A "close-up" on adolescence



Female math score, age 13.5 to 17.5



Male math score, age 13.5 to 17.5



Summing up trajectories

Students' cognitive skills appear to converge from age 1 to 5.

From 5 to 13.5, their skills appear to diverge.

"Close-up" evidence suggest divergence accelerates at age 10.5 (females) or 11.5 (males).

From 13.5 to 17.5, cognitive skills neither converge nor diverge.

Trajectories diverge in adolescence but do they harden afterwards?

I examine decile-to-decile transition matrices.

I place each student in her or his current decile based on her or his current scores.

Female mental/math score transitions, age 1 to 3

females		10 deciles of mental skill, age 3									
		1	2	3	4	5	6	7	8	9	10
10 deciles of mental skill, age 1											
	1	13.5	11.4	10.5	7.9	9.3	9.8	7.9	8.4	10.9	10.5
	2	12.4	8.6	10.3	10.3	11.5	6.5	11.2	11.2	9.4	8.6
	3	11.9	10.3	8.4	10.0	8.4	9.3	9.7	10.9	12.2	9.0
	4	9.2	11.7	11.4	11.7	9.8	9.5	7.3	10.7	10.7	8.2
	5	7.5	6.7	7.5	10.3	9.9	12.4	11.4	12.1	11.0	11.4
	6	9.2	7.0	8.2	8.2	11.4	11.4	10.1	11.1	7.0	16.5
	7	5.5	13.6	7.4	10.4	12.3	9.7	5.8	14.2	10.4	10.7
	8	7.2	8.3	7.9	8.7	7.6	12.3	9.8	10.8	11.9	15.5
	9	6.1	7.3	8.8	8.8	11.8	10.3	8.0	13.4	14.1	11.5
	10	3.6	6.0	7.2	9.6	11.6	11.6	10.0	12.4	15.6	12.4

Female math score transitions, age 11 to 13

females		10 deciles of math, age 13.5									
		1	2	3	4	5	6	7	8	9	10
10 deciles of math, age 11.5	1	48.3	28.5	13.9	5.6	2.5	0.8	0.3	0.1	0.0	0.0
	2	24.8	28.8	24.3	11.5	7.2	2.5	0.8	0.2	0.1	0.0
	3	11.3	21.5	26.9	18.0	13.5	6.0	2.1	0.5	0.1	0.0
	4	4.4	12.2	22.8	20.4	21.1	12.1	5.2	1.4	0.3	0.0
	5	1.5	5.7	14.6	17.6	24.6	19.3	11.9	4.1	0.8	0.0
	6	0.5	1.9	7.2	11.7	21.7	24.4	20.3	9.7	2.5	0.2
	7	0.1	0.6	2.3	4.9	12.3	21.2	28.1	21.5	8.2	0.8
	8	0.1	0.1	0.5	1.1	4.3	11.2	23.8	31.9	23.1	4.1
	9	0.0	0.0	0.1	0.1	0.7	2.6	9.9	24.7	41.5	20.3
	10	0.0	0.0	0.0	0.0	0.1	0.2	1.2	5.8	26.2	66.5

Male math score transitions, age 11 to 13

males		10 deciles of math at age 13.5									
		1	2	3	4	5	6	7	8	9	10
10 deciles of math at age 11.5	1	50.4	25.8	13.5	5.4	3.0	1.1	0.5	0.2	0.1	0.0
	2	27.0	27.5	22.3	10.6	7.4	3.3	1.3	0.5	0.2	0.0
	3	14.3	21.5	24.8	15.5	12.6	6.7	3.3	1.1	0.3	0.0
	4	6.8	14.3	21.9	20.6	15.5	11.7	6.2	2.2	0.7	0.1
	5	2.9	7.7	15.9	15.2	21.0	17.1	13.0	5.5	1.6	0.1
	6	1.1	3.4	8.8	11.2	19.9	20.6	19.1	11.0	4.5	0.5
	7	0.3	1.3	3.8	5.8	13.9	18.6	23.6	19.5	11.1	1.9
	8	0.1	0.3	1.2	2.0	6.1	12.0	22.4	25.6	23.4	6.8
	9	0.0	0.1	0.3	0.4	1.7	4.2	11.8	22.2	35.6	23.7
	10	0.0	0.0	0.0	0.0	0.2	0.6	2.1	7.0	25.0	65.2

Female math score transitions, age 15 to 17

females		10 deciles of math at age 17.5									
		1	2	3	4	5	6	7	8	9	10
10 deciles of math at age 15.5	1	71.4	24.5	3.2	0.7	0.2	0.0	0.0	0.0	0.0	0.0
	2	33.3	42.9	18.4	4.3	0.8	0.2	0.0	0.0	0.0	0.0
	3	7.7	29.1	34.0	17.6	8.4	2.3	1.0	0.0	0.0	0.0
	4	1.1	7.1	27.0	31.2	21.8	9.2	1.9	0.5	0.0	0.0
	5	0.6	2.5	10.6	29.8	27.8	18.9	8.7	1.0	0.0	0.0
	6	0.3	0.3	3.4	14.2	25.8	29.7	20.2	5.6	0.5	0.0
	7	0.0	0.2	0.9	5.0	14.6	29.4	30.5	16.6	2.9	0.0
	8	0.1	0.0	0.0	1.1	3.1	10.8	21.9	38.0	20.5	4.5
	9	0.0	0.0	0.0	0.2	0.4	1.8	6.2	28.0	41.6	22.0
	10	0.0	0.0	0.0	0.0	0.1	0.0	1.1	6.0	26.1	66.8

Male math score transitions, age 15 to 17

males		10 deciles of math at age 17.5									
		1	2	3	4	5	6	7	8	9	10
10 deciles of math at age 15.5	1	62.2	28.3	5.7	2.3	0.9	0.2	0.5	0.0	0.0	0.0
	2	28.7	43.5	18.3	5.7	2.9	0.8	0.2	0.0	0.0	0.0
	3	8.0	26.2	32.7	18.1	9.3	4.0	1.3	0.4	0.0	0.0
	4	0.9	8.6	21.9	31.4	20.7	11.8	2.9	2.0	0.0	0.0
	5	1.1	3.3	10.4	18.0	27.1	24.1	12.6	3.3	0.0	0.0
	6	0.7	1.5	4.0	8.8	20.8	30.5	22.8	9.7	1.3	0.0
	7	0.3	1.0	0.8	2.3	9.6	23.9	31.8	24.2	5.6	0.3
	8	0.0	0.3	0.4	0.6	2.6	7.9	19.7	37.5	24.8	6.3
	9	0.0	0.0	0.0	0.6	1.0	1.3	5.7	21.5	40.7	29.3
	10	0.0	0.0	0.0	0.2	0.1	0.5	1.5	5.2	21.6	70.9

Male math score transitions, age 15 to 17

males		10 deciles of math at age 17.5										
		1	2	3	4	5	6	7	8	9	10	Total
10 deceiles of math at age 15.5	1	62.2	28.3	5.7	2.3	0.9	0.2	0.5	0.0	0.0	0.0	100
	2	28.7	43.5	18.3	5.7	2.9	0.8	0.2	0.0	0.0	0.0	100
	3	8.0	26.2	32.7	18.1	9.3	4.0	1.3	0.4	0.0	0.0	100
	4	0.9	8.6	21.9	31.4	20.7	11.8	2.9	2.0	0.0	0.0	100
	5	1.1	3.3	10.4	18.0	27.1	24.1	12.6	3.3	0.0	0.0	100
	6	0.7	1.5	4.0	8.8	20.8	30.5	22.8	9.7	1.3	0.0	100
	7	0.3	1.0	0.8	2.3	9.6	23.9	31.8	24.2	5.6	0.3	100
	8	0.0	0.3	0.4	0.6	2.6	7.9	19.7	37.5	24.8	6.3	100
	9	0.0	0.0	0.0	0.6	1.0	1.3	5.7	21.5	40.7	29.3	100
	10	0.0	0.0	0.0	0.2	0.1	0.5	1.5	5.2	21.6	70.9	100

So, after diverging in early adolescence, students' trajectories do harden

While consistent with neuroscience, this is not *causal* evidence that students' cognitive skills are plastic with respect to exogenous experience in early adolescence.

That is, students could be "pre-programmed" to have diverging brain development or even to seek out experiences endogenously that would improve cognition.

Part 3: Plausibly causal evidence on whether early adolescents are especially affected by interventions

I need to test interventions that:

- Are age/grade specific.
- Could be applied at any grade.
- Usually have statistically significant effects.
- Can be tested for long-lasting effects.

I could think of only 2 interventions that fit these criteria

1. Having a teacher with high vs. low value-added.
2. Attending a public charter school.

There is now a rather vast literature computing teachers' value-added

- The empirical methods mimic random assignment of students to teachers.
- Various methods produce similar results—namely that teachers vary substantially in the value they add to students' academic progress.
- Teachers' value-added can also be computed on outcomes such as discipline, educational attainment, and earnings.

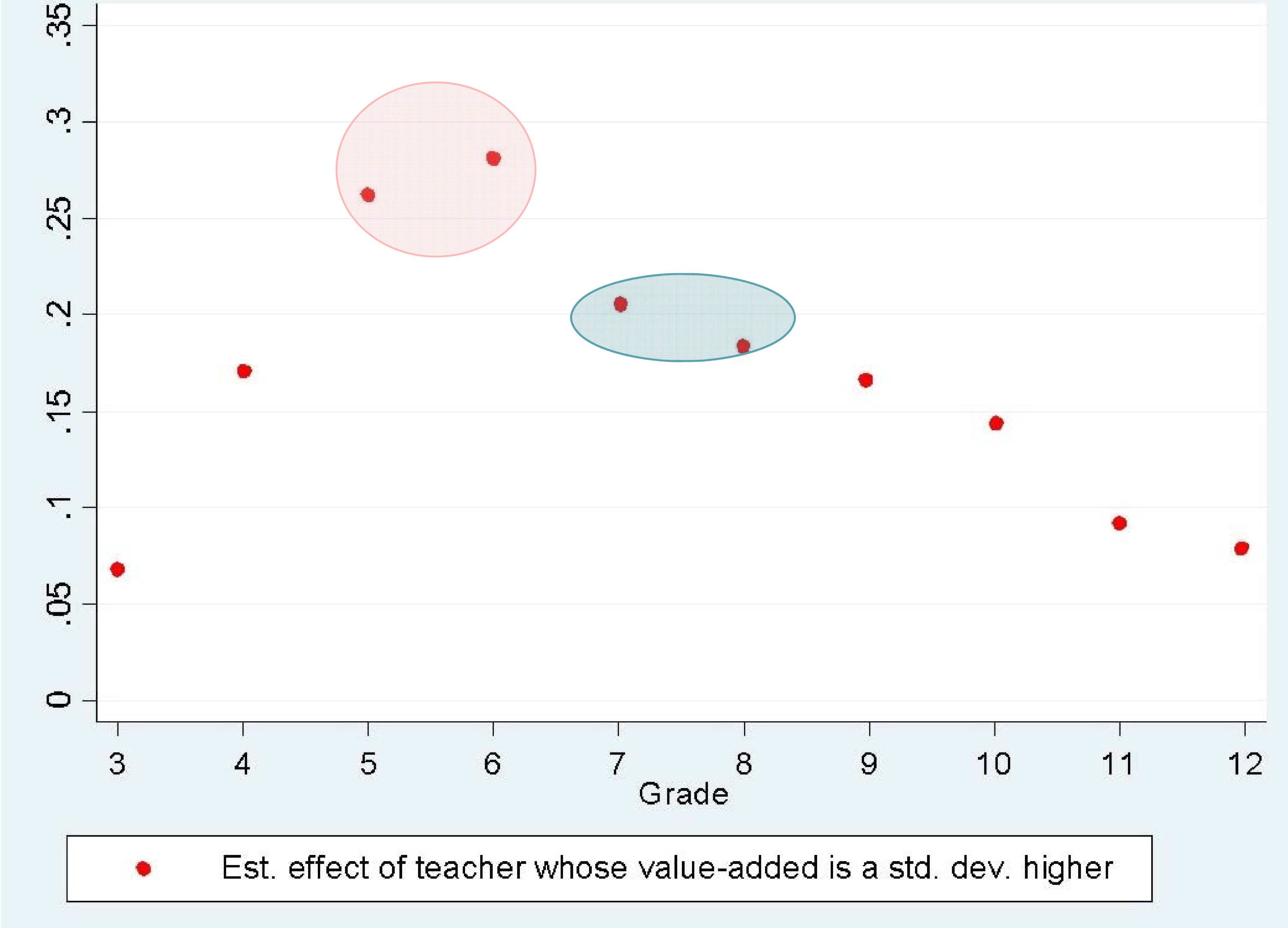
My teachers' value-added exercise proceeds:

1. Estimate each teacher's value-added based on all classes the teacher ever taught *except the classes taught in the year in which the student took the teacher's class*.
2. Put teachers' value-added into standard deviation units. Put students' scores into standard deviations. (This eases interpretation across grades.)
3. Regress each student's achievement on her or his teachers' value-added.
   - If, as a 6th grader, she gets a teacher whose value-added is 1 standard deviation higher, does this improve her scores more than if, as a 3rd grader, she gets a teacher whose value-added is 1 standard deviation higher?

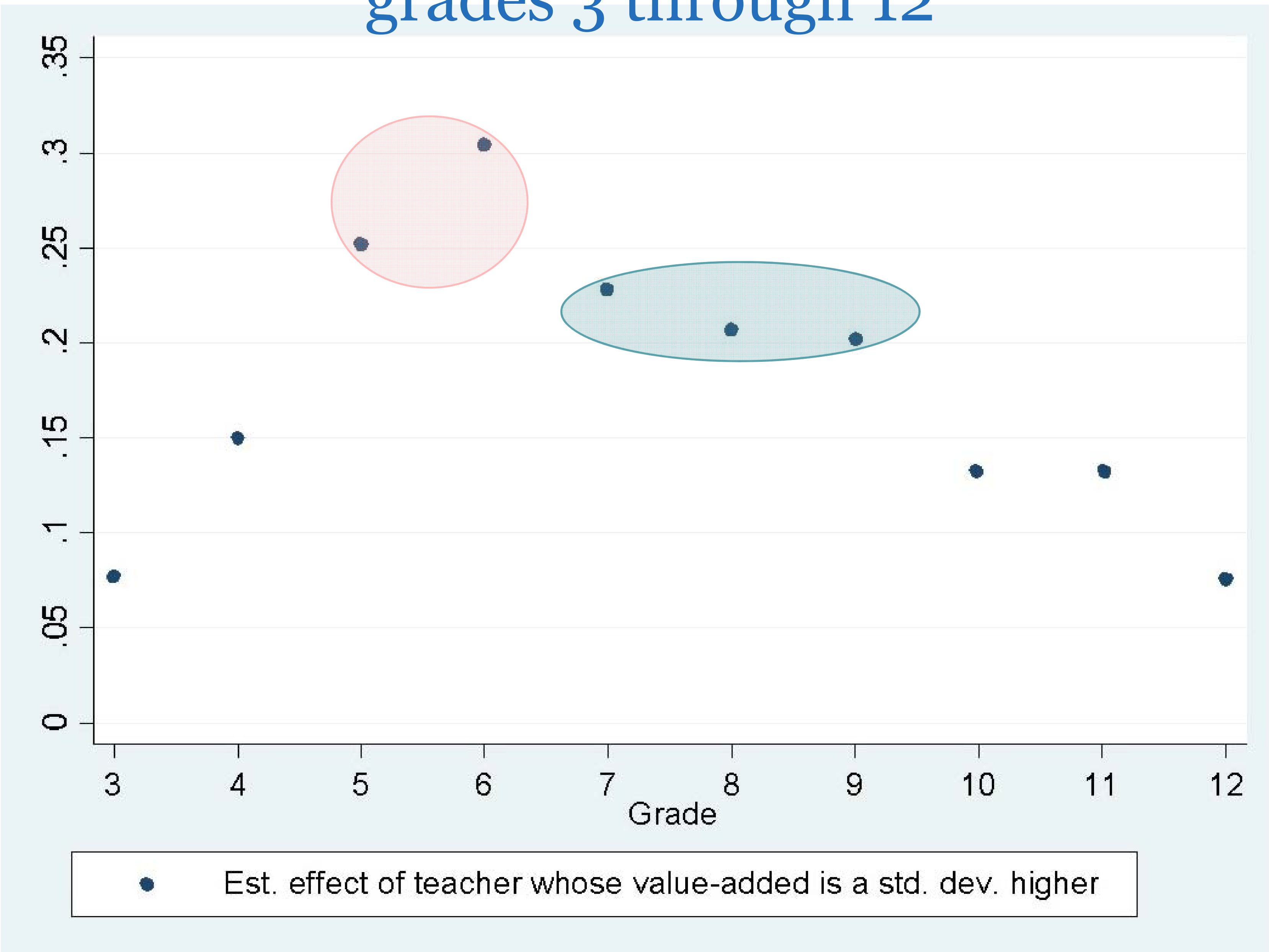
I use the most validated method of estimating value-added

1. Regress each student's test score on his or her prior test scores and all predetermined characteristics (gender, race, ethnicity, economic disadvantage, etc.).
2. Sum the residuals from this regression at the teacher-by-year-by-class level.
3. Regress each teacher-by-year-by-class sum of residuals on the other sums of residuals for the <u>same</u> teacher in different years.
4. The prediction from that regression is the teacher's value-added.
5. The estimates produced are not only validated by true randomized experiments but also have correct shrinkage.

Effect of a better teacher on females' math scores, grades 3 through 12



Effect of a better teacher on males' math scores, grades 3 through 12



So, having a teacher with high value-added matters most for early adolescents: grades 5-8 (females) or 5-9 (males).

But is the disproportionate effect long-lasting?

- We can compute each teacher's effect 2-years-on, 3-years-on, etc. For instance, if a child has a high value-added teacher in 3rd grade, how much of that effect is still present in the 5th grade?
- We look at the ratio of the years-on effect to the contemporaneous effect—e.g. "the 2-years-on effect is 40% of the contemporaneous effect."

Estimates suggest that early adolescents' teachers' effects last longer

	Two-year-on effect as a percentage of contemporaneous effect	
Grade	Females	Males
3	18%	15%
4	21%	18%
5	38%	36%
6	42%	45%
7	32%	34%
8	28%	28%

There is a substantial, lottery-based literature studying charter school effects.

- Charter schools are autonomous public schools, something like England's Academy Schools.
- They are usually start-ups, not conversions, in poor and racial minority areas.
- They admit students on a strict lottery basis.
- Because they very disproportionately serve disadvantaged students, it is important to evaluate them by using the lotteries to generate randomized controlled trials.

Lottery-based studies on charter schools find that their average effect is positive

- Studies of charter schools in Boston, Chicago, Los Angeles, Washington DC, and New York find effects of:

  0.08-0.4 standard deviations in math per year of enrollment

  0.05-0.3 standard deviations in reading per year of enrollment

The aforementioned estimates are treatment-on-the-treated effects from the method:

- Instrumental Variables Stage 1

  Use student *i*'s lotteried-in indicator times years since his lottery as his <u>intended</u> years of treatment, an instrument for his <u>actual</u> years of treatment:

$$YrsInCharter_{it} = \alpha_1 + \alpha_2 I_i^{lotteried-in} \cdot YrsSinceLottery_{it} + \gamma_i + \varepsilon_{it}$$

  where γ is a vector of lottery fixed effects so that the controls for each treated student are the students who participated in exactly for the same lottery for the same school and grade in the same year.

- Instrumental Variables Stage 2

$$Score_{it} = \beta_1 + \beta_2 YrsInCharter_{it} + \varphi_i + \varepsilon_{it}$$

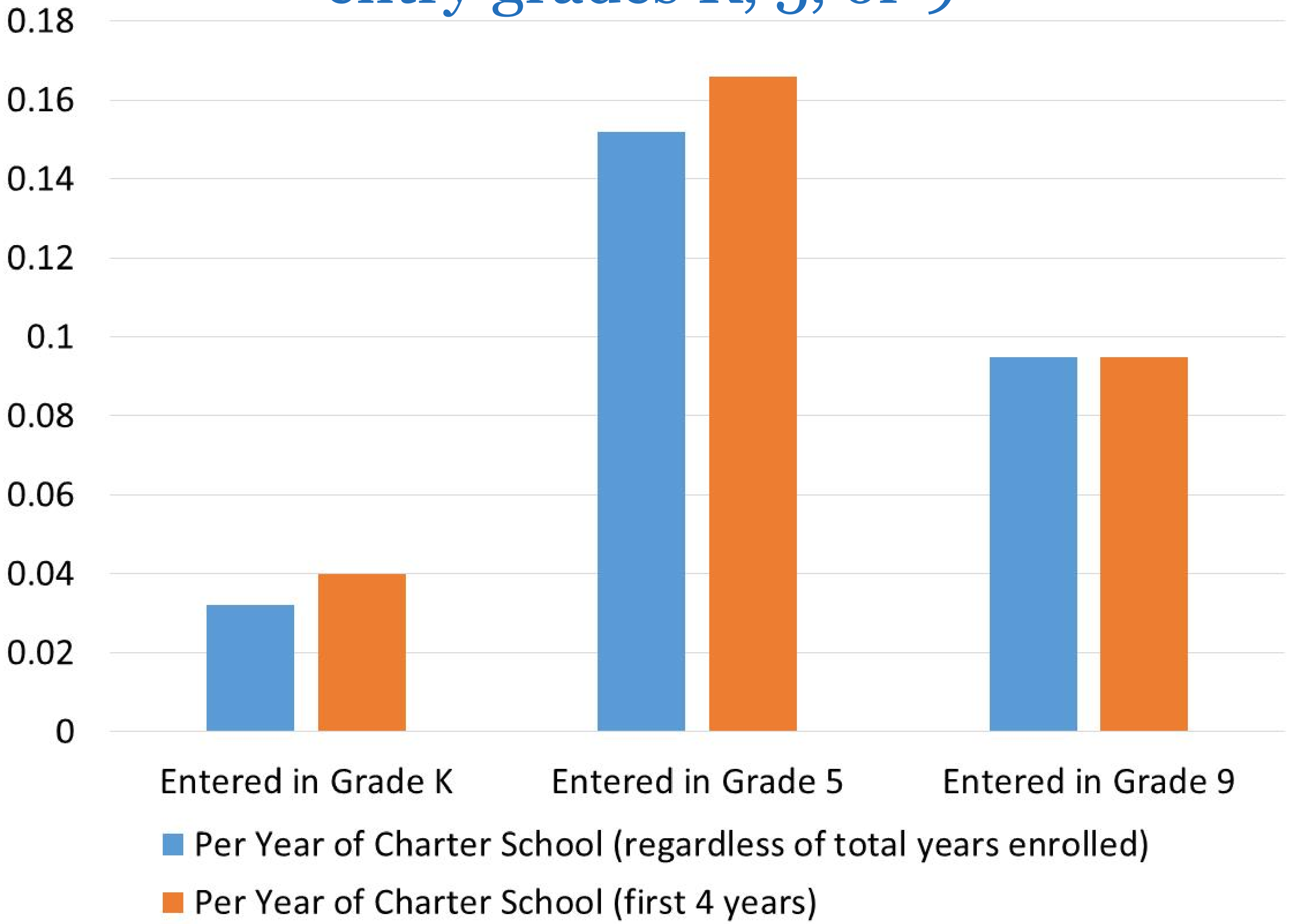
I examine New York City charter schools

Because they have “intake” grades that differ

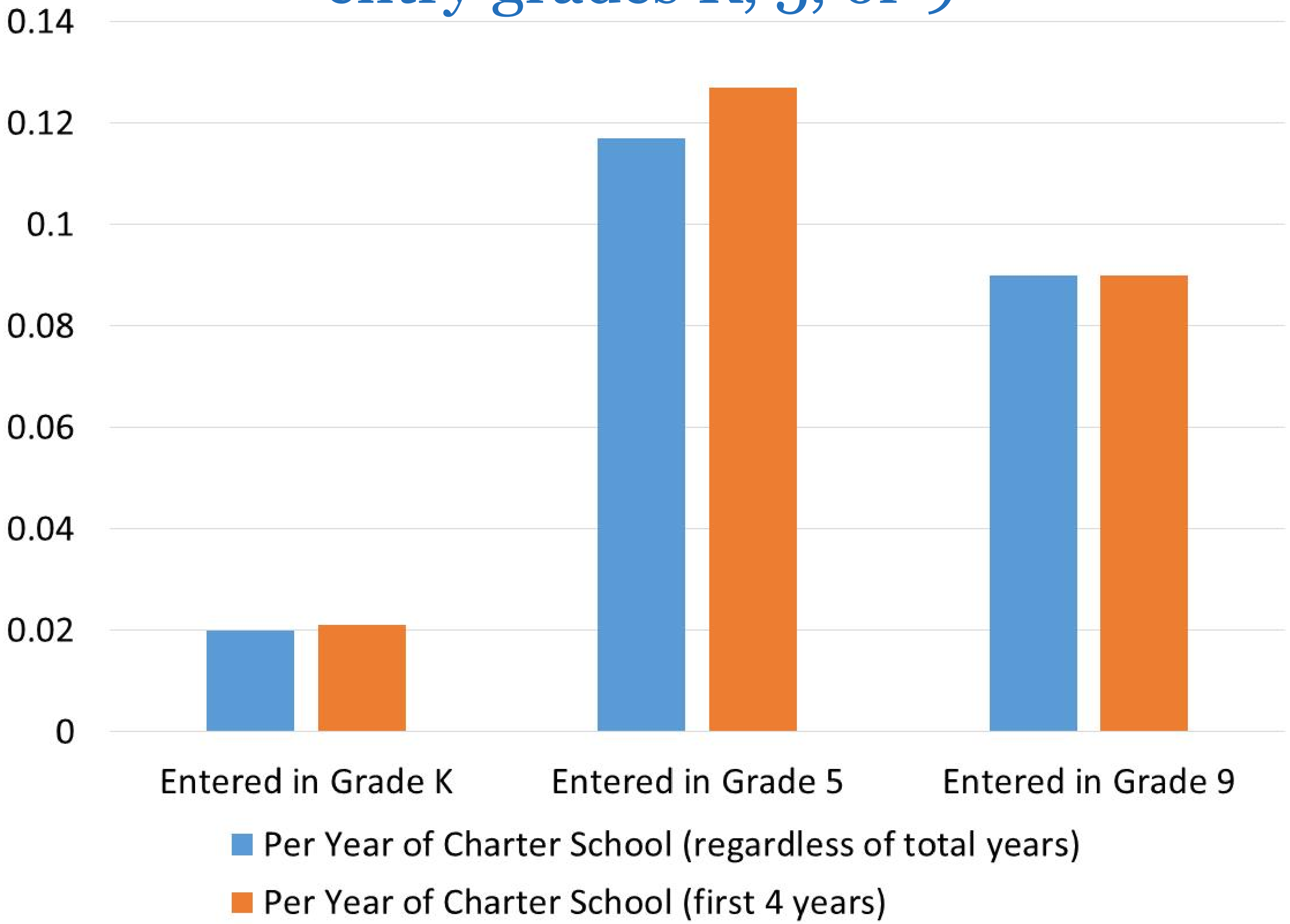
- 32% of students are lotteried-in at kindergarten to a primary school that usually offers grades K-4.
- 14% of students are lotteried-in in grades 5 or 6 to a middle school that usually offers grades 5-8.
- 10% of students are lotteried-in in grade 9 to a high school that offers grades 9-12.

I can thus compare the effect of a year of charter school for student who begin at about age 5, 10, or 14.

Effect of a better teacher on math scores, entry grades K, 5, or 9



Effect of a better teacher on reading scores, entry grades K, 5, or 9



The effects are largest for early adolescents, but are they long-lasting?

The effect on postsecondary educational attainment (a long-term outcome) per year of charter school is:

- 0.05 std deviations for students who entered in K
- 0.20 std deviations for students who entered in grd 5
- 0.09 std deviations for students who entered in grd 9

So the effects on early adolescents are not just larger but disproportionately long-lasting.

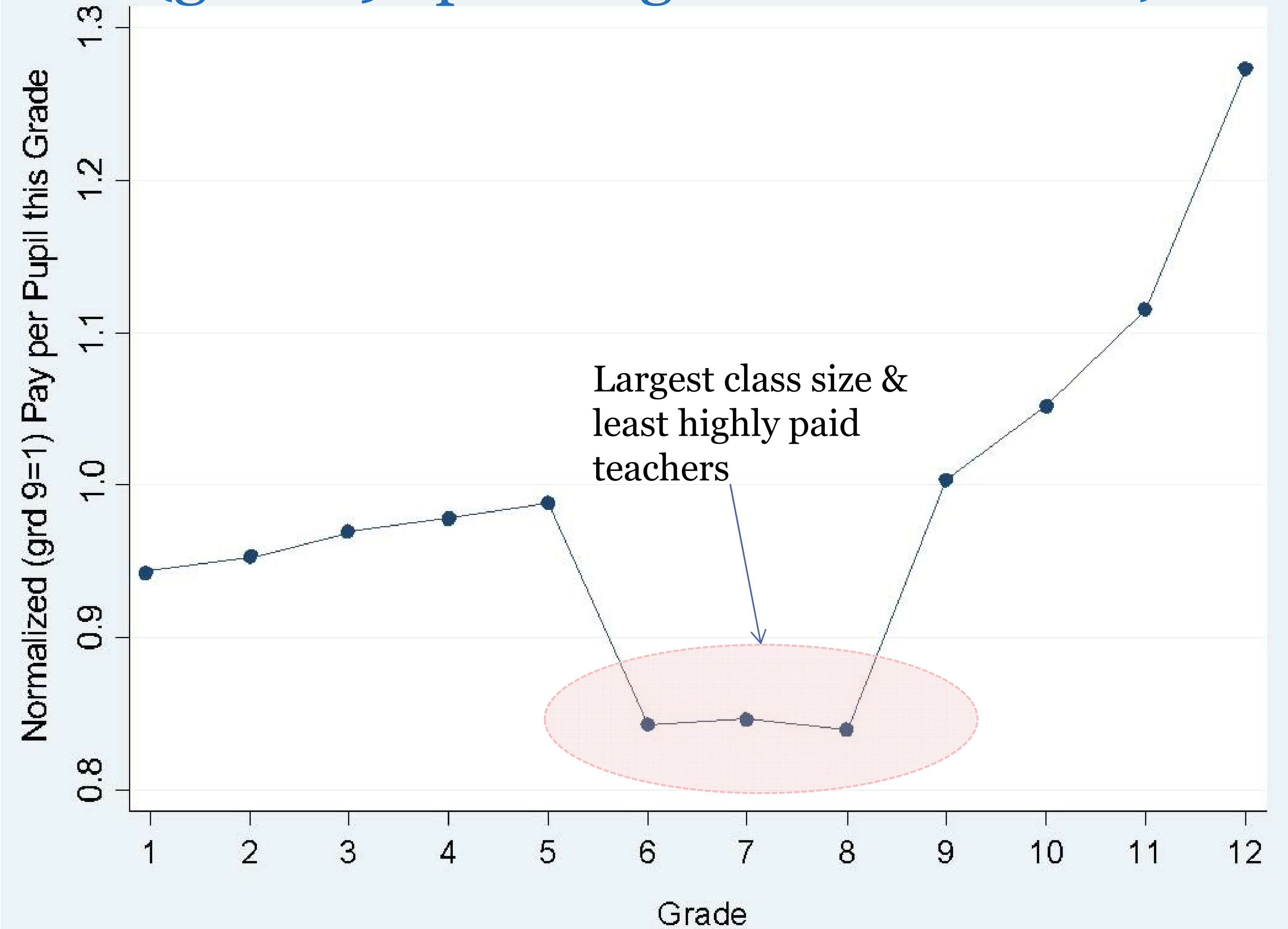
Part 4: Early adolescents are *relatively* deprived of educational resources now.

Compared to students at other ages/in other grades, early adolescents experience the lowest instructional spending.

This is probably not intentional but a function of:

1. The emphasis on small class size in early grades (a result of beliefs about the efficacy of early childhood education).
2. Small classes with more senior (more expensive) teachers in high school because classes are specialized.
3. The fact that high seniority teachers (paid more & have more choice of assignments) avoid middle-school students.

Instructional spending by grade
(grade 9 spending normalized to 1)



If we take educational productivity seriously, oughtn't we at least to investigate early adolescence?

For early adolescents, the combination of:

- Greater effects on cognitive skill
- Longer-lasting effects on cognitive skill
- Relatively low educational resources

suggests that the productivity of marginal educational resources might be unusually high for them.

More generally, I conclude

- We ought to be more attentive to neuroscience as it should give us guidance as to the form of the education production function.
- Once we think of ability as *plastic* rather than fixed or predetermined, the implications of my previous lecture (educational resources scale up greatly with cognitive skill when markets allocate resources) accentuate the importance of understanding cognitive development.