CAROLINE M. HOXBY
Stanford University

Advanced Cognitive Skill Deserts in the United States: Their Likely Causes and Implications

ABSTRACT I use mapping and age trajectories of advanced cognitive skills to better understand why these skills are more prevalent in some local areas than in others. The study begins by explaining what advanced cognitive skills are. It offers a nonspecialist's review of recent brain science that indicates that adolescence is the key period for the development of advanced cognitive skills. The paper considers three main explanations for why the prevalence of advanced cognitive skills varies substantially across US counties. Is it early childhood factors which could generate endogenous responses that are important later when advanced cognitive skills are developing? Is it factors whose influence is greatest during adolescence—the period when brain science argues that experience would most directly affect advanced cognitive skills? If so, adolescence is indeed the age of opportunity but also risk. Is the variation among counties explained by migration of individuals toward areas where other people have advanced cognitive skills similar to their own? Evidence based on cognitive skill trajectories, maps at different ages, and longitudinal regressions suggests that all three of these explanations play a role in generating areas where advanced cognitive skills are prevalent and areas where they are not—advanced cognitive skill deserts.

"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). . . .

Conflict of Interest Disclosure: The author did not receive financial support from any firm or person for this paper or from any firm or person with a financial or political interest in this paper. She is currently not an officer, director, or board member of any organization with an interest in this paper.

"Unlike elementary skills, whose development is tightly regulated by preprogrammed 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 in such circumstances], this same plasticity can be disastrous" (Steinberg 2015, 29–30).

This quotation hits on three points. Each of them is important to this project. The first point is that numerous vital skills result from very early brain development. Steinberg mentions seeing, hearing, and walking. Neuroscience indicates that we might add language, social, and numerous other noncognitive skills to this early mix. Very early brain development mainly affects the back and center lobes of the brain and is, as Steinberg suggests, focused on skills that are crucial for survival and integration into a society. ("Very early" refers to the period starting approximately with the final three months of gestation and ending when a child is about age 3. Neuroscientific evidence based on brain scans is discussed in the next section.)

It is important to note that nowhere in this paper do I argue that the aforementioned skills are anything less than highly consequential for a person's life outcomes. Indeed, Steinberg (2015) is arguing that it is precisely because they are crucial that they differ relatively little among people, presumably owing to natural selection among humans over hundreds of thousands of years. Hereafter, I refer to the aforementioned skills as "noncognitive" as a shorthand common among economists, but some of these skills (such as early language development) clearly have strong cognitive elements, as well as social, visual, and hearing elements.

Second, the quotation states that advanced cognitive skills develop mainly during adolescence, when the frontal lobe of the brain is in its most intense period of transformation. Steinberg (2015) and others argue that the fact that advanced cognitive skills develop in adolescence cuts both ways.[1] On the

1. See, for instance, Reyna and others (2012) and Dahl (2004).

plus side, adolescence is a period when society has opportunities to intervene to improve a person's advanced cognitive skills. Also on the plus side is the fact that adolescence is a stage at which children have at least some agency. To put it plainly, adolescents spend a lot of time in schools that can govern their experiences to a considerable extent. However, adolescents can take at least some control of their lives so that they can possibly acquire advanced cognitive skills even if those around them do not support their endeavors. Family assignment luck thus potentially plays a smaller role in frontal lobe development than in very early brain development. This is plausibly good news for adolescents: a child who was initially unlucky could perhaps offset some lost noncognitive skills by acquiring advanced cognitive skills.

On the minus side, if the development of advanced cognitive skills is "highly sensitive to environmental influence," as Steinberg (2015, 30) argues, then the plasticity of the frontal lobe in adolescence makes this period a risky one.

Third, the quotation suggests that there are some environments in which advanced cognitive skills are necessary for economic success. In highly developed economies such as America's, an economist's mind naturally thinks of skill-biased technological change which, by definition, favors those with advanced skills. Globalization and immigration of the sorts that are specific to the United States also come to mind, though the degree to which these are skill-biased is complex and the subject of debate. In addition, one might think that some areas of the United States might be significantly more skill-biased than others if there are agglomeration economies associated with advanced cognitive skills. The economics literature contains many examples of agglomeration economies associated with noncognitive skills, such as physical endurance needed for certain manufacturing. Nevertheless, economists have suggested that there are certain economies where people with advanced cognitive skills will thrive more than people who lack them and there are models that would justify such agglomeration.[2] In addition, if people with advanced cognitive skills share preferences for certain amenities, that could amplify or even fully justify agglomeration.[3]

If we accept the idea that there are possibly agglomeration economies associated with advanced cognitive skills, then several phenomena are

2. For a recent review article on agglomeration economies, see Mori (2017). See also Kolko (2007) and Forman (2013) for agglomeration of high-skilled workers.

3. On this point, see Couture and others (2020)

potentially relevant. Skilled-biased technological change (and plausibly trade and immigration) could exacerbate the differences in outcomes between local economies where advanced cognitive skills are and are not prevalent. High school graduates with advanced cognitive skills may be especially likely to migrate to a residential college, and people with advanced cognitive skills are—almost by definition—prevalent in college towns. Adult migration may allow people to find an economy that suits their skills or tastes for amenities. There is some evidence that more educated people make relocation decisions that are more beneficial to them economically.[4] If children can only learn advanced cognitive skills from adults in their environment who have such skills themselves, then agglomeration economies may produce places that are substantially more or less propitious for advanced cognitive skills development. Of course, this mechanism might wane with the advance of modern communications technology which could, for instance, allow children to take classes remotely.

Having set out some key arguments and logic, I now turn to what this paper tries to do. First, it attempts to test whether there is much variation among US counties in the prevalence of adults with advanced cognitive skills.[5] Being interested in areas where advanced cognitive skills are especially non-prevalent, I label such areas "deserts" as a shorthand.

One might wonder why cognitive skills are important and why I do not pursue a far simpler task such as mapping educational attainment or the prevalence of jobs in high prestige occupations. After years of researching education and economics, I am convinced that it is skills that are foundational. Every model of human capital is a model of skills. Educational attainment is merely a proxy and can be a crude one because the mapping between academic degrees and skills varies widely among schools. One high school's diploma standards may be much higher than another's. Colleges vary even more in their degree standards, due in part to differences in admissions selectivity and consequent expectations for students. If we fail to focus on skills, we can fall into the trap of promoting policies that merely produce degrees. We can also struggle to explain why some people or areas, apparently with the same educational attainment, end up with very different employment, social, and political outcomes. We can then end up focusing on explanations that are actually second order. In short, I am interested in variation that is foundational: cognition.

4. See Malamud and Wozniak (2012).

5. Maps based on Commuting Zones look broadly similar but exacerbate some problems that already plague county-based maps.

Second, this paper attempts to provide enough age-related evidence on the three explanations to help us parse them. Specifically, are advanced cognitive skill deserts associated with early-age factors that can be difficult to affect with policy? Are they associated with adolescent-age factors more likely to be influenced by policy? Finally, are they associated with individuals migrating toward areas where other people have advanced cognitive skills similar to their own?

In the previous paragraph, the choice of the word "associated" was deliberate. This is not a paper that attempts to test whether specific policies, such as school resources, *cause* variation in the prevalence of advanced cognitive skills. I take up such causal questions in two related papers.[6] Even without attempting to show causality, I believe that the descriptive evidence in this paper is revealing.

The last section of the paper discusses some implications of the evidence described, including what we learn about the mechanisms most likely to improve advanced cognitive skills. I also provide a bit of speculative evidence on possible links between advanced cognitive skills, economic fatalism, social trust, and politics.

Finally, despite the use of the word "desert," this paper is written in the spirit of Steinberg's (2015) title, *Age of Opportunity*, with an emphasis on opportunity. One of the most fundamental problems in economics is how to maximize social welfare, given the constraints imposed by individuals' endowments. Of course, the problem is more complicated but it is differences in endowments that drive inequality in utility and set up many of the tensions between equity and efficiency. Skill-biased technical change, especially if it favors advanced cognitive skills, can exacerbate these tensions. Understanding why the development of advanced cognitive skills varies so much from one geographical area to another, as I will show in this paper, may be a first step toward causal means to improving such skills for potentially many people, thereby relaxing the constraints associated with endowments. The paper thus attempts to identify channels whereby societies could avoid the seeming inevitability of increasing strain between adults who do and do not have advanced cognitive skills.

6. These two other papers make up my Tanner Lectures on Human Values for the University of California, Berkeley. These lectures were postponed due to the coronavirus pandemic so, although they precede this paper as a matter of logic, they will actually be released after it. Briefly, the first paper argues that early adolescence is a "fork in the road" because students who begin acquiring advanced cognitive skills tend to stay on that trajectory and vice versa. The second paper uses several natural experiments to demonstrate that successful learning-related interventions are especially productive in early adolescence.

I. Advanced Cognitive Skills

I.A. What Are Advanced Cognitive Skills?

Advanced cognitive skills are generally defined as those that require higher order reasoning. They require a capacity to solve problems through logic, think in the abstract, engage in critical thinking, and derive general principles from a set of facts. They are also often described as integrative or synthesizing. Advanced cognitive skills can be meaningfully differentiated from skills such as memorization, summarization, organization of facts, and other methods of acquiring concrete information. These distinctions were recognized many years ago, and they have now attracted a vast body of research.[7]

For the purposes of economics, examples may be more helpful than a summary of the research. It is instructive to start with some mathematics examples because mathematics curricula are often associated with specific school grades. Such associations are helpful for developing intuition about the relationships between the age at which a skill is typically learned and the likelihood that the skill is an advanced cognitive one.

Long division, long multiplication, addition of fractions: these are all exercises that require a person to follow an algorithm that can even be fairly complex. They differ from algebra because algebra requires a person to translate a problem into equations, which are then solved to find the solution. Algebra thus requires abstract thinking. Proof-based mathematics is even more distinct because it requires logical reasoning that can extend over many steps. In short, algebra and the mathematics that typically follow it in the curriculum can be characterized as advanced cognitive skills.

Now consider coursework in history. Earlier coursework may require a student to condense facts, organize them around narratives, and recognize similarities and differences among historical events and personalities. However, a history course involves advanced cognitive skills if it requires students to analyze cause and effect by engaging in critical thinking and drawing abstract generalizations from facts. Also, a history course might involve advanced cognitive skills in writing and reading if it requires students to integrate and synthesize material.

7. Piaget (1972) is seminal; Chapman, Gamino, and Mudar (2012) provide an excellent review.

In this paper, I rely heavily though not exclusively on mathematics-based examples and measures. This is for the reason given above: mathematics curricula tend to follow a conventional sequence that makes it easier to follow as steps in cognitive development. Also, there are idiosyncratic data constraints, described below, that sometimes force me to rely on mathematics data. However, advanced cognitive skills are by no means restricted to mathematical reasoning and its near relatives. Indeed, verbal skills data tend to show similar results when they are available (see table 2). If there were measures of planning and strategic thinking available, I would wish to include them as well. One should think of mathematics as a good marker of cognitive skills development. It is by no means the only type of advanced cognitive skill.

I.B. Adolescent Brain Development in Brief

Advanced cognitive skills are associated with frontal lobe brain development, which is particularly dramatic starting with early adolescence. During this period, the frontal lobe (which has previously undergone exuberant growth of neural circuits) intensely prunes synapses, much as one might prune a tree to keep the strongest branches so that they can grow better. Pruning is followed by myelination, which is the development of specialized membrane around axons. Myelination essentially speeds up circuits that remain after the pruning. These stages may be thought of as the laying out of cognitive possibilities (exuberant development), the training of the brain about which possibilities need to be prioritized (pruning), and making the brain work faster on the prioritized possibilities (myelination). The brain is at its most plastic, most receptive to experience, when these stages take place most rapidly and dramatically.

These same stages begin before birth within the caudal brain stem (the brain stem being the posterior part of the brain). The most rapid and intense period of back and central brain myelination has already occurred by the end of the first two years of postnatal life. That is, key stages of brain development, such as pruning and myelination, occur both in very early childhood and adolescence, but the period in which the frontal lobe is *most* plastic begins much later, with most researchers suggesting 10 to 11 years of age for females and 11 to 12 for males.

Because the frontal lobe has long been associated with higher order reasoning, researchers have argued that the age at which training for advanced cognitive skills should optimally begin is the period in which this part of the brain is most plastic. Recent studies directly link adolescent anatomical and functional brain changes to cognitive experiences and training. They depend especially on longitudinal use of magnetic resonance imaging since that noninvasive technique allows researchers to follow the same person's brain anatomy as he or she undergoes new learning experiences.[8] It should be mentioned, though, that much of this linking work is not convincingly causal because adolescents self-select into experiences that take place over an extended period—for instance, choosing which courses to take or whether to participate in chess club. Randomized controlled trials in which researchers manipulate adolescents' experiences naturally must occur over short time periods and are thus less revealing about longitudinal brain changes. I argue in a related paper for the use of natural experiments which allow for credible causal inference combined with a longer longitudinal study period.[9]

I.C. Advanced Cognitive Skills Trajectories in Early Adolescence

Psychiatry researchers and educators have long recognized that advanced cognitive skills can rapidly expand during adolescence, though they continue to be honed and to mature throughout adulthood. Nevertheless, not all adolescents experience this rapid expansion. Instead, cognitive neuroscientists and educators have observed that some students "stagnate cognitively and fail to thrive academically" in early adolescence: "With regard to vulnerability, the years when adolescents are in middle school (fifth through ninth grades) represent a period metaphorically referred to as a transitional 'black hole' in education" (Chapman, Gamino, and Mudar 2012, 124).

Cognitive neuroscientists tend to attribute such stagnation to frontal lobe development that is insufficiently rapid or dramatic. This, in turn, could be ascribed to learning experiences that are insufficiently rich or demanding to encourage frontal lobe development.

While frontal lobe development continues well past early adolescence, advanced cognitive skill trajectories are often somewhat set, in practice, by age 14 to 15 for females and age 15 to 16 for males. Although not from the aforementioned natural experiments, some evidence that early adolescence is crucial in setting these trajectories can be derived from longitudinal education data. In what follows, I show transition matrices based on two large longitudinal studies produced by the National Center for Education Statistics (NCES): the Early Childhood Longitudinal Study, Kindergarten Class of 1998–99 (ECLS-K), which covers children in kindergarten through

8. See Spear (2013) and Atkins and others (2012) for excellent reviews.
9. I am referring to one of the Tanner Lecture papers mentioned above.

Figure 1. Male Math Score Transitions, Ages 10.5 to 13.5

Deciles of math in grade 5 (age 10.5 on average)	1	2	3	4	5	6	7	8	9	10
1	67.4	23.1	5.4	1.9	1.4	0.5	0.3	0.0	0.0	0.0
2	29.2	32.9	22.2	9.3	3.5	1.5	0.3	0.6	0.6	0.0
3	10.6	23.6	25.8	18.7	11.7	6.5	2.4	0.3	0.5	0.0
4	3.6	12.7	19.0	21.6	20.0	11.4	7.0	3.9	0.8	0.0
5	1.5	3.4	11.1	17.6	24.1	21.7	11.1	6.8	2.4	0.5
6	1.0	1.4	8.4	11.2	20.1	18.4	19.1	11.0	8.1	1.2
7	0.0	1.0	4.0	7.3	13.0	16.5	21.6	19.3	12.0	5.3
8	0.0	1.4	0.9	3.9	6.1	15.0	19.1	22.7	20.2	10.9
9	0.2	0.2	0.8	1.0	3.3	6.6	14.9	23.6	26.9	22.4
10	0.0	0.0	0.0	0.2	0.8	2.2	6.2	13.6	24.6	52.4

Deciles of math in grade 8 (age 13.5 on average)

Source: Early Childhood Longitudinal Study—kindergarten to 8th grade.

Note: Row 8 shows that a male who scores in decile 8 at age 10.5 has a 6.1 percent probability of scoring in decile 5 at age 13.5, a 22.7 percent probability of scoring in decile 8 at age 13.5, and a 10.9 percent probability of scoring in decile 10 at age 13.5. The interpretation of the other cells is analogous, and higher probabilities are associated with darker shading.

eighth grade, and the National Education Longitudinal Study (NELS) which covers people from eighth grade through about age 26 to 27.[10] In each transition matrix, a child is associated with his or her national decile of mathematics skills at a lower age/grade (rows) and again associated with his or her national decile of mathematics skills at a higher age/grade (columns).[11] Thus, if every child stayed in the same decile, 100 percent of the data would fall along the diagonal. Data falling into cells off the diagonal are an indication of a transition—from, say, middling skills in the sixth decile to top skills in the ninth decile.

Figure 1 shows the transition matrix from fifth grade (average age about 10.5) to eighth grade (average age about 13.5) for males. (Males are shown because, although the matrix appears very similar for females, it would be better to start females with fourth grade because of the earlier onset of

10. The two studies are both nationally representative and have many sampling and other methodological choices in common. However, the two studies do not study the same individuals, so there is overlap in the eighth grade but there is not true longitudinal continuity between the two studies. See National Center for Education Statistics, US Department of Education, https://nces.ed.gov/ecls/ and https://nces.ed.gov/surveys/nels88/.

11. I use mathematics rather than verbal tests here, but the verbal results are very similar.

Figure 2. Male Math Score Transitions, Ages 15.5 to 17.5

Deciles of math in grade 10 (age 15.5 on average)	1	2	3	4	5	6	7	8	9	10
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

Deciles of math in grade 12 (age 17.5 on average)

Source: National Education Longitudinal Study—8th grade onward.

Note: Row 8 shows that a male who scores in decile 8 at age 15.5 has a 2.6 percent probability of scoring in decile 5 at age 17.5, a 37.5 percent probability of scoring in decile 8 at age 17.5, and a 70.9 percent probability of scoring in decile 10 at age 17.5. The interpretation of the other cells is analogous, and higher probabilities are associated with darker shading.

rapid brain development for them. Unfortunately, the ECLS-K does not test children in grade four.) To aid in interpretation, consider row 8 which shows that a male who scores in decile 8 at age 10.5 has a 6.1 percent probability of scoring in decile 5 at age 13.5, a 22.7 percent probability of scoring in decile 8 at age 13.5, and a 10.9 percent probability of scoring in decile 10 at age 13.5. The interpretation of the other cells is analogous, and a cell is shaded darker if the probability shown is higher.[12] In other words, for this example, most of the probability (77.3 percent) is assigned to cells off the diagonal. Students in a middling initial decile have an even higher probability of transitioning out of their initial decile: much of the weight in the center of the transition matrix is off the diagonal. In other words, the matrix suggests that the development of advanced cognitive skills in early adolescence is not wholly predetermined at the beginning of the period.

Figure 2 shows the analogous matrix from tenth grade (average age of 15.5) to twelfth grade (average age of 17.5). Consider row 8. It shows

12. Specifically, the shading is based on intervals of 10 percentage points: 0 to 10 percent, 10.1 to 20 percent, and so on.

that a male who scores in decile 8 at age 15.5 has a 2.6 percent probability of scoring in decile 5 at age 17.5, a 37.5 percent probability of scoring in decile 8 at age 17.5, and a 6.3 percent probability of scoring in decile 10 at age 17.5. Thus, in this example, a student's beginning decile is more determinative: only 62.5 percent of the probability is off the diagonal. Moreover, a student's beginning decile is more determinative regardless of what that decile is. Transitions are less probable everywhere or, to put it another way, skill trajectories are hardening. This hardening or decrease in plasticity is what we would expect from the brain science because the later teenage years are dominated by myelination (accelerating established axons) rather than pruning.

It is worth noting that transition matrixes for younger children, especially very young children, show very little hardening. For instance, an analogous transition matrix for age 1 to 3 would show the vast majority of probability off the diagonal; it is fairly hard even to pick out the diagonal.

II. Mapping Advanced Cognitive Skills in the United States

II.A. Methods and Data

In this section, I map advanced cognitive skills in the United States. While the maps are highly revealing in many ways, they have a few limitations.

First, I have chosen to show a classic US map of counties despite the fact that it overemphasizes sparsely populated counties that have a large land mass. I want viewers to be able to recognize regional patterns and—preferably—even recognize some counties or clusters of counties. For instance, a county that contains a college town might stand out as being prevalent in advanced cognitive skills. Such recognition would not be possible if—for instance—I used a cartogram in which counties' size corresponded to their population.

Second, my measures of advanced cognitive skills depend only on the percentage of people with the skills, not the physical density of people with the skills. That is, I do not show advanced cognitive skills per square mile. This is a deliberate choice because I wish to avoid maps that mechanically predict that rural, low-density areas are skill deserts. Generally speaking, the more sparsely populated a county is, the larger its land mass. It takes self-discipline to ignore vast counties in Nevada, Arizona, Utah, New Mexico, southeastern California, Montana, and the Dakotas.

Third, the only nationally representative measure of cognitive skills among adults in the United States comes from the Program for the International

Table 1. The Distribution of Adults' Scores on Cognitive Skill Tests Administered by the Program for the International Assessment of Adult Competencies

Level	*Below 1*	*1*	*2*	*3*	*4*	*5*
Numeracy (%)	9	20	33	27	9	1
Literacy (%)	4	15	33	35	13	1

Sources: US Department of Education, National Center for Education Statistics, Statistics Canada and OECD, Program for the International Assessment of Adult Competencies (PIAAC), PIAAC 2012–2017 and PIAAC 2017 Literacy, Numeracy, and Problem Solving TRE Assessments.

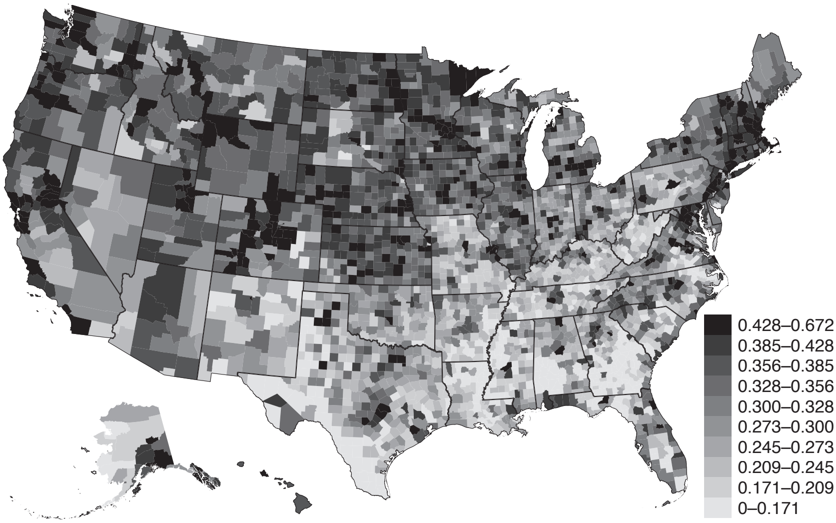
Note: Adults scoring in the top three levels (levels 3–5) can be considered proficient at working with math information and ideas. They have a range of numeracy skills from the ability to recognize math relationships and apply proportions to the ability to understand abstract representations of math concepts and engage in complex reasoning about quantities and data. Totals not equal to 100 percent are due to rounding.

Assessment of Adult Competencies (PIAAC).[13] It measures numeracy (mathematics) and literacy in those age 16 to 65. The PIAAC has six levels of skill for each test, and its tests can identify very advanced skills. For instance, its top level in both numeracy and literacy contains only 1 percent of adults, and its second-to-top numeracy level contains only 9 percent of adults. See table 1. Also, the PIAAC data can in theory be broken down by age, which would be interesting even though it would not be longitudinal data. However, if one wishes to map the data, it is not possible to use them with such fine distinctions (for reasons of confidentiality as well as statistical validity). For mapping, all of the adult ages are consolidated, only county-level statistics are possible, and the PIAAC aggregates the top three levels of skill for each test.[14] Unfortunately, this makes only the numeracy test useful for mapping advanced cognitive skills. Its top three levels contain 37 percent of the adult population—already a coarser definition of "advanced" than I would prefer. However, the literacy test's top three levels contain 49 percent of the adult population, which is simply too coarse. The PIAAC describes adults with the top three levels of numeracy skills as "proficient at working with mathematical information and ideas. They have a range of numeracy skills from the ability to recognize mathematical relationships and apply proportions to the ability to understand

13. "PIAAC Data and Tools," OECD Skills Surveys, https://www.oecd.org/skills/piaac/data.

14. The technical documentation for the county-based statistics from the PIAAC (Krenzke and others 2020) is highly informative and should be consulted by readers interested in how the statistics are computed. Readers interested in the PIAAC more generally should consult Krenzke and others (2019).

Figure 3. Percentage of Adults Whose Numeracy Skills Are at Least Somewhat Advanced (Top Three Levels)



Sources: US Department of Education, National Center for Education Statistics, Program for the International Assessment of Adult Competencies (PIAAC), PIAAC 2012-2017 and PIAAC 2017 Literacy, Numeracy, and Problem Solving TRE Assessments.

Note: Adults scoring in the top three levels can be considered proficient at working with math information and ideas. They have a range of numeracy skills from the ability to recognize math relationships and apply proportions to the ability to understand abstract representations of math concepts and engage in complex reasoning about quantities and data.

abstract representations of mathematical concepts and engage in complex reasoning about quantities and data."[15]

II.B. The Advanced Cognitive Skills Maps

Figure 3 maps advanced cognitive skills by county for the United States, based on the PIAAC numeracy data. The percentage of adults with advanced cognitive skills is divided into ten deciles. In the bottom decile, only 0 to 17 percent of adults have advanced cognitive skills. In the top decile, 42.8 to 67.2 percent of adults have these skills.

15. Institute of Education Sciences, "U.S. PIAAC Skills Map: State and County Indicators of Adult Literacy and Numeracy," https://nces.ed.gov/surveys/piaac/doc/PIAAC-SAE-Brochure.pdf. Sample items from the numeracy test are available at "PIAAC Numeracy—Sample Items," OECD Skills Surveys, https://www.oecd.org/skills/piaac/Numeracy%20Sample%20Items.pdf.

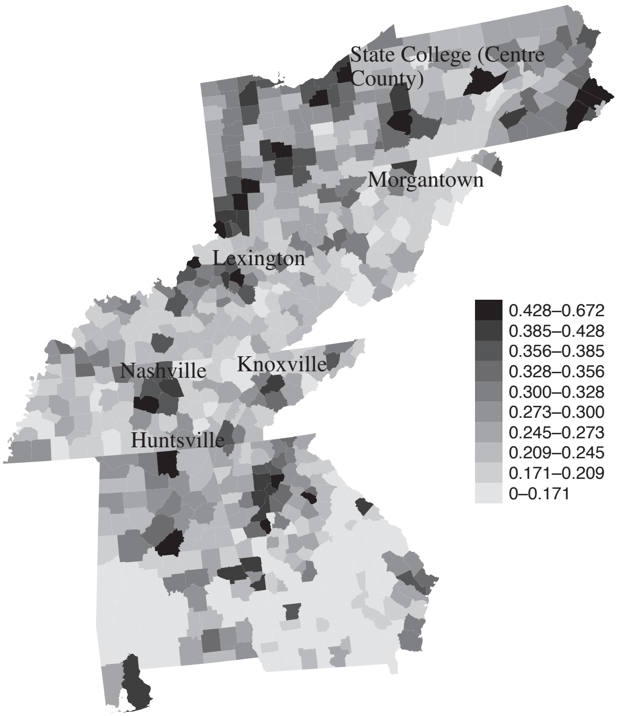
Observe the areas where advanced cognitive skills are most prevalent: most of southern New England but especially the area centered around Boston; scattered counties in New York and New Jersey but especially the area centered around New York City; coastal Washington State and Oregon but especially the area centered around Seattle; coastal California but especially the areas centered around San Francisco, Sacramento, Los Angeles, and San Diego; the Salt Lake City area; and the Washington, DC, area including parts of Maryland and Virginia. None of these findings is surprising. A finding that may surprise some readers is the overall dark shading of what might be called the "Lutheran Belt": southern Minnesota and parts of Wisconsin, Iowa, and the Dakotas.[16] The Lutheran Belt has long had a reputation for strong educational outcomes, and explanations vary. While the area does not contain an advanced cognitive skills concentration like Boston, say, most of its counties fall into the top four deciles of prevalence.

Turning to the other end of the spectrum and the inspiration for this paper's title, where are advanced cognitive skills not prevalent? The most obvious pattern is Appalachia, the area that follows the Appalachian mountain range through several states starting in northeastern Alabama and northwestern Georgia, running though eastern Tennessee and eastern Kentucky, encompassing all of West Virginia, continuing through southeastern Ohio and Pennsylvania, and finally ending in New York.[17] Although Appalachia is the most obvious skill desert, within it there are numerous counties, often in small clusters, in which advanced cognitive skills are prevalent. Figure 4 shows that these are often counties in which a major university is located. Before examining figure 4, however, also note that advanced cognitive skills are not prevalent in the Ozarks (a mountainous plateau mainly in Missouri, Arkansas, and Oklahoma) and in some inland areas of the South—for instance, inland Louisiana, inland Mississippi, and a stretch that begins in north Florida, runs through northeastern Georgia and inland South Carolina, and ends in inland North Carolina.

16. For instance, see the county map of the United States "Lutherans as a Percentage of All Residents, 2000" (ASARB 2002). County percentages based on the total number of adherents reported by the leading Lutheran church bodies, including the Evangelical Lutheran Church in America, the Lutheran Church-Missouri Synod, the Wisconsin Evangelical Lutheran Synod, and the Association of Free Lutheran Congregations, divided by the total population in 2000. The map is available at https://philebersole.wordpress.com/2011/02/22/the-geography-of-american-religion/amp/, accessed October 2021.

17. According to the official listing by the Appalachian Regional Commission, Appalachia also includes some of the western counties of South Carolina, North Carolina, Virginia, and Maryland; "Appalachian Counties Served by ARC," https://www.arc.gov/appalachian-counties-served-by-arc/ (accessed January 2020).

Figure 4. Percentage of Adults in Certain Appalachian States Whose Numeracy Skills Are at Least Somewhat Advanced



Sources: US. Department of Education, National Center for Education Statistics, Program for the International Assessment of Adult Competencies (PIAAC), PIAAC 2012-2017 and PIAAC 2017 Literacy, Numeracy, and Problem Solving TRE Assessments.

Note: Adults scoring in the top three levels can be considered proficient at working with math information and ideas. They have a range of numeracy skills from the ability to recognize math relationships and apply proportions to the ability to understand abstract representations of math concepts and engage in complex reasoning about quantities and data.

I have so far emphasized the most obvious skill deserts and their opposites, areas where advanced cognitive skills are very prevalent. However, many areas of the United States are not easy to characterize, consisting mainly of middling prevalence counties with scattered high prevalence and low prevalence counties.

Figure 4 shows the main counties in Appalachia and picks out a few especially interesting ones that have an unusual degree of advanced cognitive skill relative to the counties surrounding them.[18] All of them are counties in

18. To keep the map readable, I have excluded states where Appalachia runs through only a small part of the state.

which at least one major university exists: the University of Alabama in Huntsville, the University of Tennessee in Knoxville, Tennessee State University and Vanderbilt University in Nashville, the University of Kentucky in Lexington, the University of West Virginia in Morgantown, and Pennsylvania State University in State College. This figure demonstrates that, even if a child grows up in a county where advanced cognitive skills are not prevalent, there is often a county relatively nearby where prevalence is high. Also, the first move to any of these counties might well be to a residential dormitory, presumably a more straightforward move than striking out on one's own in another part of the country.

III. Parsing the Explanations for Advanced Cognitive Skill Deserts

At its outset, this paper reviewed three interesting and non-mutually exclusive explanations for the variation in the prevalence of advanced cognitive skills shown on the maps. The first was very early age factors that affect children through early brain development or other mechanisms that are already fairly determinative at school entry. As noted above, such causes are less likely to directly affect advanced cognitive skills development because the age at which such skills develop is substantially later than ages 0 to 3. Nevertheless, poorly developed noncognitive skills could lead to endogenous responses such as teachers routinely neglecting a child's learning throughout all of the primary grades (kindergarten to grade four) so that when the child reaches early adolescence, he or she is poorly prepared for higher reasoning. For instance, a child might be so confused about rational numbers reasoning, such as multiplication and fractions, that the transition to basic algebra is extremely difficult.

An important reason why it matters how much of a role is played by very early age factors in advanced cognitive skills is that, regardless of how much society might be willing to invest in programs for children between age 0 and 3, custodial care is a meaningful problem. Parents may wish to retain greater time with and control over their children at this stage. In contrast, most adolescents already spend six to eight hours outside the home under the supervision of adults who are not family members: transportation to school, school itself, and organized activities such as sports. Custodial care issues may make very early age factors inherently harder to change through programs conducted by organizations who employ adults other than their parents.

The second explanation was factors that might directly affect the development of advanced cognitive skills because they coincide in timing with the crucial plastic period when these skills begin to form. Obvious examples of such factors would be the middle school teaching or curriculum.

The third explanation was migration toward areas where other people have advanced cognitive skills that are similar to one's own. While it is natural to focus on the migration of individuals who have reached the age of majority (18) and can therefore make location decisions for themselves, selective migration could take place at much earlier ages. For instance, the family of an early adolescent could deliberatively move from an advanced cognitive skill desert to an area where such skills prevail because they believe that the child requires a richer or more demanding school curriculum.

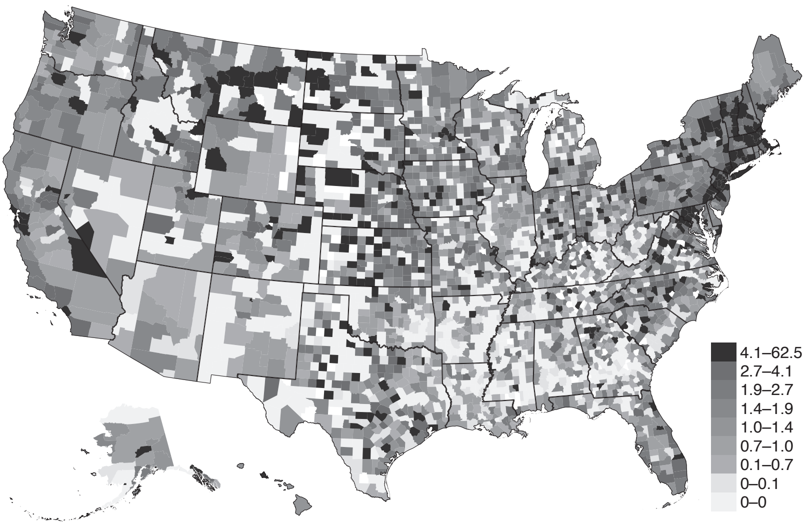
In short, it is helpful to see the age at which the advanced cognitive skills map begins to look like the adult map. Here I work backward, starting from a map based on twelfth graders' SAT and ACT scores, then showing maps based on the test scores of, respectively, eighth graders, fifth graders, and third graders. For these maps, I am constrained to use these test score data; there are virtually no alternatives. Data are needed for all (or at least nearly all) the counties in the United States.[19] Next, I need to be able to put the data for each grade on a common scale across all states. This directs my choice of the third, fifth, and eighth grades, three grades in which all states conduct tests of nearly all their students and for which the states' own test scores can be put on the National Assessment of Educational Progress (NAEP) scale. The NAEP is a test administered to American students in certain grades in a nationally representative sample that is large enough to use for rescaling but far too small for the NAEP's own scores to be mapped.[20] Unfortunately, although the NAEP sample is large enough to be used for rescaling the average score in each county, it is not large enough for computing each county's rescaled percentiles. Thus, I cannot show what I would like most to show: the percentage of children scoring in the advanced cognitive skills range.

The evidence in the maps that follow should be viewed as merely suggestive because there are such significant differences among the data and measures used for the maps at grades three, five, and eight versus grade twelve versus adulthood. It will simply not be possible to state with confidence that the maps' changing patterns only reflect true age-cognition

19. This rules out the survey data gathered by NCES.

20. I use the rescaling provided by the Stanford Education Data Archive (Version 4.1), http://purl.stanford.edu/db586ns4974.

Figure 5. Percentage of Twelfth Graders Whose Math Skills Are at or above the National 90th Percentile



Source: Hoxby and Avery (2013).
Note: The map shows, by decile, the percentage of twelfth graders who scored at or above the national 90th percentile on the math SAT, ACT, PSAT, or pre-ACT. ACT scores were converted to SAT scores using the official 2008 Concordance.

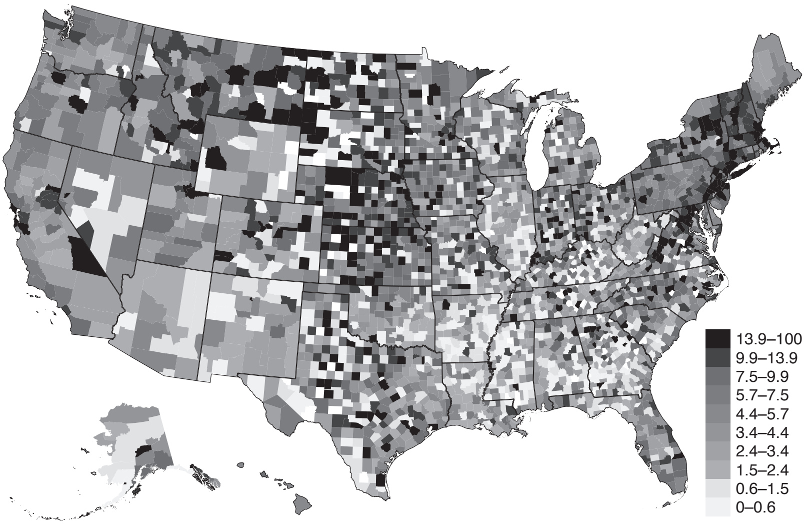
relationships. This weakness motivates the longitudinal empirical exercise that follows the maps.

III.A. Maps of Cognitive Skills for Twelfth Graders, Eighth Graders, Fifth Graders, and Third Graders

Figures 5 and 6 map advanced cognitive skills among twelfth graders. They are based on mathematics SAT and ACT scores and their preliminary versions (PSAT, pre-ACT). Although these tests are not mandatory in all states, students who are likely to score in the advanced range (at or above the 75th percentile) have a high probability of taking at least one of them. ACT scores are converted to the SAT scale based on the official 2008 ACT-SAT Concordance.

In figure 5, which uses the 90th percentile as the threshold for advanced status, the skill deserts are already quite apparent for twelfth graders. Most of the same geographic patterns that appear in the PIAAC-based map also appear in the figure. Figure 6 uses the 75th percentile and, again, the geographic patterns resemble those of the PIAAC-based map. These resemblances

Figure 6. Percentage of Twelfth Graders Whose Math Skills Are at or above the National 75th Percentile



Source: Hoxby and Avery (2013).

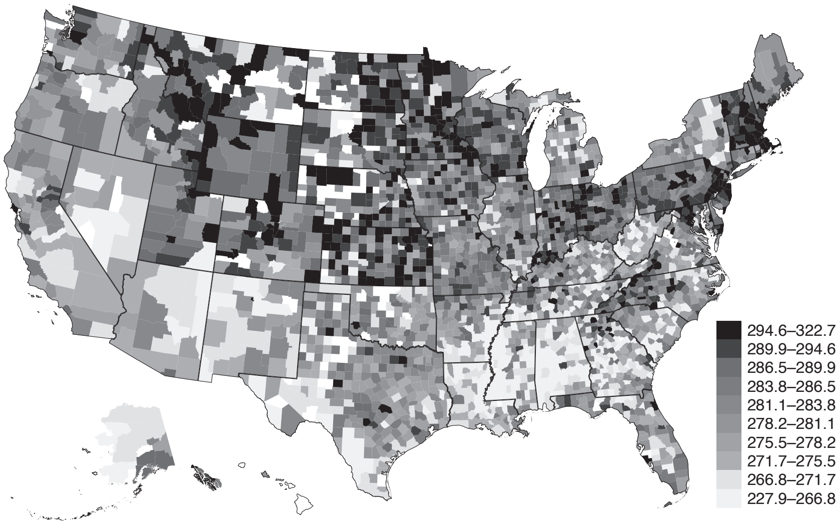
Note: The map shows, by decile, the percentage of twelfth graders who scored at or above the national 75th percentile on the math SAT, ACT, PSAT, or pre-ACT. ACT scores were converted to SAT scores using the official 2008 Concordance.

can be made more concrete. The population-weighted correlation between a county's adult advanced cognitive skills prevalence and its twelfth grade advanced cognitive skills prevalence is 0.56 for the 90th percentile threshold and 0.53 for the 75th percentile threshold.

The map for eighth grade mathematics test scores is shown in figure 7.[21] In the eighth grade, some of the skill deserts that we saw for twelfth graders and adults are already quite apparent: Appalachia and the inland South. This is somewhat striking given that the map is based on average scores, not scores above some threshold like the 75th percentile. (That is, the pattern is expected to shift for this reason alone.) There is also a skill desert on the

21. The test scores are for 2013, the year in which the most complete data are available. For grades five and eight, Virginia does not have mathematics scores that can be rescaled into NAEP scores, owing to its use of end-of-course rather than end-of-grade tests. Therefore, its mathematics scores are predicted for those grades using its English language arts scores, which can be rescaled. If an alternative measure of mathematics (such as the grade-cohort equivalent score, which is available) is used for Virginia, the Virginia map is almost indistinguishable from the one based on predicted NAEP mathematics scores. This suggests that the prediction method gives us a reliable impression for Virginia.

Figure 7. Average Mathematics Skills of Eighth Graders on State Tests (NAEP Scale)



Source: Stanford Education Data Archive.

Note: The map shows, by decile, the average (combined) math and verbal scores of eighth graders of their own state's test. State test scores are rescaled onto the National Assessment of Education Progress (NAEP) scale using the Stanford Education Data Archive, http://purl.stanford.edu/db586ns4974.

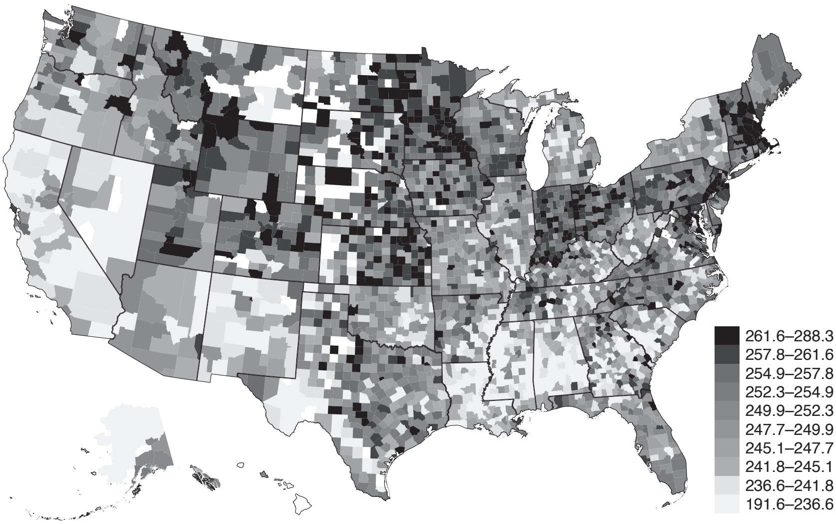
Mexican border that was not nearly so visible on the maps for twelfth graders and adults. One should be cautious with this finding, however, since these counties tend to be sparsely populated though large in land mass. One hypothesis might be that these counties' students are disproportionately likely to be recent immigrants whose lack of English language skills is evident on eighth grade tests but partially made up by the twelfth grade and even more by adulthood.[22] The population-weighted correlation between a county's adult advanced cognitive skills prevalence and its eighth grade cognitive skills prevalence is 0.67.[23]

The analogous maps for fifth and third grade test scores are shown in figures 8 and 9. These grades are important because they represent,

22. English language skills can affect mathematics scores because problems must be read. For instance, when Florida improved its reading scores through a reading-intensive third grade curriculum, its mathematics scores rose as well despite the fact that mathematics lessons were arguably getting less time. See Schwerdt, West, and Winters (2017).

23. The eighth grade measure is based on average scores so that this correlation is not directly comparable to the correlations based on twelfth grade scores where percentile thresholds were used.

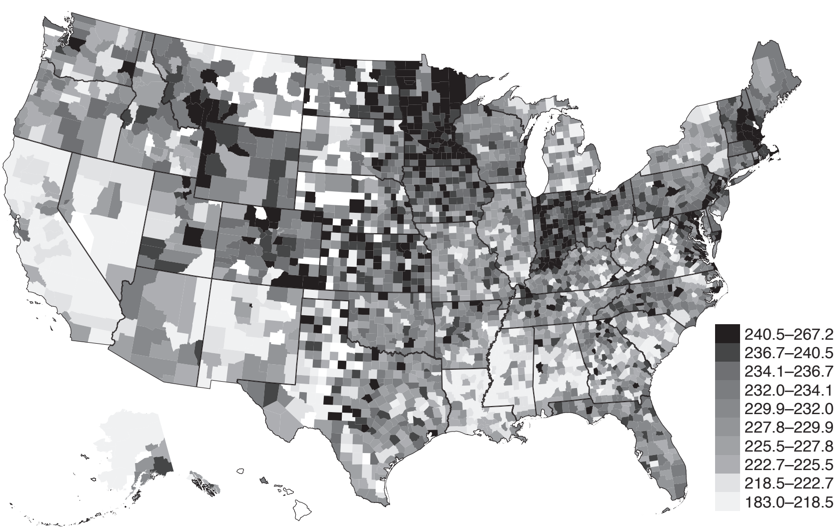
Figure 8. Average Mathematics Skills of Fifth Graders on State Tests (NAEP Scale)



Source: Stanford Education Data Archive.

Note: The map shows, by decile, the average (combined) math and verbal scores of fifth graders of their own state's test. State test scores are rescaled onto the National Assessment of Education Progress (NAEP) scale using the Stanford Education Data Archive, http://purl.stanford.edu/db586ns4974.

Figure 9. Average Mathematics Skills of Third Graders on State Tests (NAEP Scale)



Source: Stanford Education Data Archive.

Note: The map shows, by decile, the average (combined) math and verbal scores of third graders of their own state's test. State test scores are rescaled onto the National Assessment of Education Progress (NAEP) scale using the Stanford Education Data Archive, http://purl.stanford.edu/db586ns4974.

respectively, the very beginning of adolescence and the results of early childhood factors. These maps only somewhat resemble the adult maps. For instance, Appalachia is not nearly so obvious. The pattern across the South is quite different with some coastal areas appearing to be skill deserts while they were not on the twelfth grade or adult maps. Also northern Florida (a skill desert in the twelfth grade and adult maps) shows prevalent cognitive skills among third and fifth graders. Finally, the relative lack of cognitive skills has spread up from the Mexican border counties (eighth grade) deeper into Nevada and California. The population-weighted correlation between a county's adult advanced cognitive skills prevalence and its fifth grade cognitive skills prevalence is 0.54. The analogous number for third grade is 0.50. Notice that these numbers are well below the correlation for eighth grade of 0.67, suggesting that early adolescence is a period when advanced cognitive skill similarities between adults and children is rising rapidly.

What are we to make of these findings? They suggest that a child's cognitive skills in the third grade are not destiny. Even a child's skills in the fifth grade are not destiny. It is only as we look at the map for grade eight that we begin to see patterns that mostly resemble those for adults. By twelfth grade, the resemblance to the adult map is quite strong, though of course imperfect.

III.B. Longitudinal Estimates

One can draw only suggestive evidence by comparing the above maps. Unavoidable differences in data and measures hinder such comparisons. To parse the explanations (very early factors, adolescent factors, migration) with more confidence, longitudinal data on individuals are needed.

The empirical strategy for the exercise is simple.

(1) Regress a child's probability of scoring in the top 30 percent (or 20 percent) on his or her county's share of adults with advanced cognitive skills.

(2) Run this regression for children at each age (N) at which a test score is available.

(3) First run the set of age-specific regressions using adults' advanced cognitive skills from the child's initial county (jt_0) in the longitudinal data.

(4) Plot the regression coefficients to demonstrate how the correlation between children's and adults' cognition changes with the child's age. This evidence should demonstrate the degree to which starting in a county where advanced cognitive skills are more or less prevalent determines the development of a child's cognition.

(5) Repeat the exercise (steps 1 through 4) except this time use adults' advanced cognitive skills from whatever is the child's current county (jt) in the longitudinal data. A comparison between the resulting plot and the plot from stage 4 should demonstrate the degree to which migration matters and the age at which important migration tends to occur.

In practice, I combine the no-migration plot from step 4 with the migration-allowed plot from step 5.[24]

The regression estimated for each available age in steps 1 through 2 is:[25]

$$\text{Prob(Child Math Score in Top 30 percent at Age } N)_{ijt} = \alpha_N + \beta_N \text{ Share of Initial County Adults with Advanced Cognitive Skills}_{jt_0} + \varepsilon_{ijt}$$

The analogous regression for each available age in step 5 is:

$$\text{Prob(Child Math Score in Top 30 percent at Age } N)_{ijt} = \alpha_N + \beta_N \text{ Share of Current County Adults with Advanced Cognitive Skills}_{jt} + \varepsilon_{ijt}$$

Although the exercise is simple, the longitudinal data needs are unfortunately challenging. What would be ideal is a longitudinal data set, like the 1970 British Cohort Study, that traces participants from birth through midlife, tracking their cognition and location throughout. No such study exists for the United States, so I use the ECLS-K and NELS. As noted previously, these take us from about age 5.5 to about age 26.5. They both study eighth graders, whose performance looks consistent across the two studies, but they are not truly longitudinal across the eighth grade divide.[26]

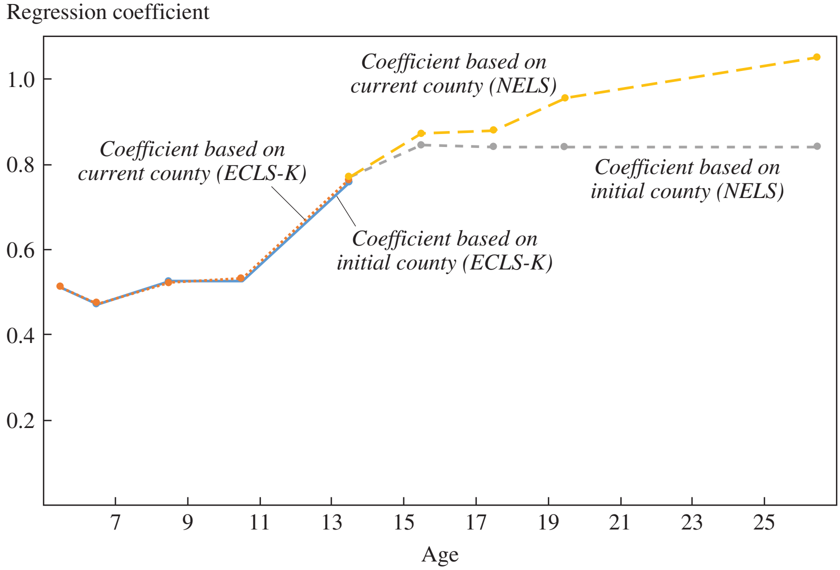
Figure 10 shows the result of the exercise using, as the dependent variable at each age, the probability of a child's math score being in the top 30 percent nationally. The plot for the initial county is quite flat from age 5.5 to 10.5 and indicates a correlation of about 0.5 between a child's cognition and the advanced cognition skills of local adults. The correlation then rises to just above 0.8 at ages 15.5 and 17.5. After that, it appears flat but this is mechanical because no new cognitive measures are available after age 17.5

24. To keep the plots uncluttered, I show only point estimates for the regression coefficients that are plotted. I do not attempt to show the standard errors of the coefficients. In fact, all of the estimated coefficients have p-values well below 0.001.

25. I show linear probability coefficients for simplicity, but probit results produce similar findings.

26. I eliminated the National Longitudinal Surveys (https://www.bls.gov/nls/) because their cognitive assessments were too irregular or sparse. I eliminated other NCES longitudinal studies for reasons of timing, follow-up, or the sample frame.

Figure 10. Results of Regressing the Probability of a Child's Math Score Being in the Top 30 Percent on Adults in the County with Math Scores in the Top Third



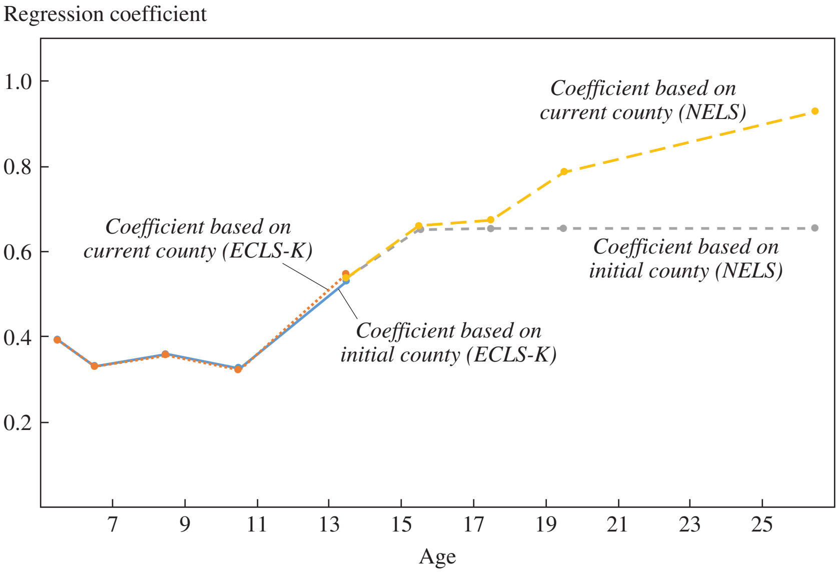
Sources: ECLS-K; NELS; PIAAC.

so that the score from that age is used at ages 19.5 and 26.5 (ages at which we know the person's location but do not have a new cognitive score).

The plot for the current county is very similar to the plot for the initial county between ages 5.5 and 13.5. Between ages 13.5 and 17.5, the plots remain similar although the current line starts to rise slightly relative to the actual line. These results, so far, suggest that consequential migration is insufficiently common before the twelfth grade to affect, more than slightly, the correlations between a child's cognition and the advanced cognitive skills of local adults. That is, migration does occur but it does not greatly alter the prevalence of adults with advanced cognitive skills in the county where a child lives: the counties of origin and destination are sufficiently similar that the coefficients are not affected much.

From age 17.5 onward, migration becomes a substantial factor. The correlation rises from just over 0.8 to more than 0.9 from age 17.5 to age 19.5. In work that is not shown, this appears mainly to be associated with a student's moving to attend college. That is, people who are actually enrolled are at age 19.5 and account for most of the moves from counties with lower

Figure 11. Results of Regressing the Probability of a Child's Math Score Being in the Top 20 Percent on Adults in the County with Math Scores in the Top Third



Sources: ECLS-K; NELS; PIAAC.

advanced cognitive skill prevalence to higher prevalence.[27] Further migration from age 19.5 to age 26.5 raises the correlation still higher—slightly above 1.0 (possible given the method). This is probably mainly associated with job-related moves but the NELS does not contain questions that would allow one to establish this reasonably credibly.

Figure 11 is analogous to figure 10 except that it uses, as the dependent variable at each age, the probability of a child's math score being in the top 20 percent nationally. The coefficient estimate at each age is lower, probably because the top 20 percent threshold used for the ECLS-K and NELS is further from the top 37 percent threshold used for adults' PIAAC scores. Otherwise, the main takeaways are largely the same: the correlation between a child's and local adults' cognition starts at a modest level (about 0.35), rises between the ages of 10.5 and 15.5, and is flat thereafter

27. College-related moves are not always stereotypical moves to a university town. There are numerous moves to, say, an adjoining county where a community college is available.

unless one takes account of migration. Migration between ages 17.5 and 26.5 accounts for a substantial further rise in the correlation.

Though causality is not established, the evidence from the longitudinal exercise suggests that local adults' advanced cognitive skills probably have some effect on a child's advanced cognitive skills starting at an early age, and this influence appears to rise starting in early adolescence. By saying that causality is not established, I mean that local adults' cognitive skills need not be the channel through which the child is affected. The channel could be any variable(s) systematically correlated with the prevalence of advanced cognitive skills among adults: schooling variables, employment variables, income variables, health variables, and so on. I return to this point in the discussion.

Migration after high school accounts for a continuing increase in the correlation but this is almost certainly due mainly to self-selective moves. I have presented no evidence, as from a random experiment, showing that people randomly induced to move to a county where advanced cognitive skills are more prevalent see a consequent rise in their own skills.[28] Studies that rely on nonexperimental family moves, especially those that substantially change a child's environment, do not produce credibly causal estimates. Major family moves are not made in a random or trifling way: they are simply too expensive and potentially consequential.

IV. Correlates of Advanced Cognitive Skills

As mentioned at the outset, this paper does not attempt causal tests of explanations why advanced cognitive skills are more prevalent in some areas than in others. However, by examining some correlates of prevalence, it may be possible to focus on some explanations. Keep in mind, though, that a variable that is highly correlated with prevalence may be so because of reverse causality. For instance, students with low cognitive skills may find it hard to succeed in college.

Table 2 shows county-level correlations between the advanced cognitive skill measures mapped above and a variety of socioeconomic factors.[29]

The first eight rows show correlations with closely related measures of cognitive skill. One takeaway is that the prevalence of advanced cognitive skills is highly negatively correlated with the prevalence of adults who

28. For a credible natural experiment along these lines, see Kawano and others (2018).
29. The correlations are weighted by the population age 8 to 65.

Table 2. Correlations between Advanced Cognitive Skill Measures and Other Factors

	Adults with advanced numeracy skills (%)	*Twelfth graders with math skills ≥ 90th percentile*	*Twelfth graders with math skills ≥ 75th percentile*	*Average math skills of eighth graders*	*Average math skills of fifth graders*	*Average math skills of third graders*
Adults with low numeracy skills (%)	–0.86	–0.44	–0.49	–0.73	–0.67	–0.66
Adults with low literacy skills (%)	–0.76	–0.36	–0.42	–0.68	–0.63	–0.63
Adults with advanced literacy skills (%)	0.99	0.56	0.55	0.67	0.60	0.56
Twelfth graders with verbal skills ≥ 75th percentile	0.51	0.91	0.97	0.49	0.50	0.47
Twelfth graders with verbal skills ≥ 90th percentile	0.55	0.95	0.96	0.50	0.50	0.44
Average English language arts skills of eighth graders	0.67	0.58	0.60	0.90	0.82	0.76
Average English language arts skills of fifth graders	0.62	0.55	0.58	0.82	0.88	0.84
Average English language arts skills of third graders	0.54	0.51	0.55	0.75	0.82	0.87
Adults with less than high school (%)	–0.78	–0.42	–0.38	–0.60	–0.58	–0.57
Adults with high school or some college less than a BA (%)	–0.44	–0.42	–0.57	–0.27	–0.17	–0.10
Adults with BA or MA (%)	0.83	0.60	0.69	0.53	0.50	0.43
Adults with professional or doctoral degree (%)	0.63	0.48	0.61	0.29	0.27	0.22
Public school spending per student	0.22	0.39	0.34	0.19	0.13	0.08
Public school staff compensation per student	0.24	0.43	0.40	0.19	0.15	0.11
Public school instructor wages	0.26	0.43	0.40	0.21	0.19	0.15
Students in private schools (%)	0.35	0.38	0.33	0.14	0.21	0.19
Pre-K student–teacher ratio	–0.12	–0.06	–0.08	–0.13	–0.17	–0.19
Kindergarten student–teacher ratio	0.00	–0.03	–0.04	–0.03	–0.02	–0.04
Primary school student–teacher ratio	0.19	–0.07	–0.07	0.05	0.05	0.05
Middle school student–teacher ratio	0.07	–0.16	–0.14	–0.07	0.00	0.05
High school student–teacher ratio	–0.02	–0.05	–0.05	–0.07	–0.07	–0.07
Poverty rate	–0.61	–0.52	–0.56	–0.64	–0.58	–0.54
Disability rate	–0.59	–0.52	–0.45	–0.54	–0.41	–0.33
Households on food stamps (%)	–0.68	–0.51	–0.52	–0.71	–0.55	–0.50
Unemployed or out of the labor force (%)	–0.63	–0.40	–0.41	–0.53	–0.55	–0.51
Child households not headed by husband and wife (%)	–0.64	–0.48	–0.51	–0.77	–0.68	–0.63
Households rural (%)	–0.34	–0.29	–0.19	–0.14	–0.08	0.01

Sources: PIAAC, Hoxby and Avery (2013), SEDA, Manson and others (2021), IPUMS National Historical Geographic Information System 2010 Census and 2000–2012 American Community Survey data, NCES Common Core of Data 2010–2011 files.

Note: Table shows population-weighted, county-level correlations between measures of cognitive skill and other factors.

score at the lowest levels (below level 1 and level 1) on the PIAAC exam. Indeed, a map of low cognitive skills looks much like a reverse image of the map of high cognitive skills. Another takeaway is that the math-based measures are highly correlated with parallel measures based on verbal skills. In short, little evidence has been lost by focusing on math-based, advanced skill measures.

The next four rows show correlations with educational attainment. Advanced cognitive skills are negatively correlated with the share of the population with no high school degree or with a high school degree and some college but less than a baccalaureate degree. Advanced cognitive skills are positively correlated with the share of the population with a baccalaureate or master's degree or with a professional or doctoral degree. These correlations are stronger when advanced cognitive skills are measured later in life, confirming some of the evidence presented above that early cognitive skills are not as determinative. Reverse causality is a serious issue for these correlations, but they are a useful sanity check.

The next nine rows show correlations with measures of the K-12 educational experience. Advanced cognitive skills in the twelfth grade and adulthood are positively correlated with measures of school spending, staff compensation, and the share of students who attend private school. The correlations weaken as one moves to cognitive skill measures based on earlier ages. Of course, these correlations may merely be picking up income since it often affects school spending and families' ability to pay tuition. Advanced cognitive skills have little evident correlation with the student-teacher ratio at various grades. Even the signs are not consistently negative as might be expected. This may seem surprising, but it is a finding that is standard in the correlational literature on class size and a finding also of at least one credibly causal study.[30]

The final six rows show correlations with the poverty rate, disability rate, share of households who receive food stamps (SNAP), share of adults who are unemployed or out of the labor force, share of households with children that are not headed by a husband and wife, and share of households that are rural. Advanced cognitive skills are negatively correlated with each of these measures. Although not shown, advanced cognitive skills are positively correlated with median and mean household income.

It is worth noting that advanced cognitive skills have little or no correlation with a variety of measures of housing (such as the percentage who rent

30. See Hanushek (1997) for a review of mainly correlational studies. See Hoxby (2000) for a credibly causal (regression discontinuity) study that finds negligible effects of class size.

or the vacancy rate) or with a variety of measures of age distribution (such as the percentage under age 18 or over age 65).

V. Discussion

V.A. Implications for Policies Likely to Affect Children Directly

I have presented evidence that there is substantial variation in the prevalence of advanced cognitive skills and that skill deserts exist where they are far from prevalent. The evidence suggests that skill deserts have factors that affect adolescents disproportionately and are associated with a local absence of adults with advanced cognitive skills. These two conditions suggest numerous possibilities. For instance, in a skill desert, there could be shortages of teachers who have the skills to teach rich and demanding curricula. There could be obstacles to putting such curricula into schools, even if skilled teachers are available. Obstacles might include a lack of funding for schools or low population density that makes it hard for schools to be of sufficient size for specialized classes. There could be a lack of sophistication among adults about college-going so that adolescents do not realize how important it is to acquire advanced cognitive skills to succeed in higher education—many two-year degree programs as well as baccalaureate programs.

The possibilities mentioned here are all concerned with education, and this makes sense if we focus on frontal lobe development. However, the frontal lobe also has a disproportionate effect on planning and self-regulation. In addition, puberty begins in early adolescence. So there are candidate explanations that fit the criteria but are not about learning per se. For instance, if cultural norms in an area expect teens to become parents, then students might tune out school once they hit puberty and adolescence. Thus, purely through fertility expectations, a child growing up in a county with low prevalence of advanced cognitive skills among adults could be less likely to develop such skills. Furthermore, this relationship would intensify as puberty hit. This story would fit the conditions and yet have no direct link to education. Solving a shortage of skilled teachers might be entirely ineffectual. In this scenario, education is merely collateral damage.

Other stories characterized by omitted variables are possible. Although there are numerous studies of cognitive skill development, only a small fraction meets standards of causality. Those that do tend to be randomized controlled trials or policy experiments that affect a limited number of students in a limited range of grades. For a review of adolescent-oriented studies that classifies them according to standards of causality, see Herrera, Truckenmiller, and Foorman (2016). Large-scale natural experiments are likely needed if we are to learn more about how the same treatment, such as teacher quality, might have different effects at different ages. These are what I employ in the Tanner Lectures mentioned above.

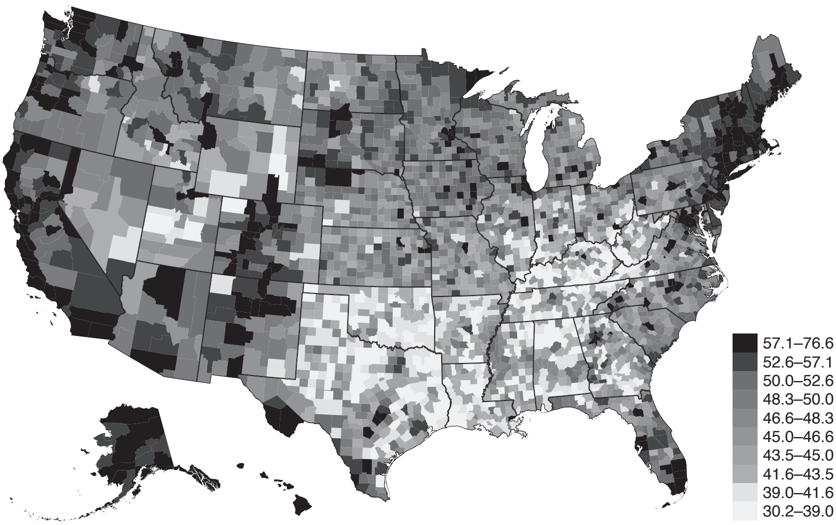
What we can almost certainly say, even without knowing the exact causes, is that we need greater analysis of the early adolescent period of schooling and brain development. In particular, since the correlation between a twelfth grader's cognitive skills and local prevalence of advanced cognitive skills among adults is still well below one, a child who begins life in a skill desert nevertheless has a reasonable probability of attaining advanced cognitive skills. More work is needed to understand why some adolescents are more resilient to such an environment. Adolescence does indeed appear to be an "age of opportunity," as expressed by so many researchers who study brain development.

V.B. Speculative Implications for Policies Unlikely to Affect Children Directly

In the process of writing this paper, I began to speculate that some children born in advanced cognitive skill deserts might reasonably develop economic fatalism, resentment toward perceived intellectual elites, or a lack of social trust in people whose skills differ from the adults most familiar to them. If so, there may be additional urgency in understanding geographic variation in the prevalence of advanced cognitive skills. Put another way, there may be additional urgency in making adolescence an age of opportunity rather than an age of risk.

Charles, Hurst, and Schwartz (2019) show that when a local area experiences a decline in manufacturing, there are large and—more importantly for economic fatalism—persistent negative effects on local employment rates, hours worked, and wages. Since jobs in the declining fields (manufacturing, mining) are less likely to require advanced cognitive skills than jobs in rapidly growing fields (technology, health care), students who reach the end of high school without acquiring advanced cognitive skills may realistically foresee a long future ahead with little hope of achieving economic security. Indications of such economic fatalism come from Charles, Hurst, and Schwartz (2019), who show associations between declining local manufacturing and rising local opioid use and deaths. Case and Deaton's (2015, 2017, 2020) influential work has also associated "deaths of despair" with economic fatalism. They have mapped such deaths, and readers can compare their maps to the maps of advanced cognitive skills in this paper. Some notable similarities will be observed.

Figure 12. Estimated Share of Adults Who Believe Most Scientists Think Global Warming Is Happening



Source: Howe and others (2015).

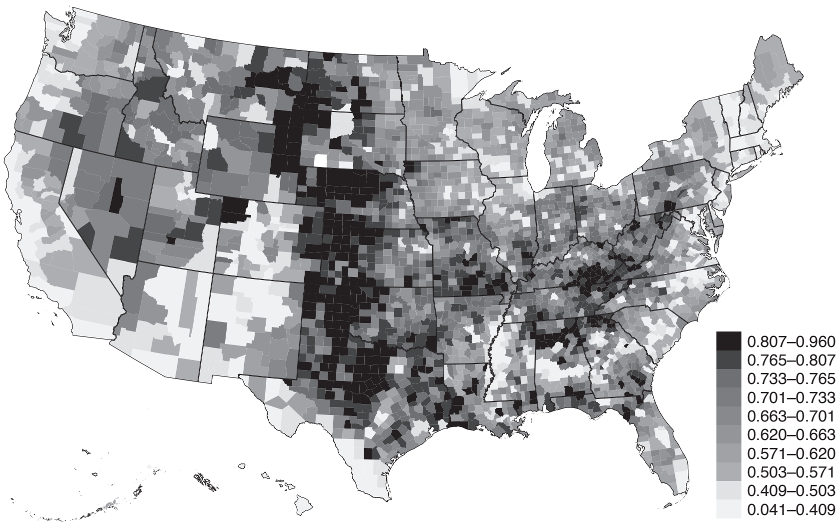
If people perceive technical change to be skill-biased (and persistently skill-biased for the foreseeable future), then those who do not learn advanced cognitive skills in adolescence may expect that demand for their skills will steadily fall while demand for the skills of perceived intellectual elites will steadily rise. This could easily lead to resentment of or distrust in the perceived elites.

Finally, if global trade and immigration policies are perceived to be exacerbating the economic forces, such as skill-biased technical change, that favor those with advanced cognitive skills, then students who reach the end of high school without acquiring advanced cognitive skills may align themselves against such policies. This might lead them to vote for politicians who oppose trade and/or immigration.

Figure 12 shows the US county map of the estimated share of adults who believe "most scientists think global warming is happening."[31] Note that this is not a question about whether the adult himself or herself believes in global warming, but a question about what most scientists think. This

31. Quoted from the question wording in the Climate Change in the American Mind Survey, a tab on the Yale Climate Opinion Maps by Howe and others (2015), accessed January 2020. This map is based on data from Howe and others (2015).

Figure 13. Share of Votes for Donald J. Trump in 2016



Source: MIT Election Data and Science Lab, 2018, "County Presidential Election Returns 2000– 2016," Harvard Dataverse, V6, https://doi.org/10.7910/DVN/VOQCHQ.

question was selected because the answer (yes) can be easily established and is well known.[32]

Figure 13 shows the US county map of the share of votes for Donald J. Trump in 2016.[33] His platform was notably more protectionist and anti-immigration than those of his opponents, including most of his primary opponents.

ACKNOWLEDGMENTS The author gratefully acknowledges comments from Janice Eberly, Erik Hurst, Brian Jacob, and James Stock.

32. The consensus is that 90 percent or more of scientists think global warming is happening. While this number could be wrong, the true number is very unlikely to be lower than or equal to 49 percent. See Cook and others (2016).

33. This map is based on data from the MIT Election Data and Science Lab, 2018, "County Presidential Election Returns 2000–2016," Harvard Dataverse, V6. https://doi.org/10.7910/DVN/VOQCHQ, accessed January 2020.

References

Association of Statisticians of American Religious Bodies (ASARB). 2002. *Religious Congregations and Membership in the United States, 2000*. Nashville: Glenmary Research Center.

Atkins, S. M., M. F. Bunting, D. J. Bolger, and M. R. Dougherty. 2012. "Training the Adolescent Brain: Neural Plasticity and the Acquisition of Cognitive Abilities." In *The Adolescent Brain: Learning, Reasoning, and Decision Making*, edited by Valerie F. Reyna, Sandra B. Chapman, Michael R. Dougherty, and Jere Confrey. Washington: American Psychological Association.

Case, Anne, and Angus Deaton. 2015. "Rising Morbidity and Mortality in Midlife among White Non-Hispanic Americans in the 21st Century." *Proceedings of the National Academy of Sciences* 112, no. 49: 15078–83.

Case, Anne, and Angus Deaton. 2017. "Mortality and Morbidity in the 21st Century." *Brookings Papers on Economic Activity*, Spring, 397–443.

Case, Anne, and Angus Deaton. 2020. *Deaths of Despair and the Future of Capitalism*. Princeton, N.J.: Princeton University Press.

Chapman, Sandra B., Jacquelyn F. Gamino, and Raksha Anand Mudar. 2012. "Higher Order Strategic Gist Reasoning in Adolescence." In *The Adolescent Brain: Learning, Reasoning, and Decision Making*, edited by Valerie F. Reyna, Sandra B. Chapman, Michael R. Dougherty, and Jere Confrey. Washington: American Psychological Association.

Charles, Kerwin Kofi, Erik Hurst, and Mariel Schwartz. 2019. "The Transformation of Manufacturing and the Decline in US Employment." *NBER Macroeconomics Annual* 33:307–72.

Cook, John, Naomi Oreskes, Peter T. Doran, William R. L. Anderegg, Bart Verheggen, Ed W. Maibach, and others. 2016. "Consensus on Consensus: A Synthesis of Consensus Estimates on Human-Caused Global Warming." *Environmental Research Letters* 11, no. 4: 048002.

Couture, Victor, Cecile Gaubert, Jessie Handbury, and Eric Hurst. 2020. "Income Growth and the Distributional Effects of Urban Spatial Sorting." Working Paper 26142. Cambridge, Mass.: National Bureau of Economic Research. https://www.nber.org/papers/w26142.

Dahl, Ronald E. 2004. "Adolescent Brain Development: A Period of Vulnerabilities and Opportunities." *Annals of the New York Academy of Sciences* 1021:1–22.

Forman, Chris. 2013. "How Has Information Technology Use Shaped the Geography of Economic Activity?" In *Handbook of Industry Studies and Economic Geography*, edited by Frank Giarratani, Geoffrey J. D. Hewings, and Philip McCann. Northampton, Mass.: Edward Elgar Publishing.

Hanushek, Eric A. 1997. "Assessing the Effects of School Resources on Student Performance: An Update." *Educational Evaluation and Policy Analysis* 19, no. 2:141–64.

Herrera, S., A. J. Truckenmiller, and B. R. Foorman. 2016. *Summary of 20 Years of Research on the Effectiveness of Adolescent Literacy Programs and Practices*. Washington: US Department of Education, Institute of Education Sciences, National Center for Education Evaluation and Regional Assistance, Regional Educational Laboratory Southeast. http://ies.ed.gov/ncee/edlabs.

Howe, Peter D., Matto Mildenberger, Jennifer R. Marlon, and Anthony Leiserowitz. 2015. "Geographic Variation in Opinions on Climate Change at State and Local Scales in the USA." *Nature Climate Change* 5:596–603. https://doi.org/10.1038/nclimate2583.

Hoxby, Caroline M. 2000. "The Effects of Class Size on Student Achievement: New Evidence from Population Variation." *Quarterly Journal of Economics* 115, no. 4: 1239–85.

Hoxby, Caroline M., and Christopher Avery. 2013. "The Missing 'One-Offs': The Hidden Supply of High-Achieving, Low-Income Students." *Brookings Papers on Economic Activity*, Spring, 1–50.

Kawano, Laura, Bruce Sacerdote, Mike Stevens, and William Skimmyhorn. 2018. "The Determinants of Children's Outcomes: Evidence from Random Geographic Movement of Military Families." Working Paper. https://conference.nber.org/conf_papers/f95269.pdf.

Kolko, Jed. 2007. "Agglomeration and Co-Agglomeration of Services Industries." Social Science Research Network, May 16. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=985711.

Krenzke, T., L. Mohadjer, J. Li, A. Erciulescu, R. Fay, W. Ren, W. Van de Kerckhove, L. Li, and J. N. K. Rao. 2020. *Program for the International Assessment of Adult Competencies (PIAAC): State and County Estimation Methodology Report (NCES 2020-225)*. Washington: US Government Printing Office. Retrieved December 2020 from https://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2020225.

Krenzke, T., W. VanDeKerckhove, N. Thornton, L. Diaz-Hoffmann, J. Hogan, L. Mohadjer, and others. 2019. *U.S. Program for the International Assessment of Adult Competencies (PIAAC) 2012/2014/2017: Main Study, National Supplement, and PIAAC 2017 Technical Report (NCES 2020-224)*. Washington: National Center for Education Statistics. https://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2020224.

Malamud, Ofer, and Abigail Wozniak. 2012. "The Impact of College on Migration: Evidence from the Vietnam Generation." *Journal of Human Resources* 47, no. 4: 913–50.

Manson, Steven, Jonathan Schroeder, David Van Riper, Tracy Kugler, and Steven Ruggles. 2021. *IPUMS National Historical Geographic Information System: Version 16.0* [dataset]. Minneapolis: University of Minnesota. http://doi.org/10.18128/D050.V16.0.

Mori, Tomoya. 2017. "Agglomeration." Working Paper 960. Kyoto: Kyoto University, Institute of Economic Research.

Piaget, Jean. 1972. "Intellectual Evolution from Adolescence to Adulthood." *Human Development* 15: 1–12.

Reyna, Valerie F., Sandra B. Chapman, Michael R. Dougherty, and Jere Confrey. 2012. "Introduction." In *The Adolescent Brain: Learning, Reasoning, and Decision Making*, edited by Valerie F. Reyna, Sandra B. Chapman, Michael R. Dougherty, and Jere Confrey. Washington: American Psychological Association.

Schwerdt, Guido, Martin R. West, and Marcus A. Winters. 2017. "The Effects of Test-Based Retention on Student Outcomes over Time: Regression Discontinuity Evidence from Florida." *Journal of Public Economics* 152:154–69.

Spear, Linda Patia. 2013. "Adolescent Neurodevelopment." *Journal of Adolescent Health* 52, no. 2 Suppl.: S7–13.

Steinberg, Laurence D. 2015. *Age of Opportunity: Lessons from the New Science of Adolescence*. Boston: Houghton Mifflin.