

BPEA Conference Drafts, March 25, 2021

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

# Advanced Cognitive Skill Deserts in the U.S.: Their Likely Causes and Implications

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## 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 non-specialist'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 why the prevalence of advanced cognitive skills varies substantially across U.S. counties. First, is it early childhood factors that are largely determined by kindergarten entry or even before? Such factors could generate endogenous responses that are important later when advanced cognitive skills are developing. Second, 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. Third, is the variation among counties explained by migration of individuals towards areas where other people have advanced cognitive skills similar to their own? Such migration might be motivated by employers' demands for certain skills but there are other possible motivations as well. Showing a variety of evidence based on cognitive skill trajectories, maps at different ages, and regressions based on longitudinal data, the paper suggests that all three of the aforementioned explanations play a role in generating areas where advanced cognitive skills are prevalent and other areas where they are not ("deserts").

## I. Introduction

“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 in such circumstances], this same plasticity can be disastrous.”<sup>1</sup>

—Laurence D. Steinberg, *Age of Opportunity: Lessons from the New Science of Adolescence*

The quotation above 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. The quotation mentions seeing, hearing, and walking. Neuroscience indicates that we might add language, social, and numerous other non-cognitive skills to this early mix. Very early brain development mainly affects the back and center lobes of the brain and is, as the quotation 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 three. 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 is

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<sup>1</sup> Steinberg (2015), pp. 29-30.

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 "non-cognitive" 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 and others argue that the fact that advanced cognitive skills develop in adolescence *cuts both ways*.<sup>2</sup> On the 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 non-cognitive 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 argues, then the plasticity of the frontal lobe in

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<sup>2</sup> See, for instance, the introductory summary chapter by Reyna *et al* in Reyna *et al* (2012) and Dahl's introductory summary chapter in Dahl and Spear (2004).

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 a 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 U.S. also come to mind though the degree these are skill-biased is complex and the subject of debate. In addition, one might think that some areas of the U.S. might be significantly more skill-biased than others if there are agglomeration economies associated with advanced cognitive skills. The economics literature contain many examples of agglomeration economies associated with non-cognitive 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.<sup>3</sup> In addition, if people with advanced cognitive skills share preferences for certain amenities, that could amplify or even fully justify agglomeration.<sup>4</sup>

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

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<sup>3</sup> For a recent review article on agglomeration economies, see Mori (2017). See also Kolko (2007) and Forman (2013) for agglomeration of high-skilled workers.

<sup>4</sup> On this point, see Couture, Gaubert, Handbury, and Hurst (2021)

High school graduates with advanced 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 skill or tastes for amenities. There is some evidence that more educated people make relocation decisions that are more beneficial to them economically.<sup>5</sup> 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 U.S. counties in the prevalence of adults with advanced cognitive skills.<sup>6</sup> Being interested in areas where advanced cognitive skills are especially non-prevalent, I label such areas "deserts" as a shorthand. This exercise is not the same as testing whether there is much variation in the share of adults employed in skilled occupations. Such occupational variation could be caused by any number of supply and demand factors that vary among areas: regulations, tax policies, natural resources, place-based policies that favor certain firms. Rather, I am interested in variation that is a layer deeper: cognition. Understanding how the variation in the supply of advanced cognitive skills arises might reveal

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<sup>5</sup> See Malamud and Wozniak (2012).

<sup>6</sup> Maps based on Commuting Zones look broadly similar but exacerbate some problems that already plague county-based maps.

ways to improve such skills. It might also have consequences for economic policies such as trade and consequences for political economy.

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 towards 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.<sup>7</sup> 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 spirit of Steinberg's

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<sup>7</sup> 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.

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 area to another 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.

## II. Advanced Cognitive Skills

### A. What are Advanced Cognitive Skills?

Advanced cognitive skills are generally defined to be 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.<sup>8</sup>

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<sup>8</sup> Piaget (1972) is seminal. Chapman *et al* (2012) provides a excellent review.

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 follows 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 teaches 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 teach advanced cognitive skills in writing and reading if it requires students to integrate and synthesize material.

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 make it easier to follow as steps in cognitive development. Also, there are idiosyncratic data constraints, described below, that sometimes force me to rely

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 equally available. 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 no means the only type of advanced cognitive skill.

#### 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 non-invasive technique allows researchers to follow the same person's brain anatomy as he or she undergoes new learning experiences.<sup>9</sup> 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.<sup>10</sup>

### C. Advanced Cognitive Skill 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:

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<sup>9</sup> See Spear (2013) and Aktins *et al* (2012) for excellent reviews.

<sup>10</sup> I am referring to one of the Tanner Lecture papers mentioned above.

"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."<sup>11</sup>

Cognitive neuroscientists tend to attribute such stagnation to frontal lobe development which 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 eighth grade and the National Education Longitudinal Study (NELS) which covers people from eighth grade through about age 26 to 27.<sup>12</sup> 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

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<sup>11</sup> Chapman *et al* (2012), p. 124.

<sup>12</sup> 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.

age/grade (columns).<sup>13</sup> Thus, if every child stayed in the same decile, 100 percent of the data would fall along the diagonal. Data falling into off-diagonal cells is an indication of a transition—from, say, middling skills in the sixth decile to top skills in the 9th 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 with fourth grade because of the earlier onset of rapid brain development for females. Unfortunately, the ECLS-K does not test children in grade four.) To aid in interpretation, consider the row labeled “8” which shows that a male who scores in decile 8 at age 10.5 has a 6.1% probability of scoring in decile 5 at age 13.5, a 22.7% probability of scoring in decile 8 at age 13.5, and a 10.9% 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.<sup>14</sup> In other words, for this example, most of the probability (77.3%) 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 the row labeled "8". It shows that a male who scores in

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<sup>13</sup> I use mathematics rather than verbal tests here, but the verbal results are very similar.

<sup>14</sup> Specifically, the shading is based on intervals of 10 percentage points: 0 to 10%, 10.1 to 20%, and on so on.

decile 8 at age 15.5 has a 2.6% probability of scoring in decile 5 at age 17.5, a 37.5% probability of scoring in decile 8 at age 17.5, and a 6.3% 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% 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.<sup>15</sup>

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 age 3 would show the vast majority of probability off the diagonal: it is fairly hard even to pick out the diagonal.

### III. Mapping Advanced Cognitive Skills in the U.S.

#### A. Methods and Data

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

First, I have chosen to show a classic U.S. map of counties despite the fact that it overemphasizes sparsely populated counties that have a large land mass. I want viewers to be

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<sup>15</sup> It is worth noting that transition matrixes for very young children, show very little hardening. For instance, an analogous transition matrix for age 1 to age 3 would show the vast majority of probability off the diagonal: it is fairly hard even to pick out the diagonal. However, it is very difficult to test infants and toddlers without adult priming, and individual adults' effects can muddy test results.

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. However, the consequence is that the viewer must consciously avoid focusing on sparsely populated counties with a large land mass: the skill measures might be based on relatively few people. The implications of a county's having only 800 people, all of whom have advanced cognitive skills are very different from the implications of having 50,000 or 300,000 people with such skills. Generally speaking, the more sparsely populated a county is, the larger its land mass. It takes self-discipline on the viewer's part to ignore vast counties in Nevada, Arizona, Utah, New Mexico, south-eastern California, Montana, and the Dakotas.

Third, the only nationally representative measure of cognitive skills among adults in the U.S. comes from the Program for the International Assessment of Adult Competencies (PIAAC). It measures 16 to 65 year olds' numeracy (mathematics) and literacy. 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, 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 PIAAC aggregates the top three levels of skill for each test.<sup>16</sup> 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. This is simply too coarse.

PIAAC describes adults with the top three levels of numeracy skills as

"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."<sup>17</sup>

#### B. The Advanced Cognitive Skills Maps

Figure 3 maps advanced cognitive skills by county for the U.S., based on the PIAAC numeracy data. The percentage of adults with advanced cognitive skills is divided in 10 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.

Observe the areas where advanced cognitive skills are most prevalent: most of southern

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<sup>16</sup> The technical documentation for the county-based statistics from PIAAC (Krenzke *et al*, 2020) is highly informative and should be consulted by readers interested in how the statistics are computed. Unfortunately, it is too long to summarize here. Readers interested in PIAAC more generally should consult Krenzke *et al* (2019).

<sup>17</sup> Sample items from the numeracy test are available at <https://www.oecd.org/skills/piaac/Numeracy%20Sample%20Items.pdf>

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 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 D.C. area including parts of Maryland and Virginia. None of these findings is surprising. A finding that may surprise some readers (although not those familiar with statistics on American education) is the overall dark shading of the so-called "Lutheran Belt" which occupies southern Minnesota and parts of Wisconsin, Iowa, and the Dakotas. 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's, say, most of its counties fall into the top four deciles of prevalence. (Remember to ignore some of its large, sparsely-populated counties.)

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 through eastern Tennessee and eastern Kentucky, encompassing all of West Virginia, continuing through southeastern Ohio, proceeding through Pennsylvania, and finally ending in New York.<sup>18</sup> Although Appalachia is the most obvious desert, within it there are numerous counties, often in small clusters, in which advanced cognitive skills are prevalent. I show in the next figure that these are often counties in which a major

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<sup>18</sup> 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. <https://www.arc.gov/appalachian-counties-served-by-arc/>

university is located. Before examining the next figure, 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 an inland stretch that begins in north Florida, runs through northeastern Georgia, through inland South Carolina, and ends in inland North Carolina.

I have so far emphasized the most obvious deserts and their opposites, areas where advanced cognitive skills are very prevalent. However, many areas of the U.S. 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.<sup>19</sup> All of them are counties in which at least 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 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.

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<sup>19</sup> To keep the map readable, I have excluded states where Appalachia only runs through a small part of the state.

#### IV. 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 skill 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 non-cognitive 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 society might be willing to invest in programs for children between age 0 and age 3, custodial care is a meaningful problem. Parents may wish to retain greater time with and control over their children at this stage than when their children are adolescents. Many 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.

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 towards 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 (eighteen) and can therefore make location decisions for themselves, it is worth noting that selective migration could take place at much earlier ages. For instance, the family of an early adolescent could deliberately move from an advanced cognitive skills 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 that of the adult map. Here, I work backwards, 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 specific data because, first, I need data for all (or at least nearly all) the counties in the U.S. This rules out the data gathered by NCES (except for the re-scaling use, described below, that I make of the National Assessment of Education Progress (NAEP)). Second, 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 in which the states' own test scores can be put on the 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 re-scaling but far too small for the NAEP's own scores to be mapped.<sup>20</sup> Unfortunately, although the NAEP sample is large enough to be used for re-scaling the average score in each county, it is not large enough for computing each county's re-scaled 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 (i) grades three, five, and eight versus (ii) grade twelve versus (iii) adulthood. It will simply not be possible to state with confidence that the maps' changing patterns only reflect true age-cognition relationships. This weakness motivates the longitudinal empirical exercise that follows the maps.

#### 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 SAT-ACT 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

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<sup>20</sup> I use the re-scaling provided by the Stanford Education Data Archive, Reardon et al (2016).

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 PIACC-based map. These resemblances 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.<sup>21</sup> 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 the 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.<sup>22</sup> The population-

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<sup>21</sup> 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 re-scaled 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 re-scaled. 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, and the method allows us to stick with a measure (NAEP) that is comparable across states.

<sup>22</sup> 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

weighted correlation between a county's adult advanced cognitive skills prevalence and its eighth grade cognitive skills prevalence is 0.67.<sup>23</sup>

The analogous maps for fifth and third grade test scores are shown in Figures 8 and 9. These grades are important because they represent, 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 (non-inland) areas appearing to be deserts while they were not on the twelfth or adult maps. Also northern Florida (a 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

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arguably getting less time. See Schwerdt, West, and Winters (2017).

<sup>23</sup> Keep in mind that 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.

imperfect.

### 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.

(i) 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.

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

(iii) First run the set of age-specific regressions using adults' advanced cognitive skills from the child's *initial* county ( $j, t_0$ ) in the longitudinal data.

(iv) 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.

(v) Repeat the exercise (steps i through iv) 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 iv should demonstrate the degree to which migration matters and age at which important migration tends to occur.

In practice, I combine the no-migration plot from step iv with the migration-allowed plot

from step v.<sup>24</sup>

The regression estimated for each available age in steps i through iv is:<sup>25</sup>

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

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

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

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 U.S. 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.<sup>26</sup>

Figure 10 shows the result of the exercise using, as the dependent variable at each age, a

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<sup>24</sup> 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.

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

<sup>26</sup> I eliminated the National Longitudinal Studies 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. If there is interest among readers, I could add the Early Childhood Longitudinal Study, Birth Cohort which follows children from birth to kindergarten. It contains several measures of cognition.

child's math score behind 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 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 not to affect the coefficients much.

From age 17.5 onwards, 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 account for most of the moves from counties with lower advanced cognitive skill prevalence to higher prevalence.<sup>27</sup> Further migration from age 19.5 to age 26.5 raises the correlation still higher—slightly above 1.0 (possible given the method). This

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<sup>27</sup> This work can be added to the paper if desired. 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.

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

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 (though causality is not established). This influence appears to rise starting in early adolescence (though causality is not established). 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.<sup>28</sup> Studies that rely on the idea that non-experimental 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.

## V. Discussion

### 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 deserts exist where they are far from prevalent. The evidence suggests that deserts have factors that (i) affect adolescents disproportionately and (ii) are associated with a local absence of adults with advanced cognitive skills. These two conditions suggest numerous possibilities. For instance, in a 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 the size needed 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 above are all concerned with education, and this makes sense if we focus on frontal lobe development. However, the frontal lobe also has a disproportionate

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<sup>28</sup> For a credible natural experiment along these lines, see Kawano, Sacerdote, Stevens, and Skimmyhorn (2018).

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 herself or himself. 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 telling, education is merely collateral damage.

Other stories with this omitted variables nature are possible.

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 desert nevertheless has a reasonable probability of attaining advanced cognitive skills. More work is needed to understand why some adolescents are or 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.

#### 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 towards 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 (2018) 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 the same paper in which the authors show associations between declining local manufacturing and rising local opioid use and deaths. Case and Deaton's influential work (2015, 2017, 2020) 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.

If people perceive technical change to be skill-biased (and persistently skill-biased for the foreseeable future), students who reach the end of high school without acquiring advanced cognitive skills may foresee a long future ahead in which demand for their skills is persistently falling while demand for the skills of perceived intellectual elites is persistently rising. This could easily lead to resentment of or distrust in the perceived elites.

Finally, if global trade and/or immigration 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.

Therefore, in the spirit of closing on a speculative note in the hope of inspiring research, I offer two additional maps for readers to compare to the cognitive skills maps in this paper. They use data produced by other studies and are largely self-explanatory.

Figure 12 shows the U.S. county map of the estimated share of adults who believe "most scientists think global warming is happening."<sup>29</sup> 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 question was selected because the answer (yes) can be easily established and is well known.<sup>30</sup>

Figure 13 shows the U.S. county map of the share of votes for Donald J. Trump in 2016.<sup>31</sup>

## VII. References

Baum, Graham L., Zaixu Cui, David R. Roalf, Rastko Ciric, Richard F. Betzel, Bart Larsen, Matthew Cieslak, Philip A. Cook, Cedric H. Xia, Tyler M. Moore, Kosha Ruparel,

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<sup>29</sup> This map is due to Howe, P., Mildenberger, M., Marlon, J., & Leiserowitz, A. (2015) "Geographic variation in opinions on climate change at state and local scales in the USA," Nature Climate Change. DOI: 10.1038/nclimate2583.

<sup>30</sup> The consensus on scientists' 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 *et al* (2016).

<sup>31</sup> This map is due to the MIT Election Data and Science Lab, 2018, "County Presidential Election Returns 2000-2016", Harvard Dataverse, V6. <https://doi.org/10.7910/DVN/VOQCHQ>

- Desmond J. Oathes, Aaron F. Alexander-Bloch, Russell T. Shinohara, Armin Raznahan, Raquel E. Gur, Ruben C. Gur, Danielle S. Bassett, Theodore D. Satterthwaite. 2020. "Development of Structure–function Coupling in Human Brain Networks During Youth," *Proceedings of the National Academy of Sciences*, 117 (1) 771-778.
- Case, Anne and Angus Deaton. 2015. "Rising Midlife Morbidity and Mortality, US Whites," *Proceedings of the National Academy of Sciences*, 112 (49), 15078-15083
- Case, Anne and Angus Deaton. 2017. "Mortality and Morbidity in the 21st Century," *Brookings Papers on Economic Activity*, pp. 397–476.
- Case, Anne and Angus Deaton. 2020. *Deaths of Despair and the Future of Capitalism*. Princeton: 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*, Valerie F. Reyna, Sandra B. Chapman, Michael R. Dougherty, and Jere Confrey, eds. American Psychological Association, pp. 123-152.
- Charles, Kerwin, Erik Hurst, and Mariel Schwartz. 2019. "The Transformation of Manufacturing and the Decline in US Employment," *NBER Macroeconomics Annual* 2018, 33(2019), 307-72.
- Cook, John, Naomi Oreskes, Peter T. Doran, William R. L. Anderegg, Bart Verheggen, Ed W. Maibach, J. Stuart Carlton, Stephan Lewandowsky, Andrew G. Skuce, Sarah A. Green, Dana Nuccitelli, Peter Jacobs, Mark Richardson, Bärbel Winkler, Rob Painting, Ken Rice. 2016. "Consensus on Consensus: a Synthesis of Consensus Estimates on Human-caused Global Warming," *Environmental Research Letters*, 11 048002.

- Couture, Victor, Cecile Gaubert, Jessie Handbury, and Eric Hurst. retrieved 2021. "Income Growth and the Distributional Effects of Urban Spatial Sorting," <https://erikhurst.com/wp-content/uploads/2020/02/welfare-implications-urban-current.pdf>
- Dahl, Ronald E. 2004. "Adolescent Brain Development: A Period of Vulnerabilities and Opportunities," in *Adolescent Brain Development: A Period of Vulnerabilities and Opportunities*, Ronald E. Dahl and Linda Patia Spear, eds. Annals of the New York Academy of Sciences, Vol. 1021, pp. 1-22.
- Forman, Chris. 2013. "How has information technology use shaped the geography of economic activity?," in Frank Giarratani, Geoffrey J.D. Hewings, and Philip McCann, eds., *Handbook of Industry Studies and Economic Geography*, Chapter 10, pages 253-270, Edward Elgar Publishing.
- Giedd, Jay N. 2004. "Structural Magnetic Resonance Imaging of the Adolescent Brain," in *Adolescent Brain Development: A Period of Vulnerabilities and Opportunities*, Ronald E. Dahl and Linda Patia Spear, eds. Annals of the New York Academy of Sciences, Vol. 1021, pp. 77-85.
- Howe, P., Mildenerger, M., Marlon, J., & Leiserowitz, A. 2015. "Geographic variation in opinions on climate change at state and local scales in the USA," *Nature Climate Change*. DOI: 10.1038/nclimate2583. <https://climatecommunication.yale.edu/>
- 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 2013, pp. 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.
- Kolko, Jed, 2007. "Agglomeration and Co-Agglomeration of Services Industries," MPRA Paper 3362, University Library of Munich, Germany.
- Krenzke, T., VanDeKerckhove, W., Thornton, N., Diaz-Hoffmann, L., Hogan, J., Mohadjer, L., Li, L., Li, J., Yamamoto, K., Khorramdel, L., and Ali, U. 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). U.S. Department of Education. Washington, DC: National Center for Education Statistics. Retrieved December 2020, from <https://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2020224>.
- Krenzke, T., Mohadjer, L., Li, J., Erciulescu, A., Fay, R., Ren, W., Van de Kerckhove, W., Li, L., and Rao, J.N.K. 2020. *Program for the International Assessment of Adult Competencies (PIAAC): State and County Estimation Methodology Report* (NCES 2020-225). U.S. Department of Education, National Center for Education Statistics. Washington, DC: U.S. Government Printing Office. Retrieved December 2020 from <https://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2020225>.
- Malamud, Ofer and Abigail Wozniak. 2012. "The Impact of College on Migration: Evidence from the Vietnam Generation," *Journal of Human Resources*. Vol 47 No. 4, pp. 913-950.
- MIT Election Data and Science Lab. 2018. "County Presidential Election Returns 2000-2016", Harvard Dataverse, V6. <https://doi.org/10.7910/DVN/VOQCHQ>
- Mori, Tomoya Mori. 2017. "Agglomeration," KIER Working Papers 960, Kyoto University,

Institute of Economic Research.

National Center for Education Statistics. 2016. Early Childhood Longitudinal Study, Kindergarten Class of 1998-99. Data base for Kindergarten through Eighth Grade. U.S. Department of Education. Washington, DC.

National Center for Education Statistics. 2016. National Education Longitudinal Study. Data base for 1988 through 2000. U.S. Department of Education. Washington, DC.

Piaget, Jean. 1972. "Intellectual Evolution from Adolescence to Adulthood," *Human Development*, Vol. 15, pp. 1-12.

Reardon, Sean F., Demetra Kalogrides, Andrew Ho, Ben Shear Kenneth Shores, and Erin Fahle. 2016. Stanford Education Data Archive. <http://purl.stanford.edu/db586ns4974>.

Reyna, Valerie F., Sandra B. Chapman, Michael R. Dougherty, and Jere Confrey. 2012. "Introduction to The Adolescent Brain: Learning, Reasoning, and Decision Making," in *The Adolescent Brain: Learning, Reasoning, and Decision Making*, Valerie F. Reyna, Sandra B. Chapman, Michael R. Dougherty, and Jere Confrey, eds. American Psychological Association, pp. 123-152.

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*, Volume 152, pages 154-169.

Spear, Linda Patia. 2013. "Adolescent neurodevelopment," *The Journal of Adolescent Health* : Official Publication of the Society for Adolescent Medicine, Vol. 52,2 Suppl 2, pp S7-13.

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

**Figure 1: Male Math Score Transitions, ages 10.5 to 13.5**

| 10 Deciles of Math in Grade 5 (age 10.5 on average) | 10 Deciles of Math in Grade 8 (age 13.5 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  |
| 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 |

Notes: How to interpret this transition matrix? The row labeled “8” shows that a male who scores in decile 8 at age 10.5 has a 6.1% probability of scoring in decile 5 at age 13.5, a 22.7% probability of scoring in decile 8 at age 13.5, and a 10.9% probability of scoring in decile 10 age 13.5. The interpretation of the other cells is analogous, and higher probabilities are associated with darker shading.

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

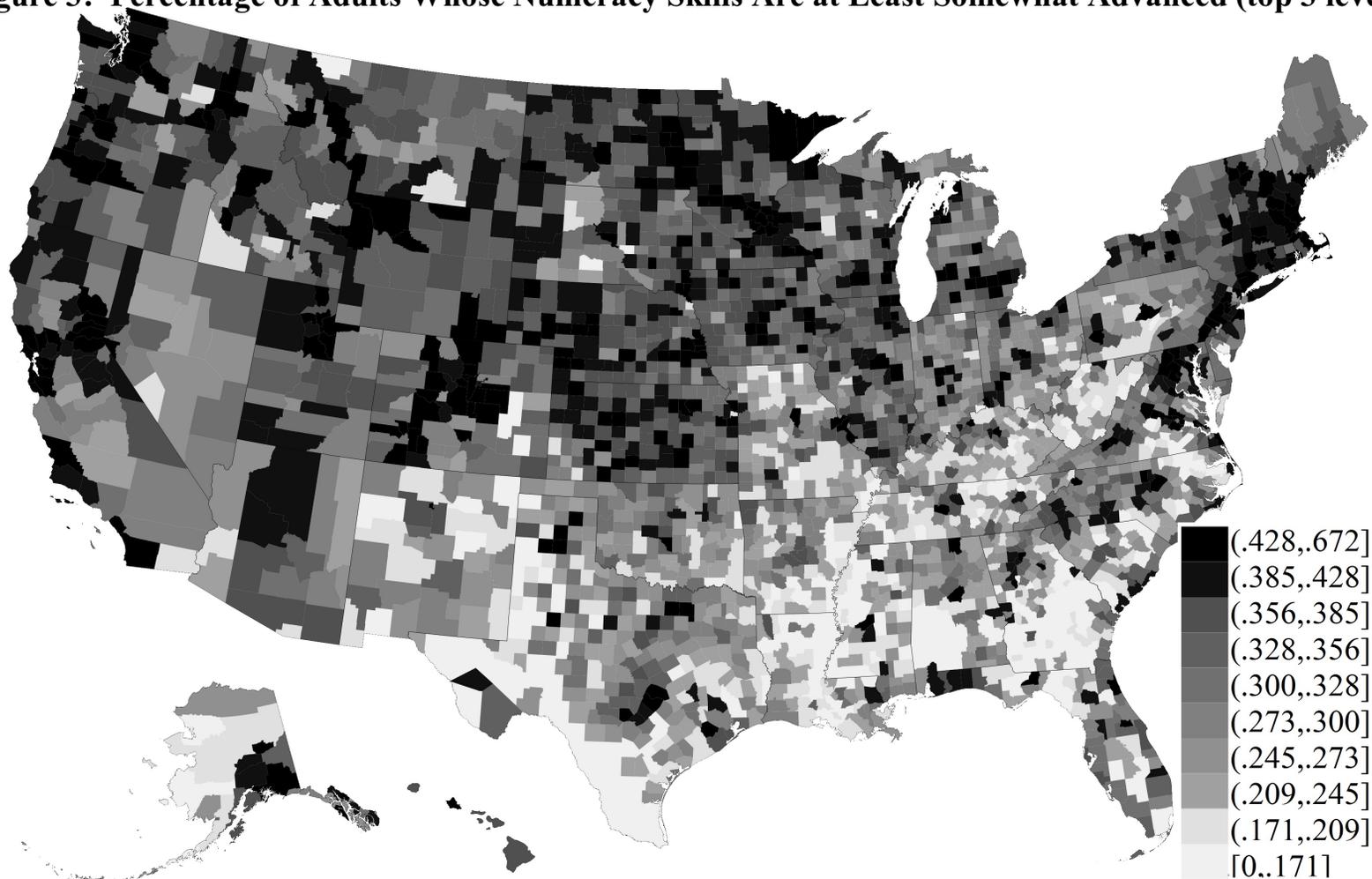
**Figure 2: Male Math Score Transitions, ages 15.5 to 17.5**

| 10 Deciles of Math in Grade 10 (age 15.5 on average) | 10 Deciles of Math in Grade 12 (age 17.5 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  |
| 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 |

Notes: How to interpret this transition matrix? The row labeled “8” shows that a male who scores in decile 8 at age 15.5 has a 2.6% probability of scoring in decile 5 at age 17.5, a 37.5% probability of scoring in decile 8 at age 17.5, and a 70.9% probability of scoring in decile 10 age 17.5. The interpretation of the other cells is analogous, and higher probabilities are associated with darker shading.

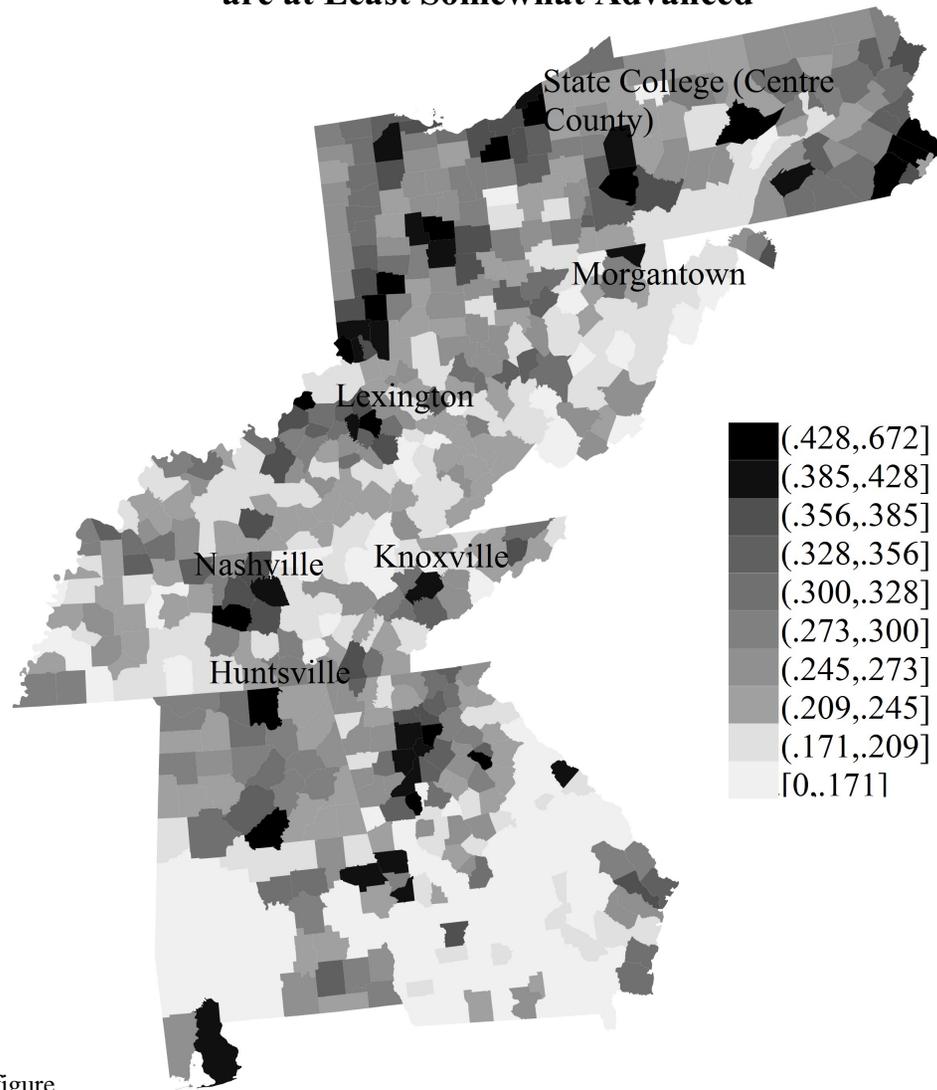
Source: National Education Longitudinal Study—8th Grade onwards.

**Figure 3: Percentage of Adults Whose Numeracy Skills Are at Least Somewhat Advanced (top 3 levels)**

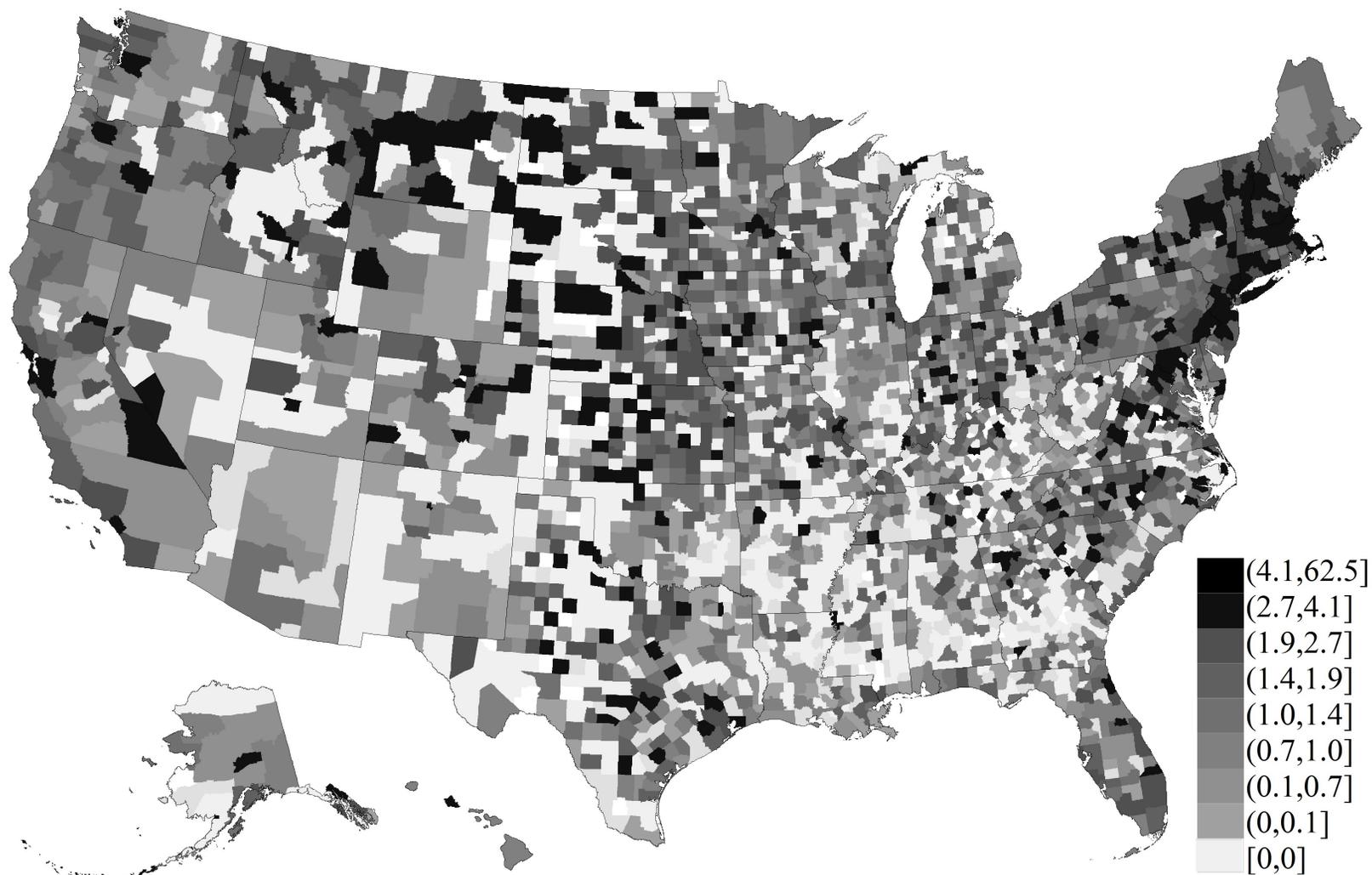


Notes: Adults scoring in the top 3 levels "can be considered proficient at working with math information and ideas. They have a range of numeracy skills from the ability to recognize math relationships and apply proportions to the ability to understand abstract representations of math concepts and engage in complex reasoning about quantities and data." Source: U.S. 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.

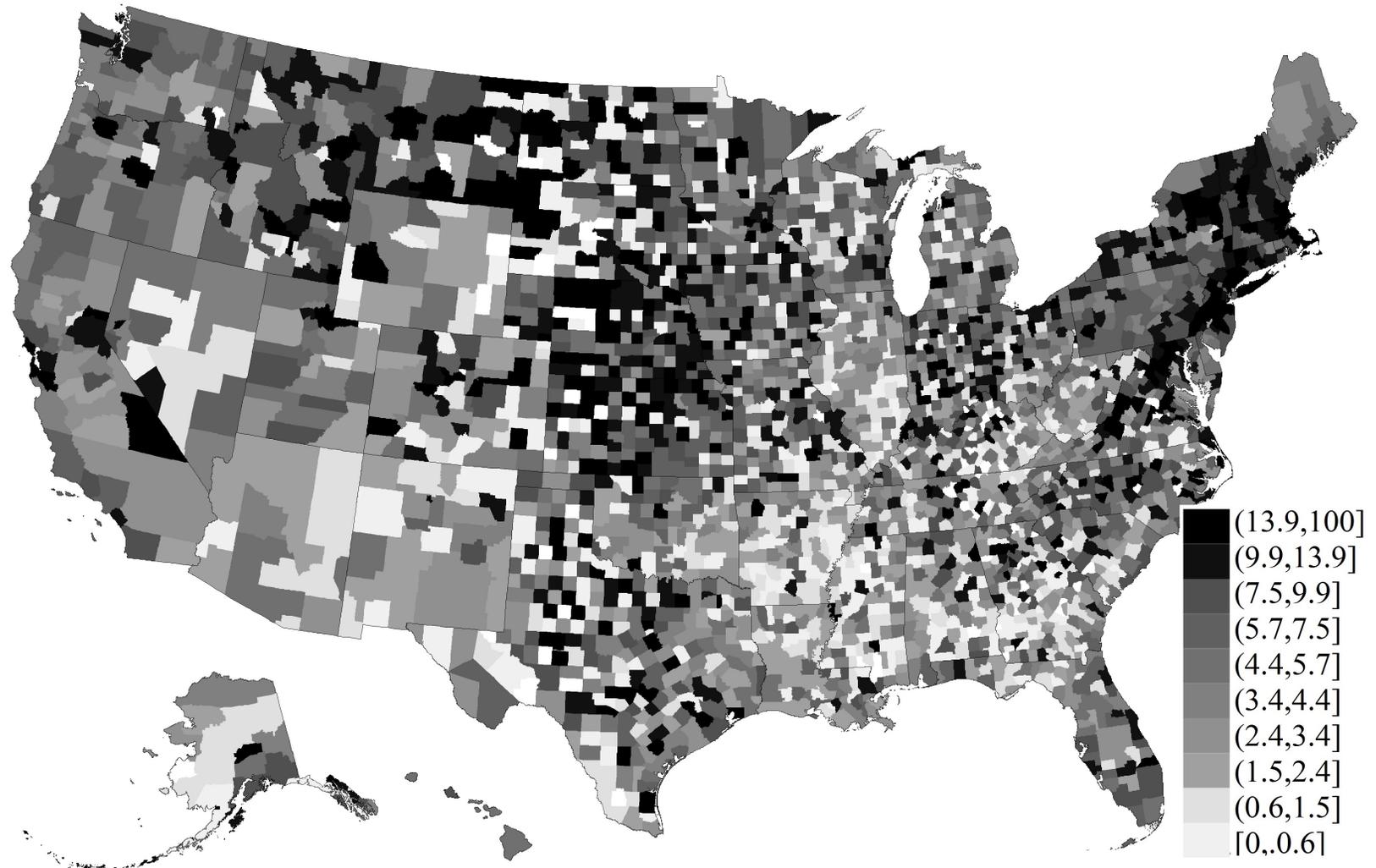
**Figure 4: Percentage of Adults in Certain Appalachian States Whose Numeracy Skills are at Least Somewhat Advanced**



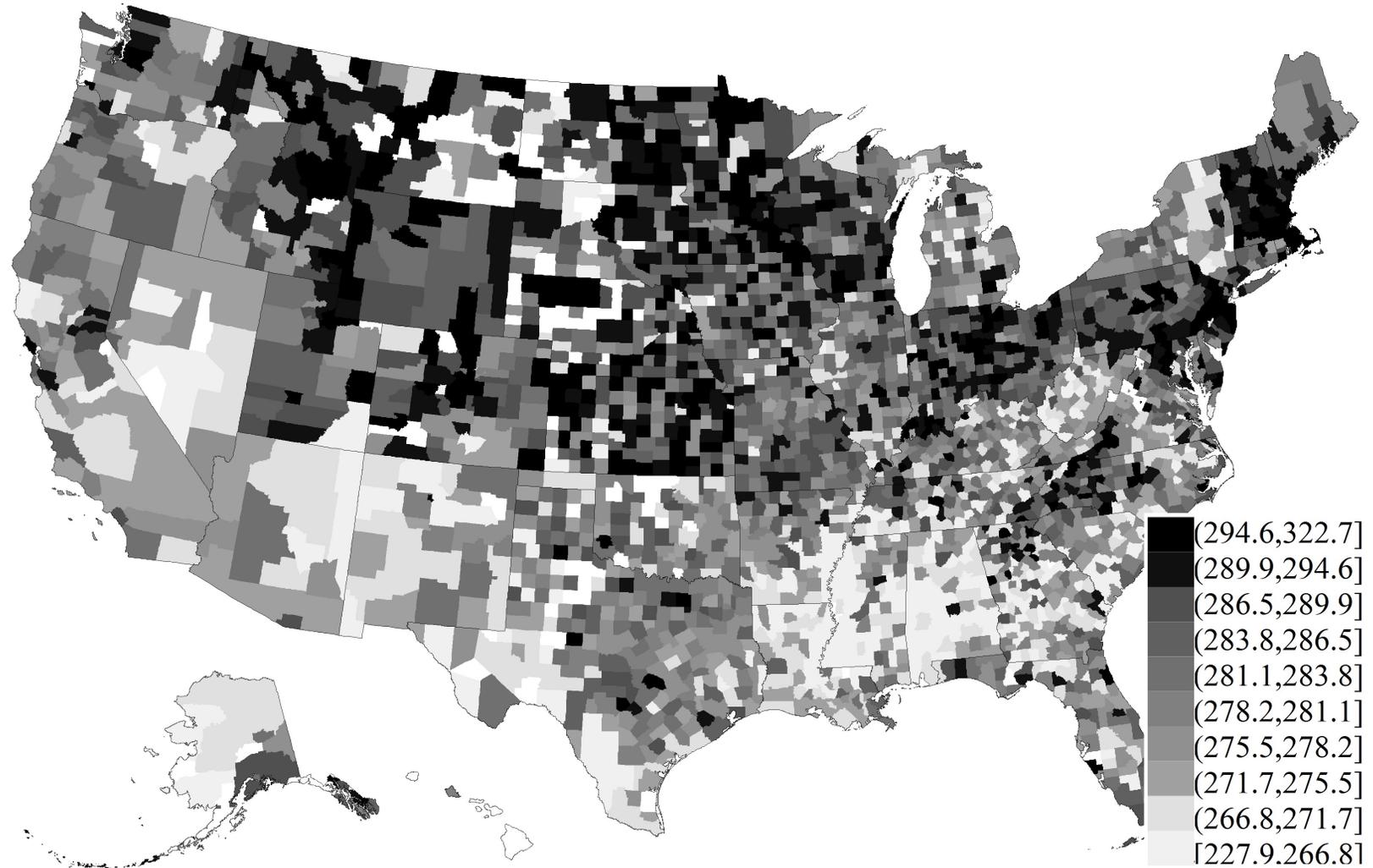
Notes: See notes for the previous figure.

**Figure 5: Percentage of Twelfth Graders Whose Math Skills are At or Above the National 90th Percentile**

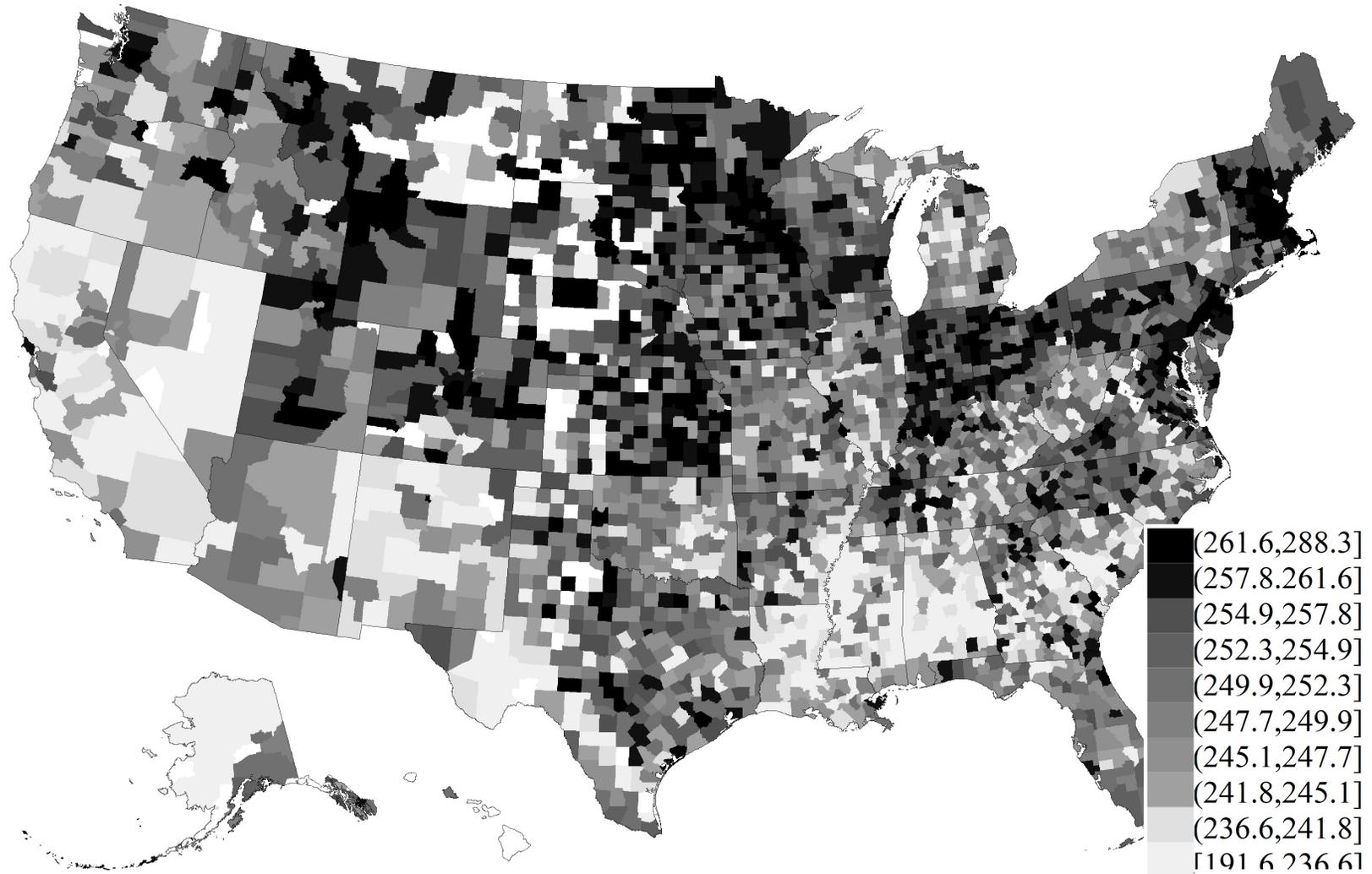
Notes: The map shows, by decile, the percentage of twelfth graders who scored at or above the national 90th percentile on the math SAT, ACT, PSAT, or pre-  
ACT. ACT scores were converted to SAT scores using the official 2008 Concordance. Data source: Hoxby and Avery (2013).

**Figure 6: Percentage of Twelfth Graders Whose Math Skills are At or Above the National 75th Percentile**

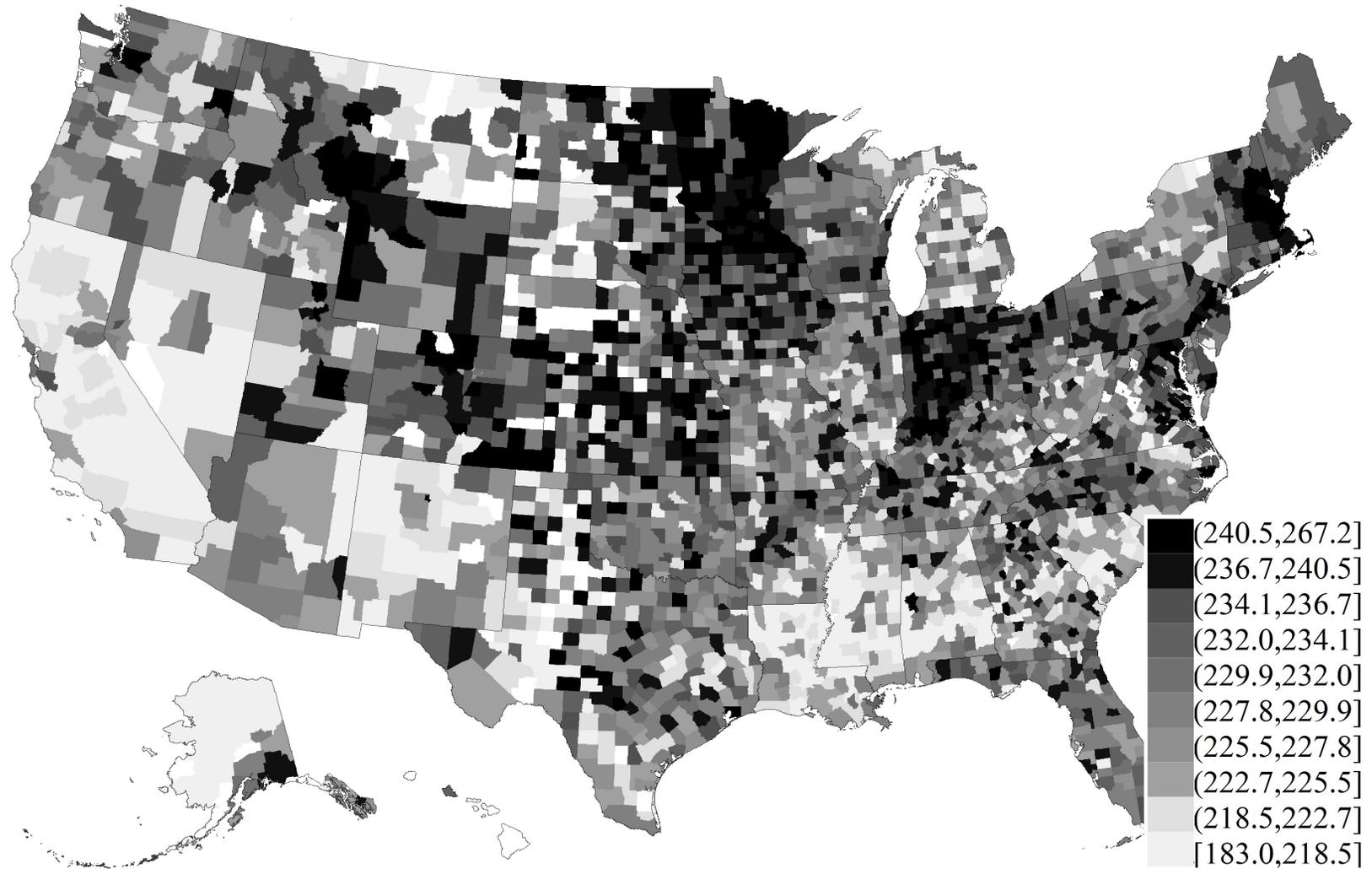
Notes: The map shows, by decile, the percentage of twelfth graders who scored at or above the national 75th percentile on the math SAT, ACT, PSAT, or pre-  
ACT. ACT scores were converted to SAT scores using the official 2008 Concordance. Data source: Hoxby and Avery (2013).

**Figure 7: Average Mathematics Skills of 8th Graders on State Tests (NAEP Scale)**

Notes: The map shows, by decile, the average (combined) math and verbal scores of 8th graders of their own state's test. State test scores are re-scaled onto the National Assessment of Education Progress (NAEP) scale using Reardon *et al* (2016). Data source: Stanford Education Data Archive.

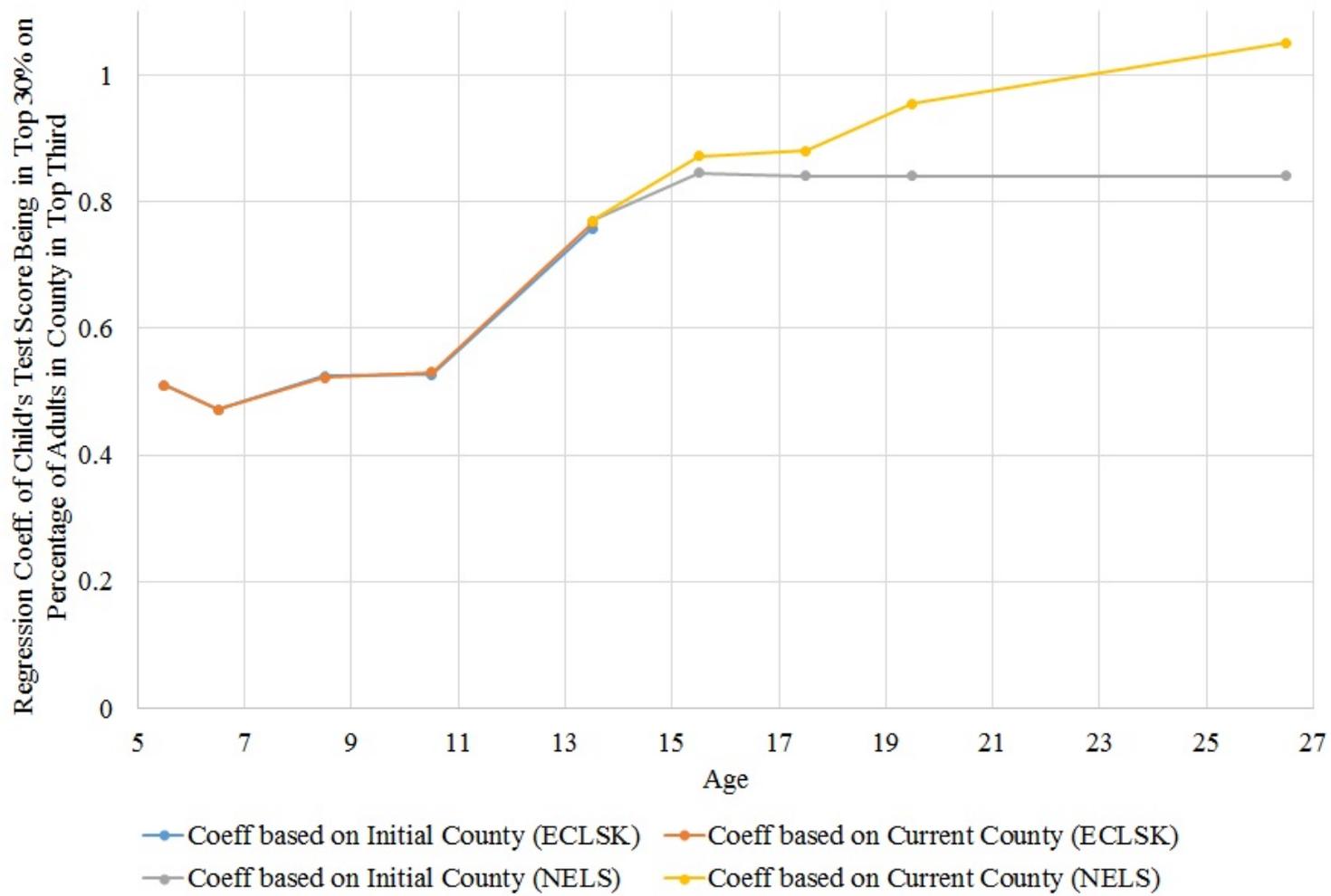
**Figure 8: Average Mathematics Skills of 5th Graders on State Tests (NAEP Scale)**

Notes: The map shows, by decile, the average (combined) math and verbal scores of 5th graders of their own state's test. State test scores are re-scaled onto the National Assessment of Education Progress (NAEP) scale using Reardon *et al* (2016). Data source: Stanford Education Data Archive.

**Figure 9: Average Mathematics Skills of 3rd Graders on State Tests (NAEP Scale)**

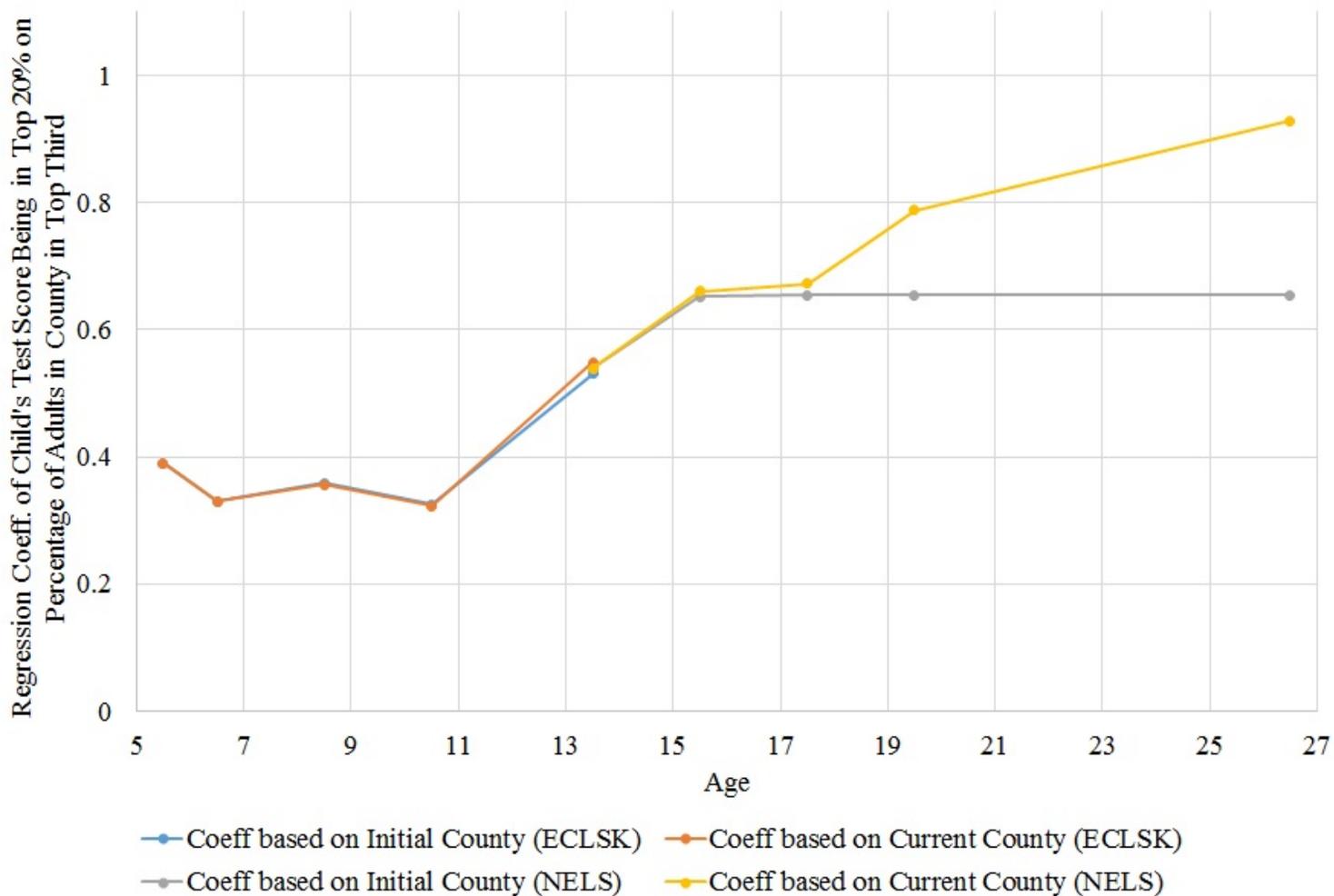
Notes: The map shows, by decile, the average (combined) math and verbal scores of 3rd graders of their own state's test. State test scores are re-scaled onto the National Assessment of Education Progress (NAEP) scale using Reardon *et al* (2016). Data source: Stanford Education Data Archive.

**Figure 10: Results of Regressing a Child's Math Score Being in the Top 30% on the Percentage of Adults in the County with Math Scores in the Top Third**



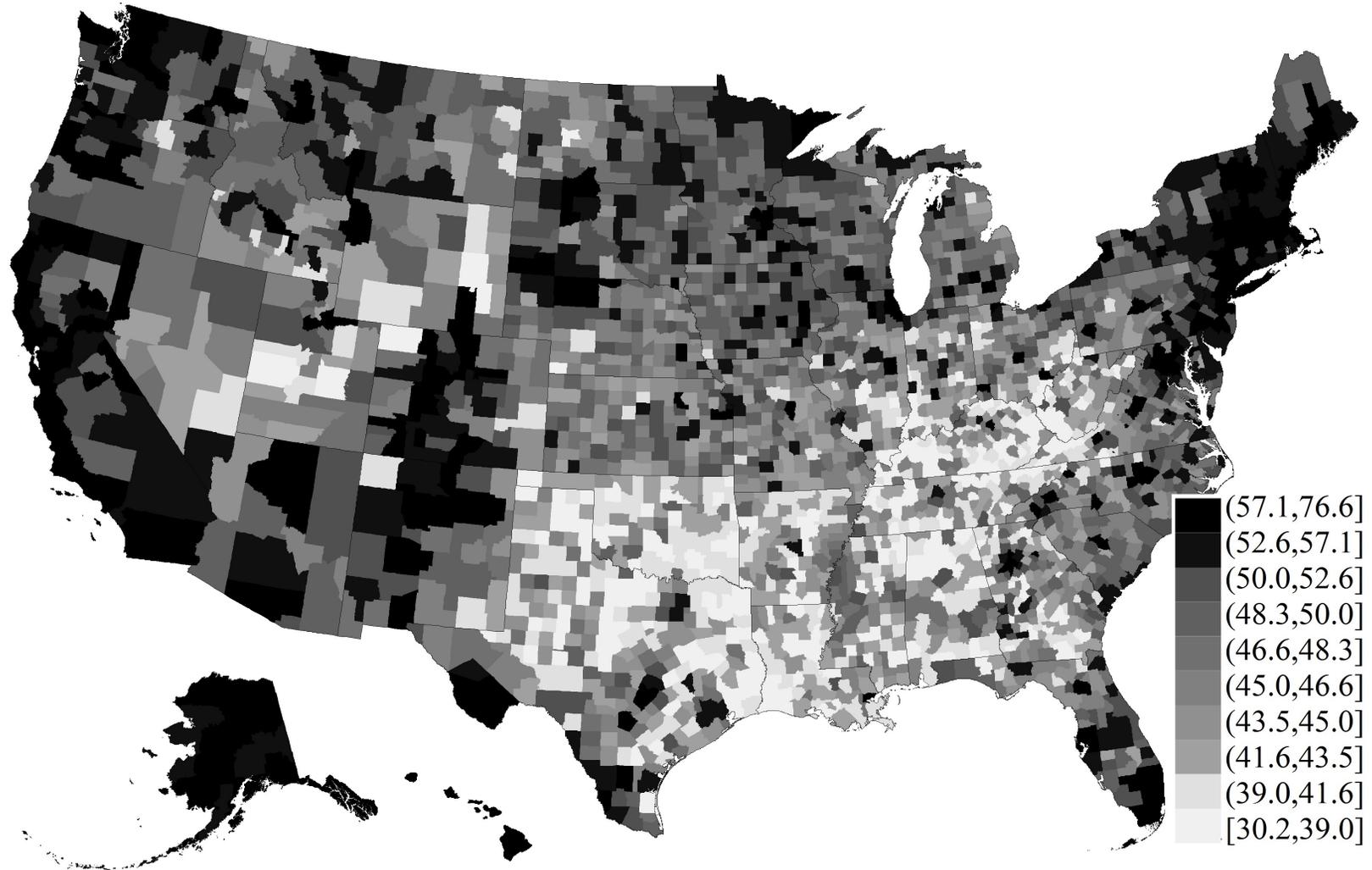
Notes: See text for explanation of the method underlying this chart. Data sources: ECLS-K, NELS, PIAAC.

**Figure 11: Results of Regressing a Child's Math Score Being in the Top 20% on the Percentage of Adults in the County with Math Scores in the Top Third**

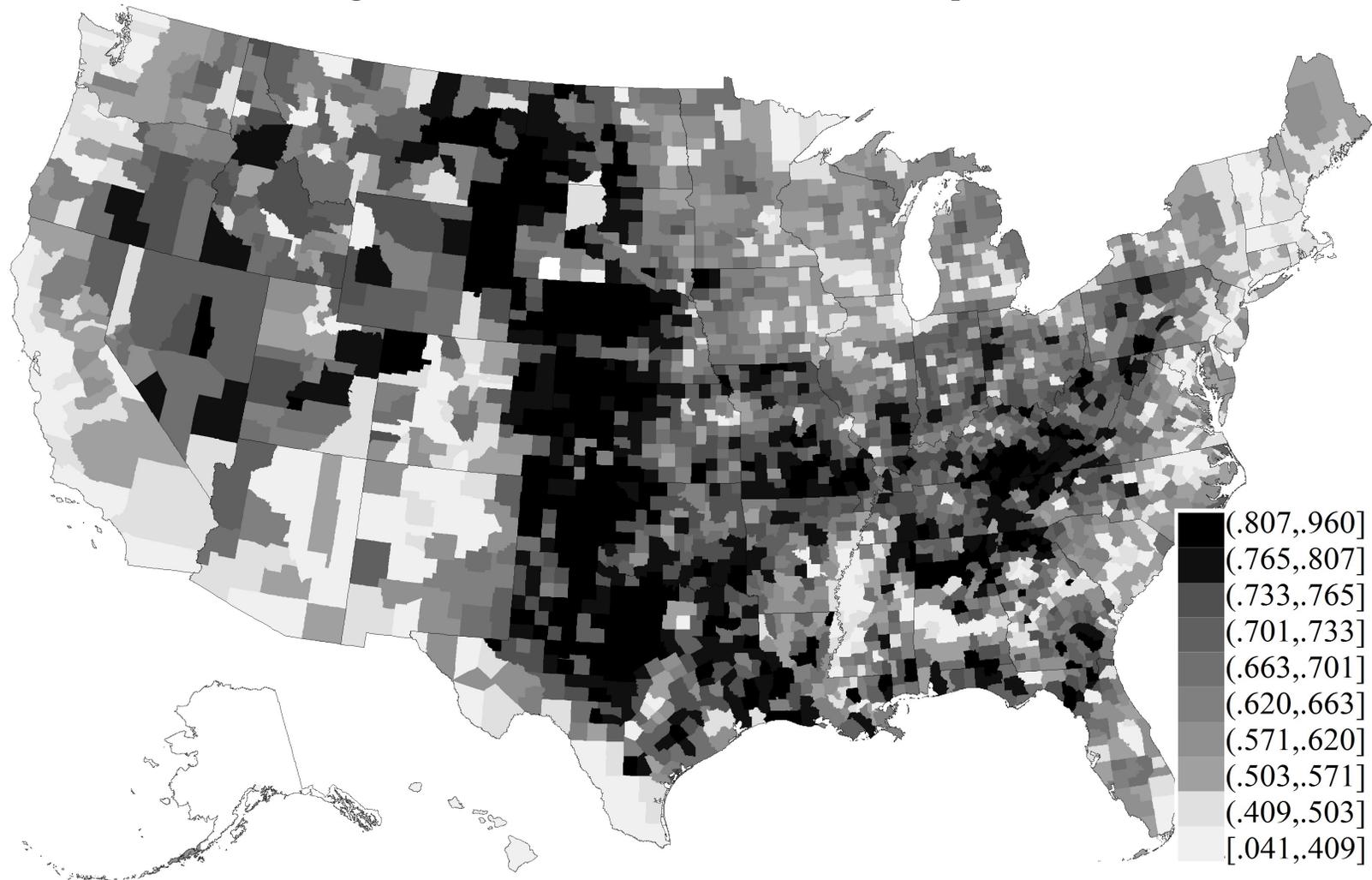


Notes: See text for explanation of the method underlying this chart. Data sources: ECLS-K, NELS, PIAAC.

**Figure 12: Estimated Share of Adults who Believe Most Scientists think Global Warming is Happening**



Notes: The source is Howe, P., Mildenerger, M., Marlon, J., & Leiserowitz, A. (2015) "Geographic variation in opinions on climate change at state and local scales in the USA," Nature Climate Change. DOI: 10.1038/nclimate2583. <https://climatecommunication.yale.edu/>

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

Notes: The source is MIT Election Data and Science Lab, 2018, "County Presidential Election Returns 2000-2016", Harvard Dataverse, V6.  
<https://doi.org/10.7910/DVN/VOQCHQ>

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

|                 | <b>Below Level 1</b> | <b>Level 1</b> | <b>Level 2</b> | <b>Level 3</b> | <b>Level 4</b> | <b>Level 5</b> |
|-----------------|----------------------|----------------|----------------|----------------|----------------|----------------|
| <b>Numeracy</b> | 9%                   | 20%            | 33%            | 27%            | 9%             | 1%             |
| <b>Literacy</b> | 4%                   | 15%            | 33%            | 35%            | 13%            | 1%             |

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."

Source: U.S. 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.