DOES TELEVISION CAUSE AUTISM?

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ABSTRACT

Autism is currently estimated to affect approximately one in every 166 children, yet the cause or causes of the condition are not well understood. One of the current theories concerning the condition is that among a set of children vulnerable to developing the condition because of their underlying genetics, the condition manifests itself when such a child is exposed to a (currently unknown) environmental trigger. In this paper we empirically investigate the hypothesis that early childhood television viewing serves as such a trigger. Using the Bureau of Labor Statistics' American Time Use Survey, we first establish that the amount of television a young child watches is positively related to the amount of precipitation in the child's community. This suggests that, if television is a trigger for autism, then autism should be more prevalent in communities that receive substantial precipitation. We then look at county-level autism data for three states – California, Oregon, and Washington – characterized by high precipitation variability. Employing a variety of tests, we show that in each of the three states (and across all three states when pooled) there is substantial evidence that county autism rates are indeed positively related to county-wide levels of precipitation. In our final set of tests we use California and Pennsylvania data on children born between 1972 and 1989 to show, again consistent with the television as trigger hypothesis, that county autism rates are also positively related to the percentage of households that subscribe to cable television. Our precipitation tests indicate that just under forty percent of autism diagnoses in the three states studied is the result of television watching due to precipitation, while our cable tests indicate that approximately seventeen percent of the growth in autism in California and Pennsylvania during the 1970s and 1980s is due to the growth of cable television. These findings are consistent with early childhood television viewing being an important trigger for autism. We also discuss further tests that can be conducted to explore the hypothesis more directly.

I. INTRODUCTION

One of the major health care crises currently facing the United States is the exploding incidence of autism diagnoses. Thirty years ago it was estimated that roughly one in 2500 children had autism while today it is estimated that approximately one in 166 is diagnosed with the condition – more than a ten-fold increase.[1] In turn, due to the high costs of treating and caring for a typical autistic individual over his or her lifetime, it is estimated that the annual cost to society of autism is thirty-five billion dollars (Ganz 2006). Clearly, the highest priority needs to be given to better understanding what is causing the dramatic increase in diagnoses and, if possible, using that improved knowledge to reverse the trend.

Despite the recent rapid increase in diagnoses and the resulting increased attention the condition has received both in the media and in the medical community, very little is known about what causes the condition. Starting with the work of Rimland (1964), it is well understood that genetics or biology plays an important role, but many in the medical community argue that the increased incidence must be due to an environmental trigger that is becoming more common over time (a few argue that the cause is a widening of the criteria used to diagnose the condition and that the increased incidence is thus illusory). However, there seems to be little consensus and little evidence concerning what the trigger or triggers might be. In this paper we empirically investigate a possibility that has received almost no attention in the medical literature, i.e., that early childhood television watching is an important trigger for the onset of autism.[2]

Although there is very little hard evidence on the subject, many believe that, due to the growth of cable television, VCRs, and DVDs, television watching by very young children has grown dramatically over the last few decades (relevant discussions appear in Kaiser Family Foundation (2003, 2006), Roberts and Foehr (2004), and Anderson and Pempek (2005)). It is

[1] This increase is not confined to the US, but has rather been seen in many countries around the world. For example, in a recent paper Baird et al. (2006) find that in South Thames in the United Kingdom roughly one in every 250 children is autistic and approximately one percent of the population has an autism spectrum disorder (the difference between these terms is discussed in Section II).

[2] We use the term "television" to refer to various activities a young child might participate in where the child views changing electronic images projected onto a screen. These include watching television, watching videos and DVDs, watching movies in a movie theater, and using a computer. Existing evidence on the issue such as found in Kaiser Family Foundation (2003,2006) indicates that almost all of this viewing for children under the age of three, which is the group our analysis focuses on, takes the form of watching television or watching videos and DVDs. See Section IV for a related discussion.

also widely believed in the medical community that television watching is deleterious for very young children.[3] But almost no one in the medical community even speculates that there might be a link between increased television viewing and increased autism, let alone there being any serious empirical investigation of the issue.[4] We are interested in empirically investigating whether or not the increase in autism diagnoses over time is being at least partly driven by an increase in early childhood television watching.

Since there are few studies that directly measure television viewing for the age group we are interested in, we start by identifying a variable that can be measured that is correlated with television viewing by very young children. In particular, we use the Bureau of Labor Statistics' American Time Use Survey (hereafter ATUS) to establish that young childhood television watching is positively correlated with precipitation. This is not surprising. When it rains or snows various outdoor activities such as going to a park become difficult, so it is not surprising that when precipitation is high young children spend more time doing typical indoor activities such as watching television.

After establishing this finding, we then test our hypothesis by using an instrumental variable approach or natural experiment, similar to the method employed in important studies such as Angrist and Krueger (1991), Levitt (1997), and Donohue and Levitt (2001). Basically, if early childhood television watching is a trigger for autism, then our finding that young children watch more television when it rains or snows means that autism rates should be higher in communities that receive a lot of precipitation, and especially among age cohorts within those communities that were exposed to a relatively large amount of precipitation. We test this by first collecting and constructing county-level aggregate and age-specific autism rates and county-

[3] The American Academy of Pediatricians recommends no television viewing for children below the age of two and no more than one to two hours per day for older children (see American Academy of Pediatrics Committee on Public Education (2001)). Also, see Anderson and Pempek (2005) for a survey that discusses the effects of early childhood television viewing on childhood development. As discussed in the latter paper, there is evidence in the literature suggesting that early childhood television viewing hurts language, cognitive, and attentional development. See Section III.B for a related discussion. Anderson and Pempek (2005) makes no mention of any possible connection between early childhood television viewing and autism.

[4] The only scientific papers we have found that suggest that television may be a contributing factor to the increasing incidence of autism are Nair (2004) and Bazar et al. (2006), where the suggestion is not the focus of either paper and neither paper provides any systematic evidence for the hypothesis. The possibility has also recently been put forth in an opinion piece by Gregg Easterbrook in the online magazine *Slate* – see Easterbrook (2006).

level precipitation levels for three states that exhibit high precipitation variability – California, Oregon, and Washington – and then conducting cross-sectional tests and time-series tests including with county fixed-effects. We find that in each of the three states and when all three states are pooled, there is substantial evidence that autism rates are indeed positively correlated with precipitation.

Although consistent with the hypothesis that early childhood television watching is an important trigger for autism, our first main finding is also consistent with another possibility. Specifically, since precipitation is likely correlated with young children spending more time indoors generally, not just young children watching more television, our first main finding could be due to any indoor toxin. Therefore, we also employ a second instrumental variable or natural experiment, that is correlated with early childhood television watching but unlikely to be substantially correlated with time spent indoors.

In our last test we examine whether county autism rates by cohort in California and Pennsylvania for children born between 1972 and 1989 are related to the percentage of households in the county who subscribe to cable television.[5] By offering more channels and channels whose target audience is young children, cable should increase the amount of time young children watch television. Over this time period both the percentage of California and Pennsylvania households connected to cable television and autism rates grew dramatically. If our hypothesis that early childhood television watching is a trigger for autism is correct, then one of the factors increasing the autism rates in California and Pennsylvania during this time period was likely the growth in cable television.

We find that, in each state and when the two states are pooled, the autism rate for a cohort (e.g., children born in Alameda county in 1975) is indeed positively correlated with the percentage of households who subscribed to cable television when the cohort was under the age of three. Note that at some level this is not surprising because both autism and cable households were growing during the time period of our analysis. But in our analysis we control for the overall growth in autism diagnoses over the time period studied using either a time trend or a full set of cohort fixed effects (we also include various other controls). Hence, what is driving our

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[5] To be precise, Pennsylvania provides autism counts for "intermediate units" rather than counties. See Section VI for a discussion.

finding is not the overall growth in cable television during the time period studied, but rather that for each cohort those areas with higher autism rates are on average areas which had higher cable percentages when the cohort was very young. Also, these results persist when we include county fixed effects, in which case our cable coefficient is identified by variation within counties over time in the growth of cable. That is, autism rates grew fastest in California and Pennsylvania among cohorts who grew up when cable rates in their county were also growing fast.

Uisng two different natural experiments, our results strongly support the hypothesis that early childhood television watching is a trigger for autism. Of course, one cannot be sure that early childhood television watching is a trigger for autism without a more direct clinical test. We outline a feasible test in the Conclusion.

As a final introductory point, although our perspective that early childhood television viewing may be an important trigger for autism diverges from current thinking in the autism medical research community, the idea is not inconsistent with current thought in the medical community more generally concerning early childhood development. As discussed in Shonkoff and Phillips (2000) (see also Knudsen et al., 2006), recent scientific findings show "…the importance of early life experiences, as well as the inseparable and highly interactive influences of genetics and environment, on the development of the brain and unfolding of human behavior…" (Shonkoff and Phillips (2000), p. 1). Our hypothesis is that it is exactly the interaction between genetics and a particular type of early life experience, i.e., early childhood television watching, that can result in the profound impact on the development of the brain referred to as autism.

The outline for the paper is as follows. Section II provides a brief primer on autism. Section III discusses four reasons to suspect that early childhood television viewing may be a trigger for autism. In Section IV we use the ATUS to show that early childhood television watching is positively correlated with precipitation. Section V employs county-level aggregate and age-specific autism rates and county-level precipitation levels to show that autism rates are positively correlated with precipitation after controlling for differences in income, population size, and demographic mix. Section VI employs age-specific autism rates and cable household percentages to show that autism is also positively related to cable television. Section VII discusses our findings both in terms of interpretation and implications. Section VIII presents concluding remarks.

II. A BRIEF PRIMER ON AUTISM

In this section we provide a brief primer on various aspects of autism. We begin by describing the nature of the condition. We then describe how the autism rate has varied over time. Finally, we discuss the literature concerning what causes autism. For more in-depth discussions see Baron-Cohen (1993), Wing (2003), and Volkmar et al. (2005).

A) What is Autism?

Autism is one of the conditions in the set of conditions referred to as the autism spectrum (the other conditions are pervasive developmental disorder not otherwise specified (PDD-NOS), Asperger syndrome, and the rare conditions Rett syndrome and childhood disintegrative disorder). We will confine the discussion to autism although some of the discussion in both the media and the medical literature concerning growth of autism is actually referring to the full spectrum.[6]

Autism is a disorder that is associated with deficiencies in three related domains. The first is language and communication. To be classified as autistic there must be a delay during the developmental period in the acquisition of language. If the individual exhibited no delay but shows other deficiencies associated with autism, then the individual is typically classified as having Asperger syndrome – especially when those other conditions are mild. A severely autistic individual will never acquire language. Such individuals are typically not able to function in society independently and eventually require institutionalization of one sort or another. More mild autism is typically associated with eventual language acquisition, but typically the individual shows clear deficiencies in the pragmatic or social use of language. Back and forth conversation is difficult and the individual will frequently discuss one or two topics of interest in an obsessive fashion. There are also a range of other related problems

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[6] What we are referring to as autism in this paper is sometimes referred to as classic autism to distinguish it from other conditions on the autism spectrum. Also, sometimes the set of conditions is referred to as pervasive developmental disorders rather than autism spectrum disorders.

concerning various issues including that facial expressions and gestures frequently do not match what is being said.

The second related domain is social interaction. Not surprisingly, given the deficiencies in pragmatic language skills, even high-functioning autistic individuals typically find social interaction difficult. In addition, there are also a number of other aspects of the disorder that make social interaction difficult. First, autistic individuals have difficulty making appropriate eye contact during social interaction. Second, there is typically a deficiency in interpreting subtle social cues such as smiles, winks, and grimaces. Third, autistic individuals frequently exhibit what is referred to as mind blindness, i.e., they lack a conceptual understanding of what other individuals are thinking. This last characteristic can lead an autistic individual to make unintentional comments that the listener finds insulting (and the autistic speaker will sometimes not understand the nature of the insult even after the fact).

The final major way in which autistic individuals show deficiencies is in terms of repetitive behaviors and obsessive interests. This set of deficiencies takes a number of different forms. One specific way this deficiency manifests itself is in terms of odd repetitive motions such as flapping arms or walking on toes. Another is in terms of a desire for consistency or sameness of everyday routines. For example, an autistic child may demand that he or she leave for school at exactly the same time every day and that exactly the same route be taken, where any deviation concerning either of these dimensions can cause the child to become extremely agitated. The last way this deficiency is manifested is in terms of obsessive interests. For example, an autistic child may become obsessed with a narrow interest such as vacuum cleaners or train schedules or wasps and want to learn everything he or she can about the topic.[7]

There are a few additional aspects of the condition that will be helpful for thinking about later results. First, autism is more common among males than among females. Specifically, typical studies find approximately four males with the condition for every female. Second, the condition is thought to develop at the latest by three years of age. This means that, if there is some environmental trigger that is serving to cause the condition, then we should look for a

[7] There are also various other related problems or deficits that are sometimes associated with autism but that are not considered as central as the three deficits discussed above. These include sensory problems, sleep problems, mental retardation, and seizures.

trigger where exposure occurs prior to the age of three. Third, there is a debate in the literature concerning the fundamental deficit associated with the condition. That is, some argue that, of the various deficits associated with the condition, one serves as the cause of the condition while the others are outcomes of the condition. Various possibilities have been suggested for the cause including that it is what is called an executive function disorder, that mind blindness is the central cause, and that the condition is a severe attention disorder.[8] As will be discussed in detail in the next section, the idea that early childhood television viewing serves as a trigger for autism makes most sense if the condition is a type of attention disorder.

B) Prevalence

Autism was first identified as a condition in a paper by Leo Kanner in 1943. Kanner described eleven young boys he had seen as patients who had significant and similar deficiencies including deficiencies concerning language development, social interaction, and repetitive behaviors. Except for the related paper of Hans Asperger a year later in 1944, there were no other contemporary descriptions of the condition.[9] So, although it is not necessarily the case, it seems reasonable to think that prevalence of the condition was very low both during and prior to this time period.

Over the next few decades the condition was thought to be quite rare and there was no discussion of growth in prevalence. A typical estimate of prevalence say in the 1970s was that autism affected roughly one in 2500 individuals. Most descriptions then point to the early 1990s as the point in time at which prevalence started to grow. In 1991 federal legislation was passed that required states to begin reporting to the US Department of Education the number of school-age autistic individuals and the result was that between the 1992-1993 and 1999-2000 school years – a mere seven years – the reported number of school-age children diagnosed with autism increased by over 400 percent. Clearly, much of this increase was not real but was just due to better reporting. For example, Illinois reported five individuals with autism in the 1992-1993

[8] An executive function disorder is one associated with deficits concerning the ability to plan, organize, and strategize in order to achieve short-term and long-term goals.

[9] The children described by Asperger had more mild symptoms and there were typically no significant delays in language development. Individuals who fit this description, as mentioned above, are said to have Asperger syndrome.

school year while by 1999-2000 it reported 2435 autistic school-aged children, a growth of 48,600 percent. Much of this increase must have occurred because Illinois was not systematically tracking the condition prior to the early 1990s. As a result of similar figures across many states, how much of the reported growth at the national level represents real growth in the underlying condition in the first few years after reporting was mandated is quite unclear.

One might have expected that within a few years after the implementation of the reporting requirement autism rates would have leveled off. But this in fact has not occurred. If, for example, one compares the US Department of Education's reported number of school-aged children diagnosed with autism in 1999-2000 with the similar figure for 2003-2004, one sees that over those four years the reported number has more than doubled. This is unlikely due solely to a change in the reporting requirement.[10] Although many argue that at least part of the more recent change represents a real change in the prevalence of the underlying condition, some argue that this is not the case. Some argue that over time there has been a broadening of the criteria used to diagnose the condition and that, in fact, none of the increase in diagnoses that has occurred over time represents a real increase in prevalence (see, for example, Gernsbacher et al. (2005) and Shattuck (2006)). The results we report later strongly suggest this is not the case.

C) Theories of the Causes of Autism

Early on there were two competing theories for the causes of autism. One theory put forth by Bruno Bettelheim and his followers was the "refrigerator mother" theory (see Bettelheim (1955,1967)).[11] In this theory autism is due to a mother who does not properly bond with the child with the result that the child rejects the mother and winds up living in his or her own world isolated from social interaction. The competing theory, first argued forcefully by Bernard Rimland (1964), was that the condition is biological and thus genetic in nature. Over time as numerous studies found evidence in favor of a genetic component such as the twin study of Folstein and Rutter (1977), Bettelheim's theory eventually became discredited. Since then

[10] As discussed in Gernsbacher et al. (2005), at least part of this increase was in some sense a response to the earlier change in the reporting requirement in that Massachusetts reported a 400 percent increase in 2002-2003 which was primarily due to a change in how the number was calculated (where the previous method of calculation was unchanged since 1992-1993).

[11] This theory can in fact be traced back to some of Kanner's early articles. See, for example, Kanner (1944,1949).

most researchers pay no attention to the potential role that family environment can play in the onset of autism. In fact, some authors claim that scientific findings clearly show that family environment plays no role (see, for example, Powers (2000)). In our reading of the literature, however, we have found no evidence that would support a broad claim that the family environment plays no role whatsoever in the onset of autism.

More recently with the dramatic growth in diagnoses, two possibilities have been discussed. The first is that there are one or more environmental toxins that have become more prevalent over time that serve as triggers for autism. One specific possibility that has been well researched is that there are ingredients in vaccines, such as thermisol which is a mercury-based preservative, that serve this role. But there are a variety of studies that have looked carefully at this hypothesis and found no empirical support (see, for example, Hviid et al. (2003), Institute of Medicine (2004), and Fombonne et al. (2006)). Although there is still some debate concerning this issue, our reading of the literature is that most researchers in the field now believe that the vaccine hypothesis represents a deadend.

A few very recent studies have investigated whether air pollution of various sorts serves as a trigger. In particular, Palmer et al. (2006) and Windham et al. (Forthcoming) find results that suggest that certain types of air pollution serve as important triggers for autism. Although the results are intriguing, these tests to date have been cross-sectional, which leaves open the possibility of a spurious correlation. For example, it is possible that what is driving these results is that families that are more prone to have autistic children for other reasons tend to locate in areas characterized by higher pollution levels. This possibility could be examined using time-series data and a fixed-effects specification, but so far these researchers have not employed this type of methodology.[12] Another drawback is that these studies may not measure the "relevant" pollution level. Since as discussed earlier autism develops by the time a child turns three years old, the most informative test would be to look for a correlation between autism rates and pollution levels when the group being considered was below the age of three. Neither study addresses this concern. In contrast, our tests reported later pay particular attention to this issue.

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[12] However, even a fixed-effects specification could be misleading. Specifically, if television viewing is a trigger for autism and high air pollution causes young children to spend more time indoors and thus watch more television, then a fixed-effects specification would yield a positive correlation between autism and air pollution even if air pollution had no direct effect on autism rates.

The other possibility discussed earlier is that there is no specific environmental trigger because there has, in fact, according to this argument, not been an increase in the prevalence of the underlying condition. The standard argument here is that the increased rate of diagnoses is due to a widening of the criteria used to judge whether or not someone has the condition. One possibility, referred to as "diagnosis substitution," is that over time individuals who in years past would have received a different diagnosis such as mental retardation are now receiving an autism diagnosis with a resulting increase in the reported prevalence of the condition. A number of authors have tried to look at the data to see whether this theory seems plausible, but these studies are mixed in their conclusions.[13]

III. FOUR REASONS TO SUSPECT TELEVISION

In this paper we empirically investigate a theory concerning what causes autism that is closely related to the environmental toxin idea discussed in the previous section. That is, our hypothesis is that a small segment of the population is vulnerable to developing autism because of their underlying biology and that either too much or certain types of early childhood television watching serves as a trigger for the condition. In other words, we are also focused on an environmental trigger but one associated with the family environment rather than a pollutant of the natural environment.

In this section we discuss four reasons that lead us to believe that early childhood television watching might serve this role. These are: i) the California data; ii) the evidence concerning television and attention deficit hyperactivity disorder; iii) the behavior of "high risk" infants; and iv) the Amish. We discuss each of these four reasons separately.

A) The California Data

One reason that looking for an environmental cause of autism is difficult is that the historical data are not very good. If one tries to construct times series data on US autism rates there appears to be a rapid increase starting in the early 1990s. But as discussed earlier, it is unclear whether the early 1990s represents a true date at which a rapid increase in autism rates

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[13] Shattuck (2006) finds support for the diagnosis substitution argument, but earlier papers such as M.I.N.D. Institute (2002), Gurney et al. (2003), and Newschaffer (2005) find no support for this argument.

began. There are two other possibilities. First, the true date is either earlier or later and the early 1990s appears as the starting date because of the US Department of Education's changed reporting requirements in the early 1990s. Second, there has been no change at all in the rate of the underlying condition and the US Department of Education's changed reporting requirements simply created the appearance of a change in autism rates.

One can get around this problem by focusing on California autism rates rather than the national data.[14] In accordance with state legislation passed in 1969, California has twenty-one regional centers that provide services to individuals with developmental disabilities including autism. One can use the data collected at these centers to get evidence concerning the timing of when autism diagnoses began to rise. As shown in Figure 1, these data indicate that autism rates gradually rose during the 1970s and then the growth in autism rates accelerated starting around 1980. For example, although it may have been missed at the time because the increase started from a very low base level, the autism rate calculated by using the number of enrolled individuals with autism at these regional centers in 2005 was about thirty percent higher for individuals born in 1980 than for individuals born in 1970 and then the rate doubled by 1986 and doubled again by 1992.[15]

The timing of this growth matches quite closely with what was likely happening with early childhood television viewing. Three different factors when combined point to the idea that early childhood television viewing probably experienced a gradual increase during the 1970s and then accelerated rapidly starting around 1980. First, although products with similar features were available as early as the 1950s, the VCR did not become a mass market consumer product until the late 1970s and then diffused rapidly in the 1980s. Second, cable television was limited until the early 1970s at which point there was modest growth due to gradual cable deregulation followed by more rapid growth starting around 1980. Also, a number of channels targeted directly at children were introduced in the late 1970s and early 1980s including Nickelodeon

[14] See Department of Developmental Services (1999,2003) for detailed discussions of the California data.

[15] Most of the discussion in the literature concerning early data on autism focuses on the California data. However, there is in fact similar data for Pennsylvania that goes back to the 1970s (we use the Pennsylvania data in our cable analysis in Section VI). This data shows a similar pattern to that found in the California data, i.e., slow growth in the 1970s followed by more rapid growth starting between 1980 and 1985.

(introduced in 1979) and the Disney Channel (introduced in 1983).[16] Third, from 1970 forward there has been a gradual steady increase in the number of households with multiple television sets, where having multiple sets frequently means that a child can watch a children's program while the rest of the household watches a program targeted towards older viewers. Combining these three factors suggests that, similar to the autism data, early childhood television watching should have increased gradually in the 1970s because of gradual increases in cable and multiple-television households, and then growth should have accelerated in the 1980s due to the rapid growth of VCRs and cable and the introduction of cable channels targeted to young audiences. Figure 2 depicts the time series evidence for all three factors.

B) Television and Attention Deficit Hyperactivity Disorder

Attention deficit hyperactivity disorder (hereafter ADHD) is a condition affecting between three and five percent of children in which behavior is characterized by attention, hyperactivity, and impulsivity problems. To be diagnosed with the condition a child has to exhibit the associated behaviors by the age of seven.[17] In a recent paper, Christakis et al. (2004) found a correlation between early childhood television watching and behaviors consistent with a later diagnosis of ADHD. In particular, this study of 1345 children found that an extra hour of daily television watching at ages one and three translates into a ten percent higher probability that the child will exhibit behaviors consistent with ADHD by the time the child reaches the age of seven.

Note that the study, although quite suggestive, is not definitive concerning the effect that early childhood television watching has on the onset of ADHD because of the nature of the methodology employed. In particular, the study does not employ a controlled experiment or a natural experiment to look at the issue. Rather, the authors used evidence from government-sponsored national health surveys to show a correlation between early childhood television watching and behaviors at age seven consistent with a diagnosis of ADHD. The problem is that cause and effect may potentially be the reverse of how the authors interpret their results. That is,

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[16] See Secunda (1990) for a discussion of the early history of the VCR and Mullen (2003) for a history of cable television.
[17] See Barkley (2000) and Wender (2002) for in-depth discussions of ADHD.

rather than early childhood television watching causing ADHD, it is at least possible that children who are likely to develop the condition in the future are more drawn to television and as a result watch more of it.[18]

Despite the drawback of the study discussed above, the results found in Christakis et al. are certainly suggestive of the idea that early childhood television watching is a cause or trigger for ADHD. The reason we feel this is of interest is that, as discussed briefly earlier, one of the main hypotheses concerning the fundamental deficit in autism is that at its core it is an attention disorder and the other deficits associated with the condition are mostly outcomes of the problems concerning attention. In turn, if this is the case, then the results found in Christakis et al. are suggestive of the idea that early childhood television watching could also be a trigger for autism. That is, if in the general population early childhood television watching serves as a trigger for ADHD, it seems plausible that for a small segment of the population who are vulnerable because of their biology or genetics early childhood television watching may serve as a trigger for the more severe attention disorder called autism.

C) <u>The Behavior of "High Risk" Infants</u>

Our hypothesis that early childhood television watching is a trigger for autism is more plausible if infants who are at "high risk" of becoming autistic exhibit behaviors consistent with a high vulnerability to television viewing. For example, such a behavior might be that high risk children have more difficulty disengaging from watching television once they begin watching. A recent study by Zwaigenbaum et al. (2005) suggests that this may indeed be the case.

The idea that there is a clear genetic component to autism means that an infant with an older sibling with autism has a higher probability of developing the condition than an infant with no close relatives with autism. Zwaigenbaum et al. use this idea to identify differences in behavior in the first years of life between those who are at high risk of developing autism, i.e., those with an older autistic sibling, and those at low risk, i.e., those without a close relative with autism. In particular, they follow from six months of age up to twenty-four months of age a

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[18] There is a more recent study that find results inconsistent with a strong correlation between television viewing and ADHD – see Stevens and Mulsow (2006). However, since this more recent study considers television watching at an older age – television viewing time by kindergartners – this study does not in fact address the same issue as Christakis et al. which is the correlation between <u>early</u> childhood television watching and ADHD.

group of high-risk infants and a group of low-risk infants, where risk is defined as above. Further, one of the behaviors they focus on is what they refer to as "disengagement of visual attention," i.e., how quickly does the child disengage from a screen showing "colorful dynamic stimuli" when another similar visual stimulus is introduced into the environment. It seems plausible that children who exhibit the type of slower disengagement found by Zwaigenbaum et al. will also be slower to disengage from television viewing once viewing has begun and, as a result, any negative effects of television viewing may manifest themselves in a more extreme way. In other words, if exposure to television during early childhood causes attention problems as the work of Christakis et al. (2004) suggests, it is possible that those who exhibit slower disengagement will on average have more severe attention problems as a result of early childhood television exposure.

Zwaigenbaum et al. find that: i) at six months of age the high-risk group exhibits slower disengagement than the low-risk group; ii) the high-risk group shows less improvement on speed of disengagement between six and twelve months of age than the low-risk group; and iii) within the high-risk group the amount of improvement between six and twelve months of age is a significant predictor of whether or not the child develops autism by the age of three.[19] Although far from definitive, all three findings are consistent with the idea that television has a more significant effect on infants at high risk of autism than on others.

D) <u>The Amish</u>

The California data discussed above indicate that the longest time-series data on autism rates is consistent with the hypothesis that early childhood television watching is a trigger for autism. A related issue is, does there exist similar cross-sectional evidence concerning autism rates and, if there does, is it also consistent with our hypothesis? For example, is there a group in the population whose young children watch significantly less television than the average and, if there is, what do we know about autism rates for that population?

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[19] The first of these findings is not statistically significant at standard confidence levels. But given that on average at six months of age the high-risk group took thirty percent longer to disengage than the low-risk group, the lack of statistical significance is more likely due to small sample sizes (sixty-five high-risk infants and twenty-three low-risk infants) than to the possibility that there is no statistically important relationship between disengagement and group type.

For religious reasons the Amish do not use electricity and so young children in that population watch no or at most very little television. Thus, our hypothesis that early childhood television watching is an important trigger for autism suggests that autism rates among the Amish should be distinctly lower than in the rest of the population.

Interestingly, there has recently been an investigation of this issue. Dan Olmsted, a news reporter for United Press International, recently conducted an informal investigation of this issue (see Olmsted (2005a,b)). According to Olmsted, based on autism rates for the general population, there should be several hundred autistic individuals among the Amish. After extensive investigation, however, Olmsted was able to identify fewer than ten. Also, his interviews with individuals who should be in positions to know the general prevalence rate, such as doctors, health care workers, and an Amish mother of an adopted autistic child, indicate that the prevalence of autism among the Amish is indeed very low.[20]

Of course, this is far from definitive evidence for our hypothesis. Olmsted's investigation was informal and possibly a more thorough investigation would turn up the expected hundreds of autistic Amish. Or possibly, since the Amish lifestyle is quite different in many ways – think about what your life would be like if you could not use electricity – there is some other trigger for autism and the Amish lifestyle results in less exposure to this trigger than the typical lifestyle (see footnote 18 for a related discussion). Or, since the Amish represent a relatively isolated gene pool, it is possible that the Amish have less autism because the genes that cause the condition exist at a much lower frequency in that population. Nevertheless, even given all these caveats, Olmsted's findings do represent intriguing evidence consistent with our hypothesis.

IV. EARLY CHILDHOOD TELEVISION WATCHING AND PRECIPITATION

In the previous section we discussed four reasons why we suspect early childhood television watching may be a trigger for autism. In this section we begin our empirical investigation of the hypothesis. Specifically, in this section we use the Bureau of Labor

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[20] Olmsted conducted his investigation to test the hypothesis that vaccinations serve as a trigger for autism. His logic was that since vaccinations are rare among the Amish, if vaccinations are indeed a trigger then autism among the Amish should be low. But as discussed briefly earlier, there have been a number of comprehensive studies of the vaccination hypothesis and these studies find no support.

Statistics' American Time Use Survey, or ATUS, to investigate whether early childhood television watching is positively correlated with precipitation. We show that indeed precipitation is an important determinant of television watching for young children. In the next section we then use this finding to test whether early childhood television watching is a trigger for autism.

A) Data

The test conducted in this section employs two types of data. The first is data taken from the ATUS (see Hamermesh, Frazis, and Stewart (2005) for a detailed description of the ATUS). The Bureau of Labor Statistics started conducting the ATUS in 2003 and we use the first wave of the survey which took place in 2003. The survey asks individuals to record detailed information concerning his or her activities during a specific day, including who else in the household is present during each activity.

We are interested in the cumulative amount of television watching for children under the age of three, but the survey only contacts adults. Our approach, therefore, is to focus on respondents for whom there is a child under three in the household, where our television viewing variable is the total amount of time measured in minutes that the respondent watched television with the child present during the survey day (if the household has more than one child under the age of three, then each child is treated as a separate observation). Clearly, this technique cannot be used to measure total television watching by the child. But it will allow us to look at whether television watching is positively correlated with precipitation which is our focus.[21]

We use two different definitions of what constitutes television watching, which we refer to as narrow and wide. The narrow definition includes all activities that involve looking at a

[21] To be precise, we actually measure exposure to television rather than actual television watching since the ATUS does not tell us whether the child is actually watching the screen. However, since there should be a strong positive correlation between the number of minutes that a young child is exposed to a television screen and the number of minutes of television that the child actually watches, we do not think the fact that we have a measure of exposure rather than watching has any significant implications for our analysis. Note further, our estimates for total television viewing for children under three years of age are intermediate in terms of estimates already in the literature. For example, in our sample average daily television watching by children under the age of two is sixty-three minutes, while Kaiser Family Foundation (2006) find that average daily television watching for this age group is forty-nine minutes. On the other hand, Christakis et al. (2004) report that children at age one and a half watch 2.2 hours per day, which is more than double television watching for one-year olds in our sample.

television screen. This includes watching television, watching DVD/video movies, and watching home movies and home videos. In the wide definition we add in computer use for leisure and attending movies and films.[22]

As indicated, our television watching variable is the respondent's cumulative amount of television watching in minutes when the child is present. For each survey respondent we also record household characteristics including household income level, household type (a list of household types appears in the Appendix), and race/ethnicity. We also record the MSA/PMSA of the respondent (we restrict our sample to respondents for whom there is an MSA/PMSA and it is known) and the date of the survey.[23] As discussed next, by recording the location of the respondent and the date of the survey we are able to construct measures of the weather at the respondent's location on the day of the survey, where our main focus is the amount of precipitation.

We use raw data taken from the National Climactic Data Center to construct our precipitation variable. The National Climactic Data Center has daily weather data for over 8000 weather stations across the United States. Our precipitation variable is constructed as follows. For each data point, i.e., each survey response, we first calculate the amount of precipitation that fell on the day of the survey for each county in the MSA/PMSA of the respondent by averaging across the amounts at all the weather stations in the county. We then calculate an average precipitation level for the MSA/PMSA on the day of the survey by averaging the precipitation levels for all of the counties weighted by the year 2003 county population of children under the age of five as estimated by the US Census Bureau (the Census Bureau provides estimates by age groups at the county level not by individual ages).

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[22] The ATUS does not allow us to exactly identify activities associated with watching a television-like screen because the survey groups activities in a way that is not optimal for this purpose. For example, the television/movies category includes time spent borrowing movies from the library and returning movies to the library. Also, we are not able to include time spent playing computer games because this activity is grouped with other game playing activities such as playing Scrabble and working on jigsaw puzzles. However, as discussed later in this section, our results are quite consistent with what has been found elsewhere concerning how various factors such as race and ethnicity affect childhood television watching in general, which suggests that our methodology is a valid one for identifying how various factors affect early childhood television watching.

[23] MSA refers to Metropolitan Statistical Area while PMSA refers to Primary Metropolitan Statistical Area.

Although not part of our analysis of autism rates in Section V, we employ a second weather variable in our analysis of television watching in this section.[24] Specifically, we allow for the possibility that television watching by young children is correlated with the number of hours of daylight on the day of the survey at the survey location. The logic here is that a young child is more likely to be indoors when the sun is down and television watching is mostly an indoor activity. So our hypothesis is that television watching should be negatively correlated with hours of daylight. The reason we do not use this variable in next section's analysis of autism rates is that the average number of daylight hours over a year does not vary in a significant fashion across locations. We construct our daylight variable by using the formula in Forsyth et al. (1995) which provides number of hours of daylight as a function of latitude of a location and calendar day.

B) Tests and Results

In this subsection we investigate our hypothesis that early childhood television watching is positively correlated with precipitation for children under the age of three. The reason we focus on this age group is that, as discussed earlier, for a child to be considered autistic the condition must develop before the child reaches three years of age. So, if early childhood television viewing is a trigger for autism, the relevant viewing should be that which occurs before the age of three.

There is some evidence that television viewing for older children is positively correlated with bad weather (see Zwaga (2000)). But because there is little systematic evidence concerning the television viewing habits of very young children it is not surprising that whether bad weather or more specifically precipitation increases the television viewing of very young children has not been established. Our analysis shows that indeed increased precipitation does result in increased television viewing by children under three years of age.

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[24] We also investigated a third weather variable, i.e., average temperature in the location of the respondent on the day of the survey. This variable was constructed in much the same way as the precipitation variable. Our analysis showed that early childhood television watching is not correlated with average temperature, so to simplify the analysis we report results that do not contain the temperature variable. Including this variable did not have any effect on the qualitative nature of the results concerning other variables.

In our tests, in addition to including precipitation and hours of daylight, we include a number of control variables that are likely to have an effect on the amount of television the child watches. A number of our control variables come from results found in the recent study of Roberts and Foehr (2004) which is probably the most comprehensive existing study of the use of television and related media by children. First, since Roberts and Foehr find that television exposure for their youngest age group is negatively related to family income, we include household income as a control variable. Second, since Roberts and Foehr find that television exposure for their youngest age group is negatively related to the education level of the parents, we include a dummy variable that captures whether the adult respondent has a college degree. Third, since Roberts and Foehr find that television exposure for their youngest group is higher for Blacks and Hispanics than for Whites, we include race and ethnicity dummies. Fourth, since Roberts and Foehr find that for their youngest group television exposure is higher for males than females, we also include a dummy variable that captures the gender of the child. [25]

We also include a number of other control variables. First, we include a dummy variable for whether or not the survey date was on a weekend, where our prediction is that the adult respondent on average should be home more hours on a weekend day versus a weekday so measured television viewing should be higher. Second, we include a dummy variable for whether or not the adult respondent is working the day of the survey, where similar to the logic of the weekend dummy our prediction is that the respondent should be home less hours on a workday so measured television viewing for the child should be lower. Third, we include a gender dummy for the adult respondent where we conjecture that the proportion of time the respondent spends with the child may be higher when the respondent is female, so measured television time may be higher when the respondent is female. Fourth, we control for household type such as whether the household is a military family or a non-military family. Fifth, we control for the MSA/PMSA of the respondent since television watching time may vary with location specific factors such as the types of cable systems available in the MSA/PMSA and the

[25] Roberts and Foehr (2004) is based on a national random sample of US children's and adolescents' media use conducted by the Kaiser Family Foundation. Note, the youngest age in Robert and Foehr sample is two, but they typically report their results by age group such as two to four or two to seven. Kaiser Family Foundation (2003, 2006) are related studies focused on samples of younger children, but those analyses are less comprehensive than found in Roberts and Foehr's study. However, the 2006 study does find that television viewing for children under two is higher for males than females.

number and quality of parks in the MSA/PMSA.[26] Because we include MSA/PMSA controls, the coefficients on the precipitation variables are identified by variation in the amount of precipitation that occurred on the survey dates for surveys conducted within the same metropolitan area. Table 1 reports sample statistics for this section's analysis.

We consider the specification given in equation (1).

$$TV_i = \beta_1 + \beta_2 PRCP_i + \beta_3 PRCP_i^2 + \boldsymbol{\beta_4 X_i} + \boldsymbol{\beta_5 Z_i} + \varepsilon_i \quad (1)$$

TV_i is measured television viewing time of the child, $PRCP_i$ is measured precipitation at the respondent's location on the day of the survey, $\mathbf{X_i}$ is a vector of individual and family control variables, $\mathbf{Z_j}$ is a vector of MSA/PMSA dummy variables, and ε_i is an error term. Note that our specification allows the incremental effect of precipitation on television viewing to change as precipitation rises. This captures that once a child spends all day indoors because of precipitation, a further increase in the number of inches of precipitation has no further effect on the amount of television viewing. We run four regressions. First, as discussed above we consider both narrow and wide definitions of television viewing time. Second, for each definition of television viewing time, we consider both ordinary least squares and a Tobit specification. The rationale for a Tobit regression is that television viewing time equals zero for over fifty percent of the observations.

The results for equation (1) are reported in Table 2. Consider first the control variables (note that the table does not report the MSA/PMSA coefficients). Most of these coefficients have the predicted signs and many are statistically significant at standard confidence levels. First, the daylight coefficients, the work coefficients, and the education coefficients each have the predicted sign in all four regressions and are statistically significant at the five percent level in all four regressions (the work and education coefficient are in fact consistently statistically significant at much higher confidence levels). Second, although not reported in the table, the

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[26] We also considered whether television viewing varies with the age of the child. Based on results found in Kaiser Family Foundation (2006), our prediction was that for children under three television viewing should be positively related to age. Our analysis of this issue showed no statistically significant differences between the television watching time of very young children of different ages (one possibility for why we do not find any significant differences here is that the proportion of early childhood television watching with an adult present varies negatively with age and, because of our methodology, this negates the increase in actual television watching as a child ages). To keep the analysis easy to follow, we omit these results from what we report in this section. Note that including this variable did not have any effect on the qualitative nature of the results concerning other variables.

coefficients on the fifteen income indicator variables are generally consistent with the prediction, i.e., television viewing time decreases with household income. Third, the weekend coefficient consistently has the predicted sign and is significant at the ten percent level in three of the four regressions. Fourth, the signs of the Black and Hispanic coefficients are consistent with the predictions, although each coefficient is only statistically significant at the ten percent confidence level in one of the four regressions. Also, a result that was not predicted is that indigenous groups (American Indian, Alaskan Native, and Hawaiian/Pacific Islander) have lower television watching and the coefficient is statistically significant at the five percent level in all four regressions. Fifth, household type seems not to matter except that television viewing is lower for military families, where this coefficient is statistically significant at the five percent level in two of the regressions and statistically significant at the ten percent level in the other two regressions.

The remaining two control variables are the gender controls. Inconsistent with the prediction, measured television viewing is sometimes higher and sometimes lower when the adult respondent is female and the coefficient is never statistically significant at standard confidence levels. On the other hand, consistent with the prediction, measured television viewing is always higher when the child is male, where in two of the four regressions the coefficient is significant at the five percent level, while in the other two it is not significant at standard confidence levels. Further, the increase is also significant in an absolute sense. For example, the OLS regressions indicate that being male increases television viewing by over ten percent. Note that the finding that very young male children watch more television than very young females is of particular interest given the higher incidence of autism in males relative females. In other words, if early childhood television watching is a trigger for autism (which is what the results in the next section suggest), then the finding that very young males watch more television could mean that one reason that autism is more common among males is exactly because of the higher television watching.

The fact that so many of the results concerning the control variables are consistent with the predictions suggests that our methodology is a valid one for identifying which factors are positively correlated with early childhood television watching and which are negatively correlated. We now turn to the variable of interest which is precipitation. The coefficients on both precipitation and the precipitation-squared term have the predicted signs in all four regressions, where the coefficients on the precipitation variable are statistically significant at the one percent level in all four regressions while those on the precipitation-squared variable are statistically significant at the five percent level in all four regressions.

Further, the coefficients on the precipitation variables in these two tables are significant in an absolute sense in addition to a statistical one. For example, in the Table 2 ordinary least squares regression that uses the broad definition of television watching, the coefficients indicate that a young child watches about twenty seven more minutes of television on a day when precipitation equals one inch relative to a day with no precipitation (one inch of precipitation is the equivalent of a heavy day of rain). Since average television viewing by children in our sample is approximate sixty minutes, this result suggests that increasing precipitation from zero to one inch represents a substantial proportional increase in television viewing due to precipitation.[27] In other words, the results in this section indicate that precipitation causes increases in early childhood television watching both from statisical and absolute perspectives, and thus, that precipitation should be a valid instrument for testing the effect that early childhood television watching has on rates of autism.[28]

V. AUTISM AND PRECIPITATION

In this section we employ the finding of the previous section that precipitation is positively correlated with early childhood television watching to test the hypothesis that early childhood television watching is a trigger for autism. That is, given that early childhood television watching is higher when precipitation is higher, if such watching is indeed a trigger for autism then the autism rate itself should be positively correlated with precipitation.

To test the hypothesis we focus on three states that have a high level of precipitation variability across counties – California, Oregon, and Washington. Because of the Cascade

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[27] If we were to use the marginal effects from the Tobit specification that employs the broad definition of television viewing, then the predicted increase in television watching due to an inch of precipitation is seventeen minutes.

[28] There is one drawback of this part of our study which is that here we show that daily television viewing is positively related to daily precipitation, while in the next section our focus is on the correlation between annual precipitation levels and autism. Unfortunately, we do not know of any data set that would allow us to investigate the relationship between annual precipitation and television watching for children under three.

Mountains that run north to south across the middle of Oregon and Washington, each state is characterized by vastly different precipitation patterns across the different regions of the state. Counties in each state that lie west of the mountains and on or near the coast are characterized by heavy precipitation, while counties in the eastern part of each state that are east of the mountains and far from the coast are dry (see Figures 3 and 4). In particular, for both Oregon and Washington, the counties west of the Cascades have approximately 3.8 times more rain, on average, than counties east of the mountains. We also include California in our analysis because precipitation variability in this state is also substantial (see Figure 5) and previous literature has focused on this state. If our hypothesis that early childhood television watching is a trigger for autism is correct, it is exactly in this type of state where precipitation variability across counties is high that that the effect of precipitation on autism rates should be identifiable by a statistical analysis.

Note that the approach we are taking is an instrumental variables approach or, more specifically, our approach is to employ what economists have come to call a natural experiment. In other words, we employ the idea that early childhood television watching varies positively with precipitation to test whether autism varies both cross sectionally and over time with changes in precipitation in a fashion consistent with early childhood television watching serving as a trigger for autism. In this sense our study is similar to a number of recent studies in economics that use a natural experiment to investigate various important empirical issues (see Rosenzweig and Wolpin (2000) and Angrist and Krueger (2001) for surveys).

Many studies that use an instrumental variables approach do so because testing the theory directly results in problems such as measurement error or omitted variables. In contrast, our main reason for using an instrumental variables approach is that there are not large enough studies that directly measure both young children's television watching and subsequent health problems that could be used to study whether early childhood television watching is a trigger for autism. But even so, an advantage of our study is that by using an instrumental variables approach we avoid a problem of reverse causality. That is, a direct finding that young children who watch more television are more likely to develop autism could be due to young children vulnerable to developing autism having a prediliction for watching a large amount of television.

But a finding that precipitation is positively correlated with autism is not subject to this criticism – we can be quite certain that autism does not cause precipitation.

A) Data

We employ two different types of data on autism. Our first set of tests employ autism rates in 2005 by county in California, Oregon, and Washington for school-aged children, i.e., ages six to eighteen. To calculate these autism rates we took the autism counts for December 2005 provided to us by the state agencies and divided by the corresponding county-level total school-aged population taken from the 2000 census. We also investigate county-level age-specific autism rates. Washington was unwilling to provide us with these data while California and Oregon provided us with the figures, although for Oregon we were only provided figures when the age-specific counts by county were at least ten. For Oregon we use age-specific counts by county in 2005 and then construct autism rates by dividing by the corresponding county-level age-specific population taken from the 2000 census. For the case of California we focus on cohorts born between 1982 and 1997 (versus cohorts born between 1987 and 1999 for Oregon) and use the county autism count in the year a birth cohort was eight years old and construct the autism rate by dividing by that year's corresponding county-level age-specific population also derived from census data.[29]

For example, for children born in Los Angeles county in 1990 we use Los Angeles county's autism count of eight year olds in 1998. Our empirical methodology assumes that autistic children spent their first three years of life in the same county where they reside when they are recorded in our data set. Hence, using this type of data in the case of California rather than counts from the 2005 survey reduces measurement error by reducing the number of autistic children who changed county of residence between the age of three and the age they are recorded in our data set. We do not have this type of data for Oregon which is why in the case of Oregon

[29] For years between 1990 and 2000 we interpolated using the 1990 and 2000 age-specific county population figures. For years after 2000 we used census projected age-specific county population figures. Also, the census provides total population by age ranges – five to nine, ten to fourteen, and fifteen to nineteen. For the calculation of autism rates we assume an equal number of children at each age within a particular range.

we focus on the 2005 counts. Finally, we chose age eight for constructing the California data because most children who are diagnosed with autism receive the diagnosis by the age of eight.[30]

Our precipitation variable is constructed in a fashion similar to the construction of the precipitation variable in the previous section. To construct precipitation in a specific county in a specific year we first calculate precipitation in that county on each day of the year by averaging across all the weather stations in that county. We then add the resulting values across all the days in the year to get the total year's precipitation. We use two types of precipitation variables. First, we construct average annual precipitation by county between 1987 and 2001. Second, we construct three-year intervals of average annual precipitation by county to match when a specific age cohort was between the ages of zero and two.[31]

We also employ a number of control variables. We include a county's total population, per capita income, the percent of Hispanics, Blacks, and indigenous groups for each county's school-aged population, and county-level age-specific percentages of Hispanics, Blacks, and indigenous groups. To calculate these percentages we employ populations by group and age range taken from census data and then use similar procedures to those described above used to construct the analogous autism rates.[32] Statistics for the sample used in this section are reported in Table 3.

B) Tests and Results

In our first set of tests the dependent variable is county autism rates for school-age children in 2005. In this set of tests we consider a number of explanatory variables. First, our main focus is on average annual precipitation by county over the time period 1987 to 2001,

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[30] In our tests using Oregon data we consider each age cohort that was between six and eighteen in 2005. In our tests using California data we drop the cohorts that were six and seven years old in 2005 because of our focus on autism rates calculated using the autism counts when the birth cohort was eight years old.

[31] To be precise, in our data set a precipitation year runs from July 1 of the calendar year to June 30 of the following calendar year. For example, when we refer to precipitation for Multnomah county in Oregon in 1995 we mean precipitation from July 1, 1995 to June 30, 1996. We define precipitation this way in order to better match the three-year intervals of average precipitation with the time period in which the relevant age cohort was between zero and two.

[32] We do not employ any county education variable as a control because of the high correlation between county education levels and county income levels.

which covers a time period in which at every date some subset of school-aged children in 2005 were between zero and two years of age (remember, given autism strikes by the age of three, any trigger must be such that exposure occurs prior to the age of three). Our prediction is that there should be a positive coefficient on this variable. Second, given the finding in Section IV that early childhood television watching is higher for Hispanics and Blacks but lower for indigenous groups, we include county population percentages in 2005 for Hispanics, Blacks, and indigenous groups. Our prediction is that the coefficients on the Hispanic and Black variables should be positive since early childhood television watching is higher for Hispanics and Blacks, while the coefficient on the indigenous group variable should be negative because these groups watch less television.[33] Third, we include a county per capita income variable because in Section IV we found that income is negatively related to early childhood television watching which suggests autism rates should be negatively correlated with income.

We also employ two other explanatory variables. For the regressions in which we pool counties across the three states, we include dummy variables that control for which state the county is in. We include this variable because the criteria used to classify an individual as having the condition may vary across the three states. We also include a measure of the population of the county in 2005. We include a population size variable because large counties may be better able to afford the infrastructure required to effectively diagnose the condition which, in turn, suggests that autism rates might be higher in more populous counties. Table 3 reports characteristics of California, Oregon, and Washington counties for our sample period.

For the tests using the California counties, we also typically include a dummy variable that captures whether the county was the home of one (or more) of the twenty-one regional centers that provides services to individuals with developmental disabilities including autism. The California autism counts we rely on are counts of individuals who received services at one of these regional centers. We would expect that, in counties with a regional center, a higher

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[33] Our prediction that autism rates should be higher among Hispanics is seemingly contradicted by the findings in Centers for Disease Control and Prevention (2006). However, since that study did not control for geographic location of respondents and since United States Census Bureau (2001) shows that Hispanics are dispropotionately located in Southwestern states such as Arizona and New Mexico where state autism rates are low (and where coincidentally precipitation rates are also low), the findings in Centers for Disease Control and Prevention (2006) do not clearly show that autism rates among Hispanics are low after controlling for geographic location.

proportion of the individuals with autism would receive treatment at a regional center. Hence, our prediction is that the coefficient on the regional center variable should be positive.

The exact specifications we consider are given in equations (2) and (3).

(2) $$AUT_k = \beta_1 + \beta_2 PRCP_k + \varepsilon_k$$

(3) $$AUT_k = \beta_1 + \beta_2 PRCP_k + \beta_3 logPOP_k + \beta_4 INC_k + \beta_5 REG_k + \beta_6 HISP_k + \beta_7 BLK_k + \beta_8 IND_k + \varepsilon_k$$

In equations (2) and (3), AUT_k denotes the 2005 autism rate among school-aged children in county k, $PRCP_k$ is the average annual precipitation level in county k between 1987 and 2001, $logPOP_k$ is the logarithm of county k's total population in 2000, INC_k is county k's per capita GNP in 1999, $HISP_k$ is the percentage of school-aged children in county k who are Hispanics in 2000, BLK_k is the percentage of school-aged children in county k who are Black in 2000, and IND_k is the percentage of school-aged children in county k who fall into one of the indigenous group categories in 2000, and REG_k equals 1 if California county k has a regional center and 0 otherwise. We consider the specification in equation (2) for California counties only, Oregon counties only, Washington counties only, and we also consider both equations (2) and (3) in a pooled analysis of California, Oregon, and Washington counties.

Table 4 reports the results. Column 1 reports results for equation (2) for California counties only, column 2 report results for equation (2) for Oregon counties only, and column 3 reports results for equation (2) for Washington counties only. There is a positive relationship between autism and precipitation in Oregon and Washington, but no in California. In particular, the coefficient on the precipitation variable is positive and statistically significant at the one percent level in both Oregon and Washington. So you can see visually what the table is capturing concerning the relationship between precipitation and autism, in Figures 3 and 4 we present precipitation and autism maps for each state. Consistent with the results in the table, it is clear from the maps that there is a very strong correlation in each state between precipitation and autism.

Columns 4 and 5 of Table 4 report results for the specifications in equations (2) and (3) in which we pool the counties in all three states. The results are consistent with most of our predictions.[34] First, in both regressions the coefficient on the precipitation variable has the

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[34] We do not report the individual state regressions for equation (3) because the results are not reliable given the ratio of explanatory variables to data points. It is worth pointing out, however, that in these regressions the

predicted sign and is significant at the one percent level. Second, the coefficients on the population and income variables have the predicted sign in the relevant regression, where the former is significant at the five percent level and the latter at the ten percent level. Third, the coefficient on the indigenous group variable has the predicted sign and is significant at the one percent level, while the two predictions that are not supported are the predictions concerning the coefficients on the Black and Hispanic variables. This last result is not surprising given the relatively weak evidence in the ATUS regarding whether young Black and Hispanic children watch more television. Finally, given the very high autism rate in Oregon it is not surprising that the coefficient on the Oregon dummy variable is positive and statistically significant at the one percent level.

In our next set of tests, we define the dependent variable as the county autism rate for each age cohort from six to eighteen. As discussed earlier, we only have such data for California and for sixteen counties in Oregon because Washington was unwilling to share the data with us and because Oregon only reported the county autism count when it was greater than or equal to ten.

In this set of tests our precipitation variable is the average annual amount of precipitation in the county over the years in which the age cohort was below the age of three. So, for example, when the observation is the autism rate for children in Multnomah county who were born in 1995, our precipitation variable is the average precipitation in Multnomah county between 1995 and 1997. As discussed earlier, since autism develops before the age of three, it is only television watching and thus precipitation over those first three years that should matter.

The specification we consider for this set of tests is given in equation (4).

$$(4) \quad AUT_{k,b} = \beta_1 + \beta_2 PRCP_{k,b} + \beta_3 TIME_b + \beta_4 \log POP_k + \beta_5 INC_k + \beta_6 REG_k + \beta_7 HISP_{k,b} + \beta_8 BLK_{k,b} + \beta_9 IND_{k,b} + \varepsilon_{k,b}$$

In equation (4), $AUT_{k,b}$ denotes the autism rate in county k for birth cohort b, $PRCP_{k,b}$ is the average precipitation in county k over the years birth cohort b was below the age of three, and $TIME_b$ is the value for a time trend variable. For Oregon the population and income variables

coefficient on the precipitation variable in the Oregon regression continues to be highly statistically significant, although the precipitation coefficient in the Washington-only regression is no longer significant at standard confidence levels.

are defined as before, while for California we use a county's population and income when the birth cohort was eight years of age (i.e., for the California tests better notation would be $logPOP_{k,b}$ and $INC_{k,b}$). The three race/ethnicity variables are calculated separately for each age cohort using census data. Note that we include a time trend because California and Oregon, like many other states, experienced rising autism rates over the time period covered.

Table 5 reports the results.[35] Column 1 reports the results for Oregon for equation (4). The coefficient on precipitation has the predicted sign and is statistically significant at the five percent level. As for the control variables, consistent with the prediction, the coefficient on the income variable is negative and statistically significant at the ten percent level. The other control variables are all insignificant at standard confidence levels. Column 3 of Table 5 reports the results for California for equation (4). Consistent with the predictions, the coefficient on the population variable is positive and statistically significant at the ten percent level, the coefficient on the income variable is negative and statistically significant at the ten percent level, while the coefficient on the time trend is positive and statistically significant at the one percent level. Also, the coefficients on the other control variables are not significantly different from zero. But most importantly, the California data continues to show no evidence of a positive correlation between precipitation and autism.

One possibility for why the California data does not exhibit a positive correlation between precipitation and autism is that there is an omitted variables problem. That is, there could be another important variable that is correlated with television watching and also correlated with precipitation in the California data set in a manner that results in no significant relationship between autism and precipitation in our test of equation (4) using California data. For example, suppose that urban density is positively correlated with early childhood television watching. Then, because there are a number of counties in California such as Los Angeles, Orange, and San Diego counties with both high urban density and low precipitation, it is possible we do not find a positive correlation between autism and precipitation in our California test of equation (4) because our test does not include a measure of urban density. Note that this problem can be avoided by employing a fixed-effects specification which is our next set of tests.

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[35] Although not reported, we ran the equation (2) regression on the sixteen counties that remain in the Oregon sample and the results were similar to what was reported in column 2 of Table 4 for the full twenty-eight counties.

In column 2 of Table 5 we employ a fixed-effects specification using age-specific county autism rates in Oregon to investigate whether our finding of a positive correlation in Oregon between precipitation and autism continues to hold even after we control for time-invariant county characteristics. The coefficient on the precipitation variable in this test is determined solely by how each county's autism rate deviates from its average over time when the county's precipitation level deviates from its average. As depicted for Oregon in Figure 6, there is a substantial amount of variation in precipitation from year to year, and this variation differs by county. For children born in 1990, for example, Deschutes county received one percent less precipitation between 1990 and 1992 relative to its average, whereas Yamhill and Polk counties received twenty six percent and twenty two percent less than their averages, respectively. The results continue to support a positive association in Oregon between autism and precipitation. Specifically, the coefficient on the precipitation variable is positive and statistically significant at the one percent level while the coefficient on the time trend is also positive and statistically significant at the one percent level. As for the magnitude of this effect, a one-standard deviation increase (21.3 inches per year) in the amount of precipitation a cohort was exposed to before they were three would be predicted to increase the autism rate for that cohort by twelve percent.

In column 4 of Table 5 we employ a fixed-effects specification using age-specific county autism rates in California. In contrast to earlier results concerning the California data, we now find a positive correlation between autism and precipitation. Specifically, similar to what was true for the Oregon test, the coefficient on the precipitation variable is positive and statistically significant at the five percent level. Further, in this case a one-standard deviation increase (17.4 inches per year) in the amount of precipitation a cohort was exposed to before they were three would be predicted to increase the autism rate for that cohort by twenty eight percent.[36]

In columns 5 and 6 we pool the data across California and Oregon counties and consider equation (4) and the fixed-effects specification. Column 5 shows that when we pool the data across the two states, as was the case in the Oregon regression in column 1, the coefficient on the

[36] Interestingly, when we construct the California autism rates by using data on six year olds rather than eight year olds, the precipitation coefficient is no longer positive and statistically significant. One possible explanation is that children who become autistic due to the incremental television watching due to precipitation have a relatively mild version of the condition that is diagnosed at an older age. Since these are the children who we are relying on to identify the effect of precipitation on autism rates in our empirical tests, it would be more likely that we find a positive correlation between autism and precipitation using data on eight year olds than data on six year olds.

precipitation variable is positive and statistically significant at the five percent level. In terms of the other variables, we only find statistical significance for the coefficient on the Hispanic variable which, consistent with our prediction, is positive and statistically significant at the ten percent level, and for the coefficient on the indicator variable that captures whether the county is in Oregon which not surprisingly is positive and statistically significant at the one percent level. Column 6 reports the results of the fixed effects specification when we pool the data. Here, as was the case for the Oregon regression in column 2, the coefficient on the precipitation variable is positive and statistically significant at the one percent level.

Overall, we believe that the results in this section strongly support the hypothesis that early childhood television watching is a trigger for autism. That is, in each of the three states that we consider there is evidence of a positive relationship between autism and precipitation as predicted by the television as trigger hypothesis. In particular, in Oregon we find evidence for such a correlation using cross-sectional, time-series, and fixed-effects specifications. Further, when we pool the data across either two or three states, we consistently find positive coefficients on the precipitation variable that achieve high levels of statistical significance.

VI. AUTISM AND CABLE TELEVISION

In the previous section we used county-level data in California, Oregon, and Washington to investigate whether there is a positive correlation between autism and precipitation as predicted by the hypothesis that early childhood television watching is a trigger for autism. In this section we use county-level data from California and "intermediate unit" data from Pennsylvania to investigate whether there is a positive correlation between autism and the percentage of households with cable television as predicted by the television as trigger hypothesis.[37] The idea here is that, if early childhood television viewing is indeed a trigger for autism, then the increased access to cable during the 1970s and 1980s was likely an important factor in the growth in autism during this time period. That is, since having cable television in the home typically expands the variety of children's shows available and the proportion of the

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[37] Pennsylvania provides autism counts for intermediate units rather than counties, where an intermediate unit is either a populous county or a grouping of two to five less populous counties.

day in which at least one children's show is being televised, children in households with cable to watch a lot of television. With this in mind, in our tests we use cable subscription rates as an instrumental variable for the amount of early childhood television watching.

A) Data

Using 1990 data, for each county in California and intermediate unit (IU) in Pennsylvania we calculated an autism rate for each cohort of individuals born between 1972 and 1984. Using autism rates for six-year olds in December 1991, 1992, 1993, 1994, and 1995, we then extended this data set to include autism rates for each California county and Pennsylvania IU for each cohort of individuals born between 1972 and 1989. We focus on this time period for two reasons. First, during this time period there was substantial growth in California of both the percentage of households with cable television and the percentage of children diagnosed with autism.[38] Second, in the 1990s there was substantial growth in satellite television which serves as a substitute for cable and, because of a lack of county-level and IU data concerning households with satellite television, it is difficult in the 1990s to get an accurate picture at the county level and IU level of the percentage of households with the expanded offerings typically associated with cable and satellite television.

Our cable data are taken from the Services Volume of the *Television Factbook*. For each cable company, this publication, which appears (almost) annually, reports the number of subscribers, the primary community served, and the county or counties served.[39] For each year between 1972 and 1991 we used these data to construct the number of households with a cable subscription in each county. For the small number of years in which the data on cable subscribers were not available – 1976, 1977, and 1980 – we used a linear interpolation to estimate the number of cable households (e.g., the number of subscribers in a county in 1980 is

[38] The mean autism rate in California and Pennsylvania for the 1972 birth cohort was .0104 percent while by the 1989 cohort it had grown to .0661 percent, a 6.4 fold increase. Over this same time period the average percentage of households with a cable subscription increased from twenty six percent to sixty percent.

[39] A small number of cable companies serve multiple counties. In these instances we assigned all subscribers to the county of the primary community served.

assumed to the average of the numbers in 1979 and 1981). We then divided these numbers by the total number of households in the county in the relevant year which we estimate using the decennial census. Specifically, for 1971-1979 we linearly interpolate using the 1970 and 1980 censuses, while 1981-1989 values are estimated using a linear interpolation of the 1980 and 1990 censuses. For Pennsylvania we then used a population based weighting to construct our cable subscription variable.[40]

Our tests focus on a subset of California counties and Pennsylvania IUs. Some California and Pennsylvania residents received poor over-the-air reception at the beginning of the time period of our study, 1972. Many of the residents in these counties likely subscribed to cable in order to watch the three major networks (ABC, CBS, and NBC), whereas in other counties the main reason to subscribe to cable was to receive expanded channel offerings. As previously indicated, in our tests we use cable subscription rates as an instrumental variable for the amount of early childhood television watching. This use of the variable only makes sense for counties and IUs with good over-the-air reception where cable was mostly employed for expanded channel offerings. We thus dropped from our analysis California counties and Pennsylvania IUs with poor over-the-air reception. Our specific procedure for dropping counties and IUs was as follows. The Federal Communications Commission describes a television station as providing "Grade B" service when "the quality of picture (is) expected to be satisfactory to the median observer at least 90% of the time for at least 50% of the receiving locations within the contour, in the absence of interfering co-channel and adjacent-channel signals." We dropped the California counties and Pennsylvania IUs where in 1972 a majority of the county's or IU's area lacked at least Grade B service. The result was that seven of California's fity-seven counties and one of Pennsylvania's twenty eight IUs were dropped from our cable analysis.[41]

In Figure 7 we plot the growth in cable households between 1972 and 1989 for some of the California counties in our data set (the other California counties and Pennsylvania IUs

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[40] There are two instances in the Pennsylvania data where a single county is divided across two IUs. First, Clearfield county except for the DuBois area is in IU 10 while the DuBois area is in IU 6. Second, York county except for Northern York county is in IU 2 while the northern part is in IU 5. Because of lack of data on population and demographics for parts of counties, in each case the whole county was assigned to the IU which most of the county was a part of, i.e., Clearfield county was assigned to IU 10 and York county was assigned to IU 2.

[41] The California counties dropped were Inyo, Lassen, Mendocino, Modoc, Nevada, and Toulumne, while the Pennsyvania IU dropped was the one containing Cameron, Elk, McKean, and Potter counties.

exhibit similar growth). As suggested by the figure, although cable grew substantially in basically every California county and Pennsylvania IU during this time period, there was substantial variation across counties both in the initial levels of cable subscriptions and rates of growth.

We employ the same control variables in our cable analysis as in the precipitation analysis, where values are taken from 1990. There is one small difference, however, which is that the number of school-age Native Hawaiian and Pacific Islanders by county is not available for 1990. Therefore, our indigenous group variable includes the percentage of school-age children who are American Indian or Alaskan Native only, rather than combining this group with Native Hawaiian and Pacific Islanders as we did in the precipitation cross section regressions. The population, racial percentages, and income levels are 1990 measures because most of the autism rates are calculated using 1990 data.

B) Tests and Results

The dependent variable is the county or IU autism rate for a specific age cohort, while the main explanatory variable is the average percentage of county or IU households with a cable subscription over the time period the cohort was less than three years of age. Our prediction is that this cable percentage should be positively correlated with autism rates. Note that the logic here for focusing on the average cable percentage when a cohort was below three years of age is the same as the logic discussed earlier for the similar approach taken in our precipitation tests. That is, autism develops by the age of three, so if early childhood television watching is serving as a trigger then autism should be correlated with television watching that occurs prior to the age of three. Also, as indicated earlier, with one exception we include the same set of control variables as in the precipitation tests, where the predictions are the same as before.

Finally, an important concern in conducting the tests in this section is that, since autism rates and household cable percentages both rose substantially over the time period studied, one would expect a positive coefficient on the cable variable even if cable had no causal effect on autism rates. We control for this problem in two different ways. In our first set of tests we include a time trend variable. Because of the seriousness of the concern, however, we also report a second set of results where we omit the time trend variable but include dummy variables for each age cohort.

The specifications we employ for our first test is given in equation (5).

$$(5)\qquad AUT_{k,b} = \beta_1 + \beta_2 CAB_{k,b} + \beta_3 TIME_b + \beta_4 logPOP_k + \beta_5 INC_k + \beta_6 REG_k + \beta_7 HISP_k + \beta_8 BLK_k + \beta_9 IND_k + \varepsilon_{k,b}$$

In equation (5), $AUT_{k,b}$ denotes the autism rate in county or IU k for age cohort b, $CAB_{k,b}$ is the average percentage of households with cable in county or IU k over the years that cohort b was below the age of three, $TIME_b$ is the value for a time trend variable, and the other variables are defined as in equation (4) but are measured in 1990.

Column 1 of Table 6 reports the ordinary least squares estimate of equation (5) for California, while column 3 reports the results for Pennsylvania. The first thing to note is that the coefficient on the cable variable has the predicted sign and is significant at the five percent level in the California test, while it is positive but insignificant in the Pennsylvania test. That is, in California but not in Pennsylvania, even after including a time trend, autism rates are higher for cohorts where a relatively large percentage of households subscribed to cable television during the cohort's first three years.

The results concerning the control variables are as follows. Not surprisingly, for both states the coefficient on the time trend variable has the predicted sign and is strongly statistically significant. The coefficients on the population and Black variables also have the predicted sign in both states, where the coefficient on the population variable is significant at the one percent level in the California test (but not in the Pennsylvania test) while the coefficient on the Black variable is statistically significant at the ten percent level in both the California and Pennsylvania tests. The coefficient on the regional center variable in the California test also has the predicted sign but is not statistically significant at standard confidence levels. The coefficient on the Hispanic variable is small in magnitude and statistically insignificant in both states, while the coefficient on the indigenous group variable has an unexpected sign and is significant at the ten-percent level in the California test but has the expected sign and is significant at the ten percent level in the Pennsylvania test.

The final variable is income, where the coefficient has the opposite sign of the prediction in both states and the coefficient is significant at the five percent level for California. We conjecture that the effect of income on television viewing might be quite different in the time period of this study than in that of the ATUS study. By 2003 VCR and DVD machines were widely diffused and likely had little correlation with family income. In contrast, during the time period of our cable study VCRs were just starting to diffuse and high-income households were probably more likely to own them. This could explain the income coefficient in column 1 of Table 6. That is, if having a VCR machine was strongly positively correlated with income, then during this time period it is quite possible that, in contrast to what was true in the ATUS study, income was positively rather than negatively correlated with early childhood television watching.

In columns 2 and 4 of Table 6 we investigate the robustness of the findings in columns 1 and 3. As discussed, rather than including a time trend variable, we include dummy variables for the various age cohorts. Any concerns about a spurious correlation between autism and cable due to the rise in both during the period of the study should be eliminated with this more flexible specification. We see that this alternative specification has no effect on the results. The coefficients of interest are basically unchanged as are levels of statistical significance.

In columns 5 and 6 of Table 6 we pool data across the two states. The main result here is that in both regressions the coefficient on the cable variable is positive and significant at the one percent level.

Our final set of tests employ a fixed-effects specification in which we control for time invariant county (California) or IU (Pennsylvania) effects. Columns 1 and 2 of Table 7 report the results of this test for California, while columns 3 and 4 report the results for Pennsylvania. For both states the coefficients on the cable variables are positive as predicted. Although the coefficients are not statistically significant in the California tests, the magnitude is essentially the same as in the OLS regressions in Table 5, whereas the standard errors are twice as large. This is not surprising because including fixed effects reduces the amount of variation in the cable variable. The cable coefficient is statistically significant at the one percent level in the Pennsylvania test that employs a time trend and statistically significant at the five percent level in the Pennsylvania tests that uses cohort indicator variables. In columns 5 and 6 of Table 7 we report results for the fixed-effects specification where we pool the two states together. Here we find that in both regressions the coefficient on the cable variable is positive and statistically significant at the one percent level.

Overall, the results in this section strongly support our hypothesis that early childhood television viewing is a trigger for autism. This hypothesis makes the prediction that, even after controlling for the overall growth in cable in the time period studied, there should be a positive correlation between household cable percentages and autism rates. In turn, there is substantial evidence for exactly this type of positive relationship in the California data, in the Pennsylvania data, and especially when we pool the data across the two states.

VII. INTERPRETATION AND IMPLICATIONS

As discussed briefly at the beginning of Section V, if we had a direct measure of early childhood television watching and showed that children who developed autism had watched more television before the age of three, we would have evidence consistent with the hypothesis that early childhood television watching is a trigger for autism but there would be a question of cause and effect. That is, especially given the findings of Zwaigenbaum et al. (2005) discussed earlier, it is possible that such a correlation could be due not to early childhood television watching causing autism but rather to children who are prone to developing autism being more drawn to television and therefore watching more of it. Note that this is basically the same drawback discussed earlier concerning the study of Christakis et al. (2004) concerning television and ADHD.

But by using an instrumental variables or natural experiment methodology we avoid the problem of cause and effect. Our first set of instrumental variables tests shows that in California, Oregon, Washington – three states with high precipitation variation across counties – there is a positive association between precipitation and autism. Clearly, there is no meaningful sense in which the presence of a high number of young children in a county prone to autism "causes" precipitation in that county to be high. On the other hand, there is the possibility that for one reason or another families more prone to having autistic children locate in areas with high levels of precipitation. But this explanation for our results concerning precipitation is ruled out by our finding that in California and Oregon precipitation is correlated with autism when a fixed-effects specification is employed. That is, the fixed-effects specification controls for other unobserved county variables, so the positive and statistically significant coefficients on the precipitation variable in that specification indicate that, even after controlling for the composition of families in a county and the diagnostic criteria being used, autism diagnoses in California and Oregon are higher in years when precipitation is higher than average. We believe the most plausible explanation for this finding is that there is a trigger for autism where exposure to this trigger is positively related with the amount of precipitation in the child's community prior to the age of three.

Based on our findings using the ATUS, one plausible candidate for this trigger is early childhood television watching. But this is not the only possibility. Given that it is also likely that for young children indoor activities in general, not just television watching, are positively correlated with precipitation, potentially any trigger for which indoor activities lead to more exposure than outdoor activities could explain our precipitation findings. With this in mind, we also investigated a second instrumental variable for television viewing. If early childhood television watching is a trigger for autism, then one would expect the percentage of households in a community or county with a susbscription to cable television to be correlated with the autism rate in that community or county. We investigate this issue using autism and corresponding cable rates broken down by geographic area in California and Pennsylvania for children born between 1972 and 1989 and show that indeed cable subscription rates are positively correlated with autism rates. Further, this is true even after one controls for the general increase in autism rates during the time period of the analysis. That is, our finding of a positive and statistically significant correlation between cable subscription rates and autism rates is not due to the fact that both cable subscription rates and autism rates both grew during the time period studied. Rather, the correlation is driven by the idea that autism grew faster, on average, in those counties in which cable subscription rates grew faster.

Because we do not provide a direct test of the effects of television watching on autism, we do not consider our results to be definitive evidence in favor of the television viewing as trigger hypothesis. However, we believe that when viewed in combination our empirical findings provide strong support for the hypothesis. Whereas there is a readily plausible alternative explanation for why precipitation seems to be frequently positively correlated with autism, we have more trouble finding a plausible alternative explanation for why precipitation and cable subscriptions would both be positively correlated with autism. For example, it is theoretically possible that autism is positively correlated with cable subscription rates because young children in families with cable spend more time indoors and there is a toxin where exposure is higher for indoor activities than outdoor activities. But, although theoretically possible, we do not believe the effect of cable on time spent indoors by young children is likely to be large enough to make the "time spent indoors" hypothesis a plausible explanation for our cable findings.

Another possibility is that households predisposed to having autistic children may for one reason or another find cable more desirable than the average household. But this possibility neither explains our precipitation results, nor is it a particularly plausible explanation for our cable results since the number of households predisposed to having autistic children is unlikely to be sufficiently large to significantly affect county-wide cable subscription rates. So, although as indicated we do not believe our tests provide definitive evidence for our hypothesis, we believe the most likely explanation for our findings is that early childhood television watching is indeed a trigger for autism.

A related issue is, if early childhood television watching is a trigger for autism, what percentage of autism diagnoses is due to early childhood television viewing? In other words, if all early childhood television watching was eliminated, how much would the autism rate fall? We cannot use our results to estimate this decrease because, for example, even if we assume that television watching is the sole factor driving our finding of a positive correlation between autism and precipitation, we do not know how the autism rate would be affected by eliminating the television watching that remains when precipitation equals zero.

We can, however, use our results to estimate lower bounds on the reduction in autism that would occur if all early childhood television watching were eliminated. For example, assuming television watching is the sole factor driving the positive correlation between autism and precipitation, we can estimate a lower bound by deriving an estimate of the reduction in autism that would occur if all the incremental television watching due to precipitation were eliminated. Using the results found in Table 3's pooled cross-sectional analysis of California, Oregon, and Washington's county-level autism rates, we find that if early childhood television watching is the sole trigger driving the positive correlation between autism and precipitation then thirty-eight percent of autism diagnoses are due to the incremental television watching due to precipitation. [42]

Similarly, we can use the results of our cable analysis to estimate the reduction in autism that would occur if the incremental television watching due to cable were eliminated. For example, using the cable coefficient found in column 5 of Table 7, we predict that approximately seventeen percent of the increase in autism rates between the 1972 and 1989 birth cohorts in California and Pennsylvania is due to the growth of cable households and the resulting increase in early childhood television watching.[43] Hence, our results suggest that early childhood television watching, or whatever is the trigger driving our finding of a positive correlation between autism rates and precipitation and autism rates and cable, is an important factor in autism diagnoses both from statistical and absolute standpoints.

VIII. CONCLUSION

One of the most important health care crises facing the United States currently is the rising incidence of diagnoses of autism. In this paper we have investigated the possibility mostly ignored by previous researchers in this area that early childhood television watching is an important trigger for autism. Using the Bureau of Labor Statistics' American Time Use Survey, we first showed that early childhood television viewing is positively correlated with precipitation. Given this finding, our hypothesis that early childhood television viewing is an important trigger for autism translates into the prediction that autism rates should also be positively correlated with precipitation. With this in mind we then investigated how the rate of autism diagnoses varies with precipitation. Looking at county autism rates in California,

[42] To estimate the decrease in autism that would occur if all incremental television watching due to precipitation were eliminated, we multiply the coefficient on the precipitation variable by annual precipitation averaged across counties and years between 1987 and 2001. The resulting product equals thirty-eight percent of the 2005 autism rate calculated by averaging 2005 county-level school-age autism rates across California, Oregon, and Washington counties.

[43] To estimate the percentage of the increase in autism between the 1972 and 1989 birth cohorts in California and Pennsylvania due to the growth of cable, we multiply the coefficient on cable in column 5 of Table 7 by the average increase in cable in the two states over this time period and then divide by the average increase in autism in the two states over this time period.

Oregon, and Washington, we found support for such a positive correlation in all three states and when we pool the three states together. We then used California and Pennsylvania data to look at the correlation between autism rates and the percentage of households with cable television. Again, we find the evidence supports our hypothesis that early childhood television watching is a trigger for autism.

Although our findings are consistent with our hypothesis, we do not believe our findings represent definitive evidence for our hypothesis. We believe the only way to establish definitively whether or not early childhood television watching is a trigger for autism is to more directly test the hypothesis. For example, one could monitor the viewing habits of a large number of children from the ages of zero to three and see whether the children who are eventually diagnosed with autism on average watched more television before the age of three. The finding that those diagnosed with autism had indeed watched more television would be subject to the criticism that maybe those prone to autism are more drawn to television viewing (this is similar to the criticism of Christakis et al.'s (2004) study of television viewing and ADHD). But if a condition of participation in the study was that parents were required to limit television viewing, one could judge whether television viewing is important by looking at the overall rate of autism in the sample.

The other way to extend our research would be to look more generally at the effects of early childhood television viewing. There is a belief in the medical community that, particularly before the age of two, television watching has negative health consequences. But because it is difficult to measure early childhood television viewing, it has been difficult to establish firm findings in this area. However, one can potentially use our findings of a positive correlation between early childhood television viewing and precipitation and also the cable data to look at possible consequences of early childhood television viewing other than autism. For example, one could look to see whether diagnoses of ADHD vary with precipitation and cable prescription rates in a manner similar to how autism varies with precipitation and cable. Or similarly, one could look at how precipitation and cable subscription rates vary with other important variables such as obesity, rates of violent behavior, and IQ levels.[44]

As a final point, although as discussed our results do not definitively prove that early childhood television watching is an important trigger for autism, we believe our results provide sufficient support for the possibility that until further research can be conducted it might be prudent to act as if it were. In other words, maybe there should be additional emphasis placed on the recommendation of the American Academy of Pediatricians that early childhood television watching should be eliminated or at the very least quite limited (as discussed in footnote 3, the current recommendation is that there should be no television watching before the age of two and no more than one to two hours per day for older children). We see little downside in taking this step and a very large upside if it turns out that television indeed causes autism.[45]

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[44] Gentzkow and Shapiro (2006), using historical data concerning the timing of television's introduction across communities, found that exposure to television improved average IQ. It would be interesting to see whether average IQ varies with precipitation and cable subsription rates in a fashion consistent with this finding.

[45] Along similar lines, it might also make sense to incorporate limited television watching into standard treatments for autism. There is evidence that on average autistic children spend large amounts of time watching television and are also prone to obsessing about television (see Baron-Cohen and Wheelwright (1999) and Venkatesan (2005)) and, if television is a trigger, it would not be surprising if it also aggravated the condition after initial onset.

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Table 1: Sample Statistics of the 2003 American Time Use Survey (ATUS)

	Mean	Standard Deviation
Minutes the adult respondent spent watching TV with his/her child present on the day of the interview:		
a) Narrow definition: TV, DVD/video movies, home movies, and home videos	59.0	104
b) Wide definition: narrow activities plus computer use for leisure and attending movies	60.7	105
Precipitation (inches)	0.110	0.263
Daylight (hours)	12.2	1.84
Interview on weekend	0.519	0.500
Respondent has bachelor's degree	0.381	0.486
Respondent worked day of survey	0.388	0.487
Adult respondent is female	0.574	0.495
Child is male	0.513	0.500
Household type:		
- two parents, <u>not</u> in the armed forces	0.781	0.413
- two parents, 1+ in the armed forces	0.022	0.145
- single parent, <u>not</u> in armed forces	0.181	0.385
- single parent in armed forces	0.001	0.031
- other	0.015	0.121
Respondent's race/ethnicity		
- White	0.820	0.384
- Black	0.104	0.306
- Asian	0.049	0.215
- indigenous group	0.013	0.114
- two or more races	0.014	0.117
- Hispanic	0.206	0.404
Household income		
- respondent did not provide	0.073	0.260
- respondent did not know	0.009	0.094
- $0 to $4,999	0.023	0.150
- $5,000 to $7,499	0.019	0.135
- $7,500 to $9,999	0.011	0.106
- $10,000 to $12,499	0.022	0.145
- $12,500 to $14,999	0.025	0.155
- $15,000 to $19,999	0.046	0.209
- $20,000 to $24,999	0.050	0.218
- $25,000 to $29,999	0.055	0.227
- $30,000 to $34,999	0.049	0.215
- $35,000 to $39,999	0.053	0.223
- $40,000 to $49,999	0.084	0.278
- $50,000 to $59,999	0.084	0.277
- $60,000 to $74,999	0.110	0.313
- $75,000 or greater	0.288	0.453

Notes: the sample includes 2,035 adult respondents who were living with a child less than three years of age, and who live in a Metropolitan Statistical Area (MSA) or Primary Metropolitan Statistical Area (PMSA) that is recorded on the survey.

Table 2: Coefficient Estimates of Time Spent Watching Television

Variable	Narrow TV Definition Tobit	Narrow TV Definition OLS	Wide TV Definition Tobit	Wide TV Definition OLS
Precipitation (in inches)	126***	57.9***	117***	59.2***
	(44.4)	(20.3)	(43.5)	(20.6)
Precipitation squared	-76.2**	-32.7**	-65.8**	-32.1**
	(34.4)	(14.6)	(33.1)	(14.8)
Daylight (hours)	-7.19***	-2.66**	-7.43***	-2.65**
	(2.66)	(1.27)	(2.65)	(1.28)
Interview on weekend	17.1	9.04*	18.3*	9.56*
	(10.7)	(5.17)	(10.7)	(5.24)
Respondent has bachelor's degree	-39.7***	-20.7***	-40.5***	-21.9***
	(12.3)	(5.78)	(12.2)	(5.87)
Respondent worked day of survey	-82.1***	-37.5***	-82.9***	-38.8***
	(11.8)	(5.56)	(11.7)	(5.63)
Adult respondent is female	4.94	-6.61	3.78	-6.18
	(10.6)	(5.02)	(10.5)	(5.09)
Child is male	21.5**	7.37	19.5**	7.32
	(9.51)	(4.54)	(9.45)	(4.61)
Household (omitted group is two parents, not in armed forces)				
- 2 parents, armed forces	-85.9**	-32.5*	-86.9**	-33.3*
	(41.4)	(18.9)	(41.4)	(19.2)
- single parent, not armed forces	2.33	4.33	2.08	4.59
	(14.4)	(7.10)	(14.4)	(7.20)
- single parent, armed forces	112	49.1	113	46.6
	(151)	(81.7)	(152)	(82.8)
- other	9.59	-1.25	7.17	-1.68
	(38.7)	(19.2)	(38.7)	(19.5)
Respondent's race (omitted = white)				
- Black	25.0	14.3*	19.0	11.4
	(17.0)	(8.43)	(17.0)	(8.55)
- Asian	2.54	-1.03	-0.98	-2.59
	(22.8)	(10.8)	(22.7)	(10.9)
- indigenous group	-106**	-43.5**	-107**	-44.7**
	(43.3)	(19.8)	(43.3)	(20.1)
- two or more races	-7.01	2.66	-5.99	3.87
	(39.6)	(20.3)	(39.6)	(20.6)
- Hispanic	20.2	12.4*	16.0	9.48
	(14.6)	(7.20)	(14.6)	(7.31)
Constant	340*	139	321*	140
	(189)	(102)	(188)	(104)
Observations	2035	2035	2035	2035
Pseudo R^2, or R^2	0.04	0.24	0.04	0.24

Notes: dependent variable is number of minutes the adult respondent spent watching television with his/her child. A full set of MSA/PSMA fixed effects are included in the regressions but are not reported in the Table. Standard errors are reported in parentheses. Fifteen indicator variables are included for family income ranges (e.g., between $10,000 and $12,500). *** = significantly different from zero at a one-percent confidence level; ** = significantly different from zero at a five-percent confidence level; * = significantly different from zero at a 10-percent confidence level.

Table 3
Characteristics of California, Oregon, and Washington Counties

	California (n=55)		Oregon (n=28)		Washington (n=36)		Three States Combined (n=119)	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Autism rate of 6-18 year olds	0.0018	0.0007	0.0068	0.0025	0.0023	0.0014	0.0031	0.0026
Average annual precipitation, 1987-2001 (in inches)	19.0	10.5	30.4	17.6	25.7	18.2	23.7	15.5
Log of population	12.1	1.68	11.1	1.10	11.0	1.49	11.6	1.59
Per capita income, 1999 ($000s)	20959	6317	18,699	2766	18810	3748	19777	5039
Regional center located in a California county	0.273	0.449					0.126	0.333
Percentage of six to 18 year olds who are:								
- Hispanic	30.4	17.8	12.7	9.79	13.7	15.0	21.2	17.5
- Black	3.65	4.19	0.84	1.43	1.35	1.76	2.29	3.32
- American Indian, Native Alaskan, Hawaiian Islander, or Pacific Islander (indigenous groups)	2.89	2.50	3.19	4.20	3.74	4.36	3.22	3.56

Table 4
Ordinary Least Squares Coefficient Estimates of 2005 County-specific Autism Rates (in percentages)

	California	Oregon	Washington	Three States Pooled	
	(1)	(2)	(3)	(4)	(5)
Average annual precipitation, 1987-2001	-0.00053	0.0098***	0.0041***	0.0049***	0.0050***
	(0.00005)	(0.0019)	(0.0013)	(0.0010)	(0.0012)
Logarithm of population					0.026**
					(0.012)
Per capita income (000)					-0.0038*
					(0.0020)
Percentage Hispanic					-0.00044
					(0.00093)
Percentage Black					0.00059
					(0.00260)
Percentage indigenous groups					-0.00774***
					(0.00244)
Indicator for an Oregon county				0.444***	0.465***
				(0.041)	(0.044)
Indicator for a Washington county				0.016	0.046*
				(0.25)	(0.025)
Indicator of whether a regional center is located in a California county					0.029
					(0.023)
Constant	0.187***	0.378***	0.120***	0.083***	-0.133
	(0.019)	(0.067)	(0.037)	(0.021)	(0.118)
Mean of dependent variable	0.177	0.677	0.226	0.309	0.309
Observations	55	28	36	119	119
R-squared	0.01	0.47	0.27	0.73	0.77

Notes: the dependent variable is the percentage of children between the ages of six and 18 in December 2005 who have autism in a particular county (i.e., the autism rate multiplied by 100). Precipitation is measured in inches for July 1, 1987 through June 30, 2001. Indigenous groups include American Indians, Alaskan Natives, Hawaiian Islanders, and Pacific Islanders. *** = significantly different from zero at a one-percent confidence level; ** = significantly different from zero at a five-percent confidence level; * = significantly different from zero at a 10-percent confidence level.

Table 5
Coefficient Estimates of Age- and County-specific Autism Rates for Oregon and California

	Oregon	Oregon	California	California	Pooled	
	(1)	(2)	(3)	(4)	(5)	(6)
Precipitation when cohort was 0-2 years of age	0.0093**	0.0053***	0.00033	0.0015**	0.0029**	0.0023***
	(0.0039)	(0.0020)	(0.0034)	(0.00073)	(0.0013)	(0.00069)
Logarithm of population	-0.306		0.017*		0.0011	
	(0.216)		(0.0086)		(0.0144)	
Per capita income (000)	-0.0065*		-0.0015*		-0.0023	
	(0.029)		(0.00083)		(0.0014)	
Percentage Hispanic	0.022		0.00010		0.0017*	
	(0.016)		(0.00049)		(0.0010)	
Percentage Black	0.027		-0.00083		0.0028	
	(0.034)		(0.00086)		(0.0028)	
Percentage indigenous groups	0.0118		0.00095		-0.0010	
	(0.129)		(0.0030)		(0.0055)	
Indicator of whether a regional center is located in a California county			0.0072		0.032	
			(0.012)		(0.023)	
Indicator of whether a county is located in Oregon					0.782***	
					(0.0769)	
Time trend	0.011	0.032***	0.015***	0.014***	0.015***	0.014***
	(0.015)	(0.0056)	(0.0012)	(0.0011)	(0.0019)	(0.0011)
Constant	3.76	0.438***	-0.204*	-0.051***	-0.136	0.0059
	(2.37)	(0.103)	(0.106)	(0.019)	(0.155)	(0.020)
County fixed effects?	NO	YES	NO	YES	NO	YES
Mean of dependent variable	0.93	0.93	0.094	0.094	0.186	0.186
Observations	109	109	880	880	989	989
R-squared	0.57	0.38	0.22	0.17	0.68	0.14

Notes: for Oregon (column 1 and column 2) the dependent variable is the age-specific (for ages six through 18) percentage of children who had autism in December 2005 in a particular county (i.e., the autism rate multiplied by 100). For California, the dependent variable is the percentage of 8-year olds with autism measured in December of each year between 1990 and 2005. Precipitation is the average annual precipitation, measured in inches, for the years when a cohort was under the age of three. Indigenous groups include American Indians, Alaskan Natives, Hawaiian Islanders, and Pacific Islanders. Standard errors are adjusted in column (1), column (3), and column (5) to allow for correlation of error terms between age cohorts within a county. *** = significantly different from zero at a one-percent confidence level; ** = significantly different from zero at a five-percent confidence level; * = significantly different from zero at a 10-percent confidence level.

Table 6: Ordinary Least Squares Cable Regressions

	California		Pennsylvania		Pooled	
	(1)	(2)	(3)	(4)	(5)	(6)
Percentage of households with cable when cohort was 0-2 years of age	0.00014**	0.00014**	0.00021	0.00016	0.00015***	0.00015***
	(0.00005)	(0.00005)	(0.00018)	(0.00017)	(0.00005)	(0.00005)
Logarithm of population	0.0038**	0.0038**	0.0069	0.0070	0.0042**	0.0042***
	(0.0017)	(0.0018)	(0.0068)	(0.0068)	(0.0017)	(0.0017)
Per capita income (000)	0.00099**	0.00099**	0.00068	0.00058	0.00091**	0.00091**
	(0.00046)	(0.00047)	(0.00094)	(0.00094)	(0.00044)	(0.00044)
Percentage Hispanic	0.00006	0.00005	0.00018	0.00030	0.00004	0.00004
	(0.0001)	(0.0001)	(0.0010)	(0.0010)	(0.00011)	(0.00011)
Percentage Black	0.0007**	0.0007**	0.00089**	0.00081**	0.00059***	0.00059***
	(0.0003)	(0.0003)	(0.00039)	(0.00037)	(0.00015)	(0.00015)
Percentage indigenous groups	0.0019*	0.0019*	-0.132*	-0.130*	0.0018**	0.0018**
	(0.0010)	(0.0010)	(0.072)	(0.074)	(0.00089)	(0.00090)
Indicator for a Pennsylvania intermediate unit					0.0054	0.0054
					(0.0053)	(0.0054)
Indicator of whether a regional center is located in a California county	0.0016	0.0016			0.0015	0.0014
	(0.0036)	(0.0036)			(0.0036)	(0.0036)
Time trend	0.00094***		0.0041***		0.0021***	
	(0.00027)		(0.00060)		(0.00031)	
Constant	-0.062***	-0.027	-0.105	-0.0020	-0.076***	-0.017
	(0.23)	(0.023)	(0.078)	(0.081)	(0.021)	(0.020)
Age indicators included?	NO	YES	NO	YES	NO	YES
Mean of dependent variable	0.0211	0.0211	0.0249	0.0249	0.0225	0.0225
Observations	882	882	486	486	1,368	1,368
R-squared	0.11	0.14	0.35	0.47	0.16	0.21

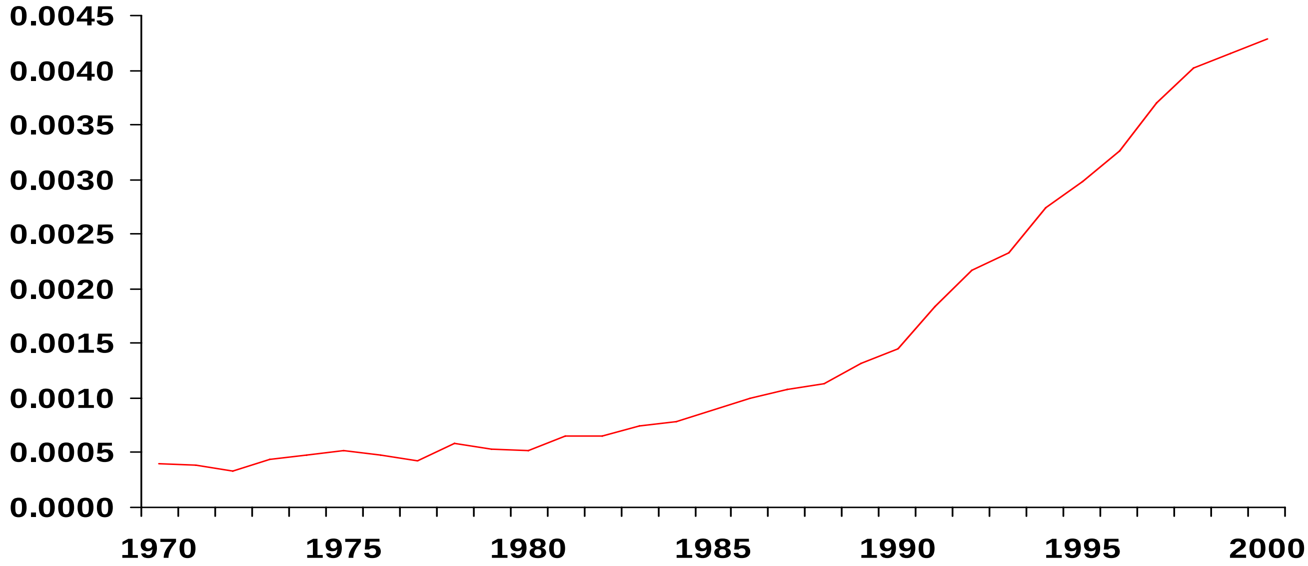
Notes: the dependent variable is the age-specific (for ages six through 18) percentage of children who had autism in December 1990 in a particular county (i.e., the autism rate multiplied by 100), and the county-specific autism rate for six year-olds in December 1991, 1992, 1993, 1994, and 1995. Seven California counties and four Pennsylvania counties that received reception from only a single television station in 1972 are omitted from the regressions. Indigenous groups include American Indian and Alaskan Natives. A set of indicator variables for each cohort are included in the specifications in column (2), column (4), and column (6). *** = significantly different from zero at a one-percent confidence level; ** = significantly different from zero at a five-percent confidence level; * = significantly different from zero at a 10-percent confidence level.

Table 7: Fixed Effects Cable Regressions

	California		**Pennsylvania**		**Pooled**	
	(1)	(2)	(3)	(4)	(5)	(6)
Percentage of households with cable when cohort was 0-2 years of age	0.00014 (0.00010)	0.00015 (0.00010)	0.00048*** (0.00019)	0.00034** (0.00017)	0.00027*** (0.00009)	0.00027*** (0.00009)
Time trend	0.00094*** (0.00027)		0.0035*** (0.00051)		0.0018*** (0.00026)	
Constant	0.0076** (0.0032)	0.042*** (0.0073)	-0.027*** (0.0059)	0.072*** (0.0126)	-0.0048* (0.0029)	0.050*** (0.0065)
Age indicators included?	NO	YES	NO	YES	NO	YES
Mean of dependent variable	0.0211	0.0211	0.0249	0.0249	0.0225	0.0225
Observations	882	882	486	486	1,368	1,368
R-squared	0.04	0.07	0.25	0.39	0.10	0.15

Notes: the dependent variable is the age-specific (for ages six through 18) percentage of children who had autism in December 1990 in a particular county (i.e., the autism rate multiplied by 100), and the county-specific autism rate for six year-olds in December 1991, 1992, 1993, 1994, and 1995. Seven California counties and four Pennsylvania counties that received reception from only a single television station in 1972 are omitted from the regressions. A set of indicator variables for each cohort are included in the specifications in column (2), column (4), and column (6). *** = significantly different from zero at a one-percent confidence level; ** = significantly different from zero at a five-percent confidence level; * = significantly different from zero at a 10-percent confidence level.

Figure 1
California Autism Rate by Birth Year Based on 2005 Data

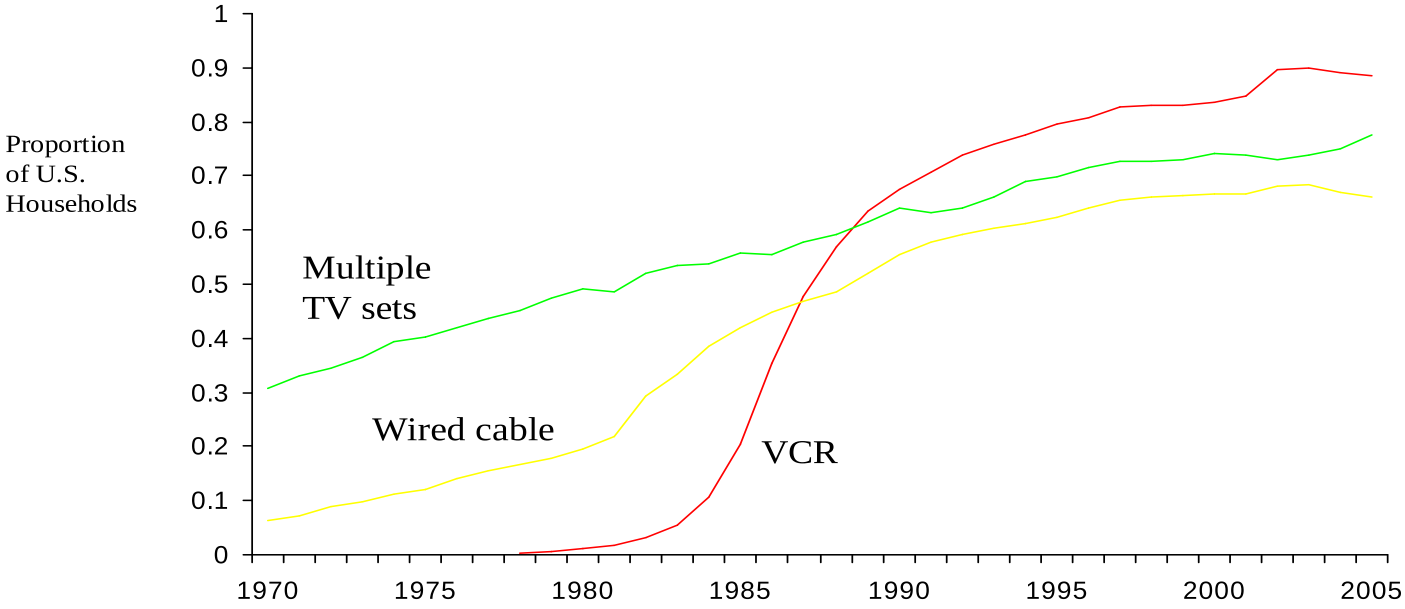


Source: California Department of Developmental Services, NCHS.

Notes: based on people who were receiving services in 2005 at a California Department of Developmental Services regional center.

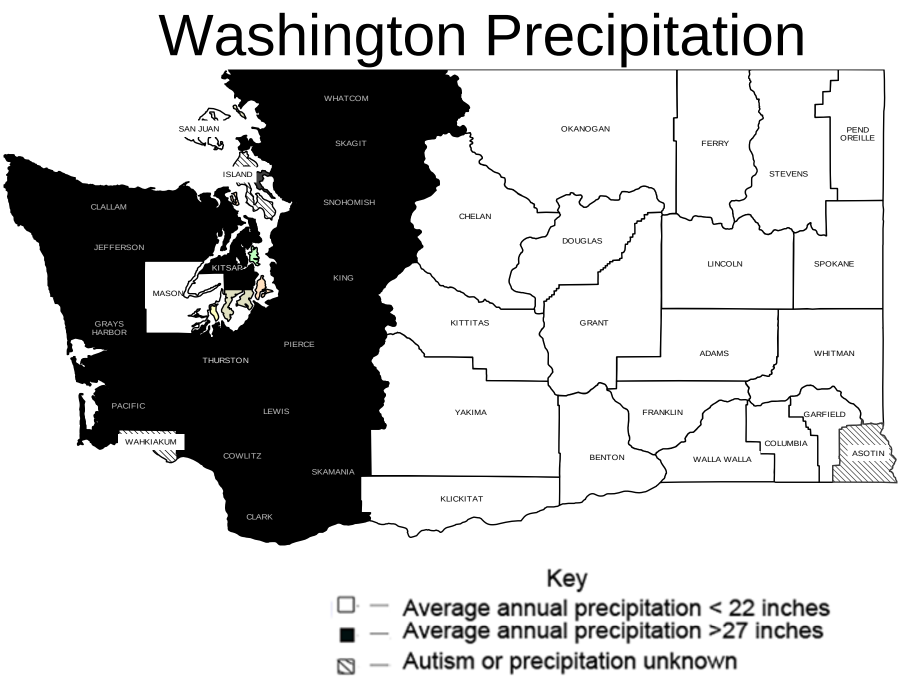
Figure 2

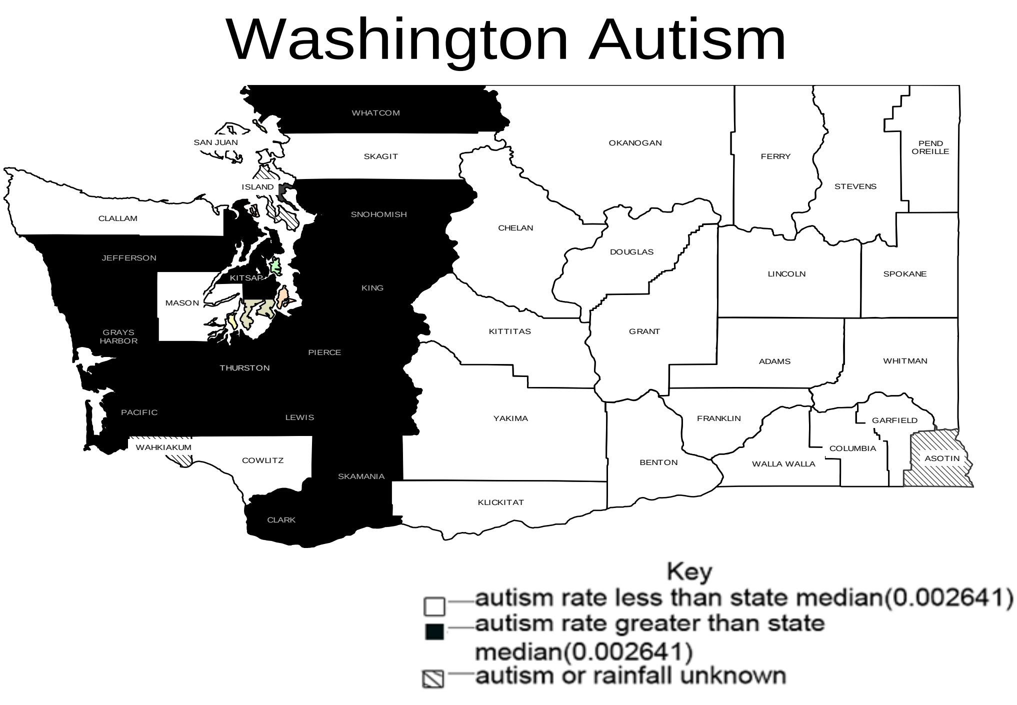
Proportion of U.S. Households With a VCR, Cable, or Multiple TV Sets



Source: Nielsen Media Research.

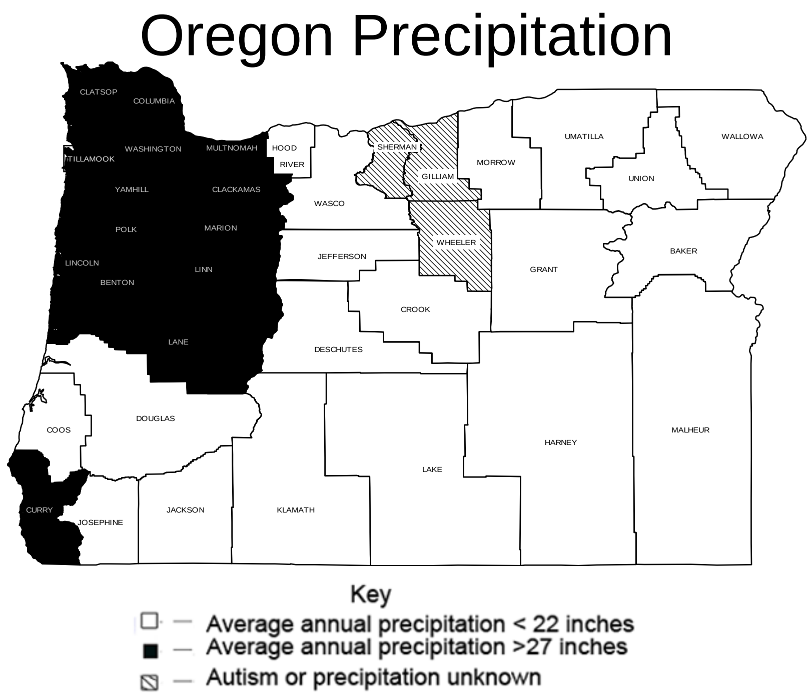
Figure 3
Precipitation (1990-2001) and Autism Rates (2005) of Washington Counties

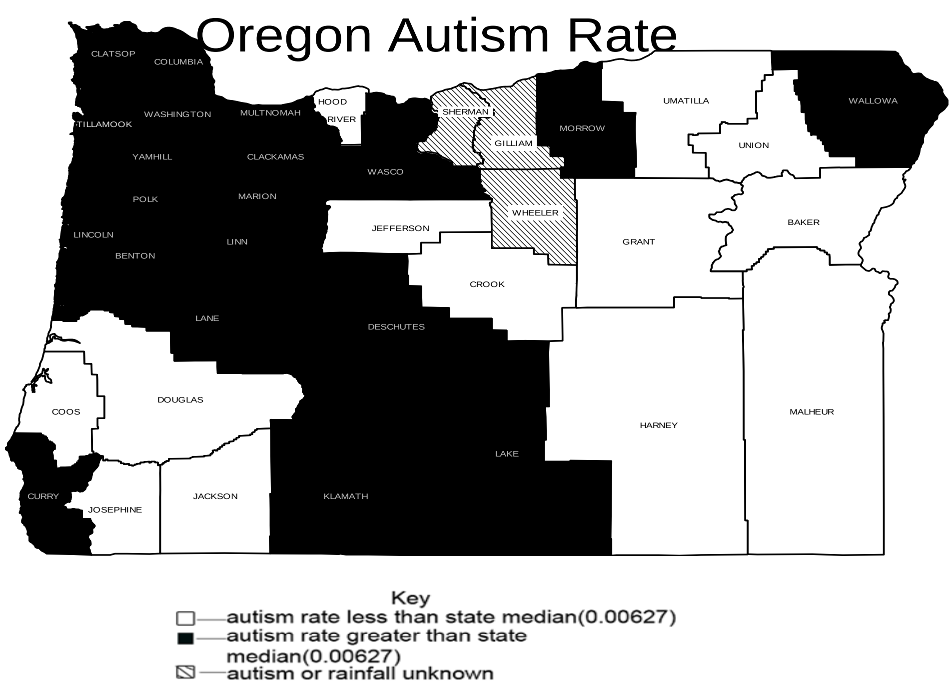




Notes: autism rates are for children between the ages of six and 18. Precipitation data are measured from July 1, 1990 through June 30, 2001.

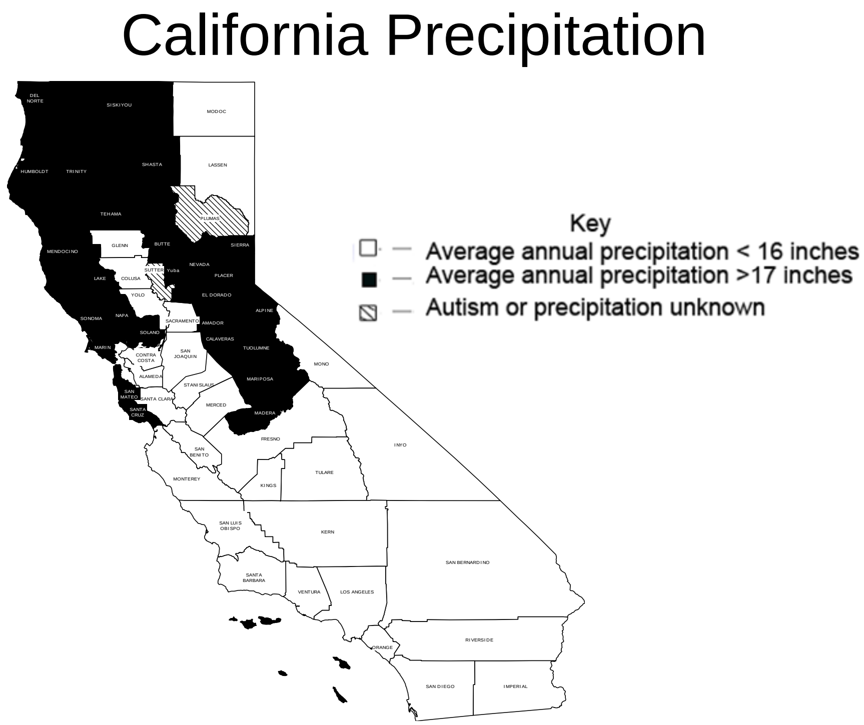
Figure 4
Precipitation (1990-2001) and Autism Rates (2005) of Oregon Counties

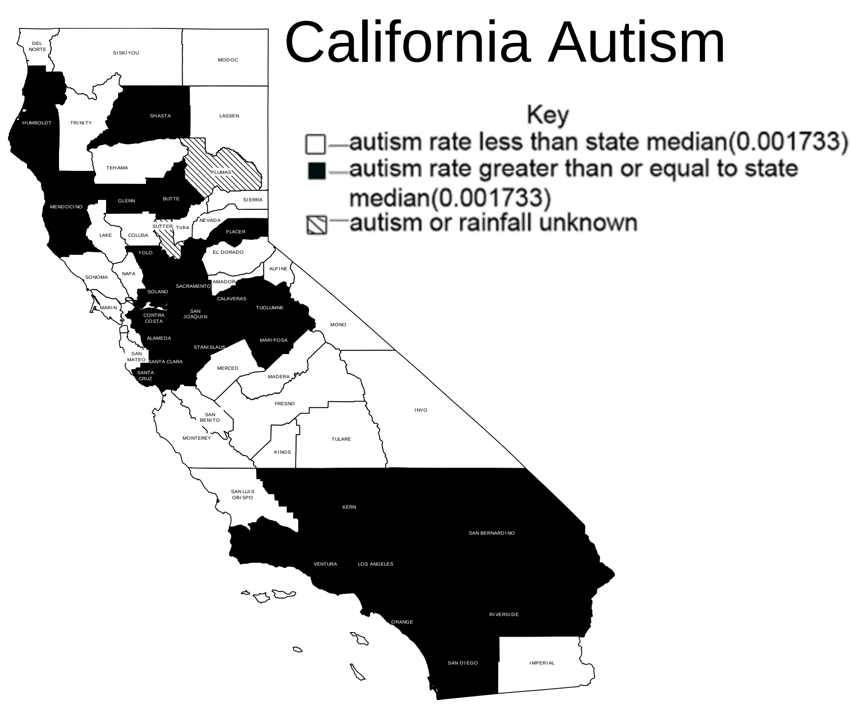




Notes: autism rates are for children between the ages of five and 18. Precipitation data are measured from July 1, 1990 through June 30, 2001.

Figure 5
Precipitation (1990-2001) and Autism Rates (2005) of California Counties





Notes: autism rates are for children between the ages of six and 18. Precipitation data are measured from July 1, 1990 through June 30, 2001.

Figure 6

Precipitation in a County When a Cohort Was Under the Age of 3 (Indexed to Each County's 1987-2001 Mean)

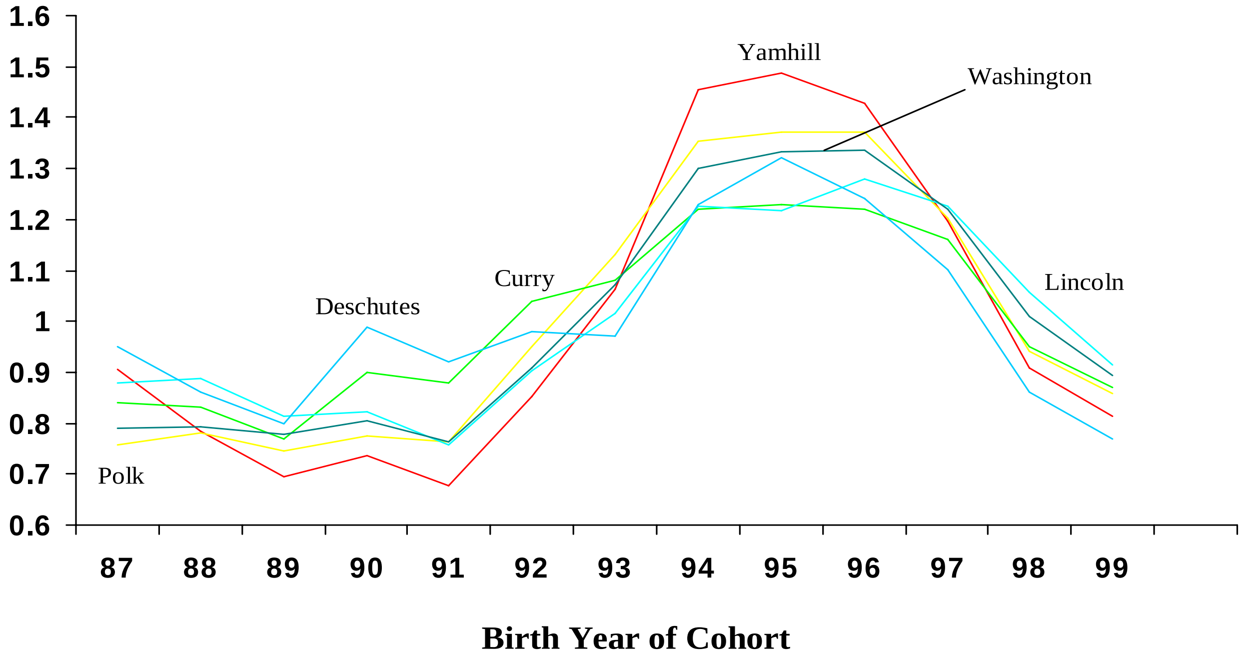


Figure 7

Proportion of Households in a County Who Had a Cable Subscription When a Cohort Was Under the Age of 3