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ABSTRACT

The Effects of Pharmacological Treatment of ADHD on Children's Health*

We are the first to investigate longer-term effects of pharmacological treatment of ADHD on children's health. We rely on a difference-in-differences strategy while exploiting Danish register-based panel data for children born in 1990-1999. We study effects of treatment initiated between ages five and ten and document that treated children benefit in terms of fewer hospital contacts in general, fewer emergency ward contacts, and fewer injuries. Estimated effects are large: early treatment is effective in reducing the probability of at least one hospital contact in a given year with around 30% compared to the mean. Effects are significantly smaller in later cohorts where more children are diagnosed and treated.

JEL Classification: I1

Keywords: ADHD, evaluation, health

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"TO date, no study has found any long-term benefit of attention-deficit medication on academic performance, peer relationships or behavior problems, the very things we would most want to improve. Until recently, most studies of these drugs had not been properly randomized, and some of them had other methodological flaws."

- Professor Emeritus of Psychology, L. Alan Sroufe, Minnosota: "Ritalin Gone Wrong", New York Times, January 12, 2012.

I. Introduction

One of the most publicly debated new medical technologies is pharmacological treatment of children diagnosed with Attention-Deficit/Hyperactivitiy-Disorder (henceforth ADHD). There are concerns, even among some professionals in the field, that children are over-diagnosed with ADHD; that we know too little about effects of ADHD medication and that children are, in fact, over-treated with ADHD medication. This is the first paper to investigate longer-run health effects of pharmacological treatment of ADHD. More generally, our paper speaks to the literature on the impacts of early health interventions.

ADHD is one of the most common chronic mental health problems among young children. ADHD is estimated to affect about 3-7 % of all children (The Danish Association for Child and Adolescent Psychiatry, 2008; American Psychiatric Association, 2000) or on average one child – more often a boy than a girl – in every classroom. Core symptoms associated with ADHD are attention deficiencies, hyperactivity and impulsiveness and children often simultaneously suffer from other behavioral problems along with depression and anxiety. Hence, ADHD is likely to affect not only one's overall health capital but also one's tendency to engage in risky health behaviors.

It is well documented that individuals suffering from ADHD – even when in pharmacological treatment – have much worse long-term outcomes than others who are comparable in terms of age and gender (Dalsgaard et al. (2002), Mannuzza and Klein (2000)). In addition, both Currie and Stabile (2006) as well as Fletcher and Wolfe (2008) document that ADHD symptoms reduce learning outcomes as measured by short-run educational attainment. Numerous randomized controlled studies document that treatment with central nervous system stimulants[1] is effective in terms of reducing ADHD core symptoms and improving social behavior (van der Oord et al. (2008)). However, as will be discussed in detail below, many of these randomized controlled trials suffer from serious problems related to external validity and most of them only involve a small number of children. In addition, most existing studies have very short follow up periods implying that we effectively know very little about long-term effects of pharmacological treatment on human capital accumulation in general and health capital more specifically. Though symptoms are relieved by pharmacological treatment, it is not clear whether and how health, education and labor market outcomes are affected. Accordingly, our paper presents novel evidence of the effect of early pharmacological treatment on children's health capital.

[1] Methylphenidate is the most common pharmacological treatment for ADHD, better known under the brand name Ritalin. A more recent development is Concerta; a once daily extended release formulation of methylphenidate. Another commonly used agent is dexamphetamine, however no extended-release formulations of this are available in Denmark and the use therefore very limited.

In order to credibly identify causal effects, we rely on a difference-in-differences strategy. Specifically, since a diagnosis is rarely established and treatment initiated before the age of five, we compare outcomes of treated children prior to (age four and three) and after treatment (age 10 +) with untreated diagnosed children before and after.[2] This identification strategy allows for non-random selection into treatment based on, for instance, severity of symptoms or parental backgrounds as long as these mechanisms are constant over time. As outcomes we consider hospital contacts, emergency ward visits, and the occurrence of injuries.

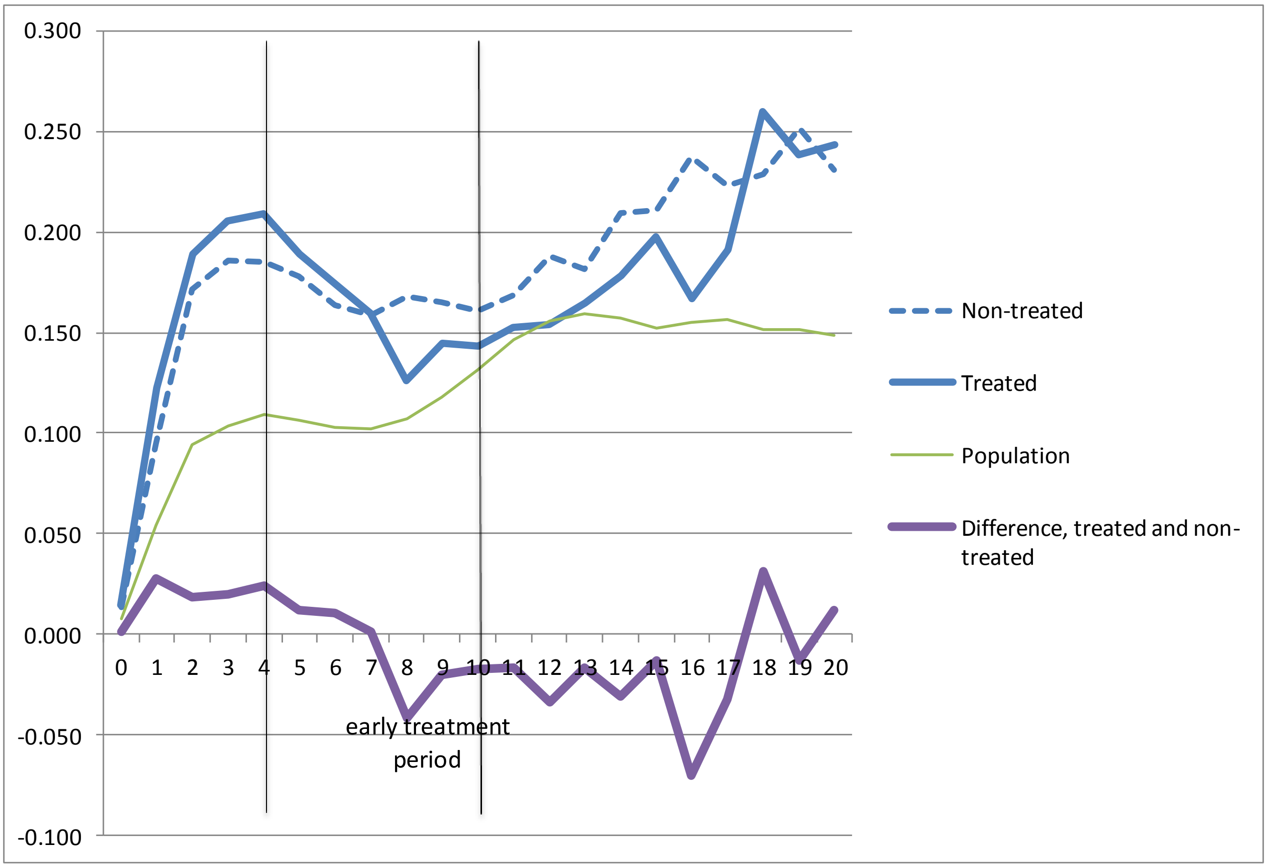
Figure 1 illustrates our identifying variation and main results for the probability of injuries in a given year.[3] The figure demonstrates that treated children have a higher injury probability prior to diagnosis and treatment than non-treated children, but that (except for the year of birth when children are very rarely exposed to injury) the development is otherwise parallel. After the diagnosis is established and treatment is initiated), this tendency is reversed, however. After the age of seven, treated children – who were initially more disadvantaged – perform better than non-treated children.

[2] Our data allow us to exclude the few children diagnosed before the age of five. Among these 419 children excluded, one was treated before the age of five.

[3] The picture is similar if we consider other outcomes. Contacts with general hospitals are shown in Figure A2 in the Appendix.

FIGURE 1

PROBABILITY OF INJURIES BY TREATMENT STATUS*



*Treatment is defined as pharmacological treatment for at least six months in a year before the age of ten. Details about the measurement of the outcome and the sample follow below.

We use a combination of Danish longitudinal population registers that apart from rich socio-economic background variables include the following key information: 1) links between parents and all children via unique personal identifiers, 2) the history and exact timing of prescription drug usage for parents and children, 3) psychiatric history and timing of diagnoses for parents and children, and 4) inpatient disease histories. Such data are practically inexistent outside of Scandinavia and improve the prospects for documenting long-term impacts of pharmacological treatment because it does not suffer from attrition or sample selection, which are inherent in followups of populations from randomized controlled trials forming the basis for the main part of the previous literature. In addition, outcome measures of intrinsic importance are readily available.

In line with Figure 1, we find that extensive use of health care services and a high number of injuries at ages 1-4 are predictive of later diagnosis and treatment. Furthermore, our results show that treated children benefit from pharmacological treatment in terms of emergency ward contacts, injuries and poisoning. These results are robust to a number of alternative specifications and sensitivity checks. We do, however, find heterogeneous effects across cohorts. Estimated effects are significantly smaller in later cohorts where more children are diagnosed and treated pharmacologically before the age of ten. There are still significant gains from treatment in the later cohorts, but the results support a hypothesis of diminishing returns to broadening the group of treated.

The paper is structured as follows: Section II reviews the literature on causes of ADHD and links between ADHD and accumulation of health capital, Section III presents the background for the analysis and Section IV shows data. Section V presents the empirical framework, Section VI the results and Section VII concludes.

II. Causes of ADHD and Links between ADHD and Health Capital

Recently, a series of papers such as Cunha et al. (2006), Currie (2011), and Currie and Almond (2010) have emphasized the importance of investing early in particularly vulnerable children. Moreover, Cunha and Heckman (2007) show theoretically that early investments not only have a large potential pay-off, they are also efficient in the sense that an equity-efficiency trade-off does not exist, which is the case for later investments. The reasons are that skills acquired in one period persist into future periods and that skills produced at one stage raise the productivity of investment at subsequent stages. Importantly, skills are multidimensional and are likely to complement each other. The group of children with ADHD is a prime example for which we would expect early investments with immediate effects on health capital in general to also have long-term consequences for later health and human capital attainment. This paper investigates investments via pharmacological treatment. Early take-up of pharmacological treatment may have long-term effects on health simply because it improves behavior and therefore the likelihood of future treatment but also because of dynamic complementarities: treatment may improve cognitive skills[4] including less impulsive behavior and more awareness of the consequences of one's actions that feed back on health behavior.

To set the scene, we sketch a simple model for the production of skills during childhood. We follow Heckman (2008) and co-authors. The model consists of three periods, $t = 1,2,3$, corresponding to early and late childhood and early youth. Parents invest in their children in period one and two and the investments of interest for this paper are ADHD related interventions in period one, I_1. The technology of skill production for a given child in period t can be summarized in the following way:

$$O_{t+1} = f_t(h, O_t, I_t),$$

where O is a vector of outcomes, f is the production function, h measures initial conditions such as birth weight, mental health (ADHD) and parental abilities, and I indicates parental investments such as pharmacological treatment.[5]

[4] IQ, for example, is malleable up until the age of 10, see Cunha et al. (2006)

[5] Here we ignore the fact that seeking the actual diagnosis may be affected by parental background or the peer group, see e.g. Elder and Lubotsky (2009).

Given the production function, it is clearly critical to be aware of the causes of ADHD since they may be correlated with initial conditions that determine later outcomes. Though not perfectly described, it is well known that genetic factors are very important (Faraone and Doyle (2001)), but also premature birth, birth complications, maternal smoking and alcohol use during pregnancy are associated with ADHD (Linnet et al. (2003)). In our sensitivity section we will therefore investigate whether effects of treatment vary with health at birth and maternal smoking during pregnancy. Children with ADHD are also more likely than others to have language, cognitive and memory problems (e.g. Jensen et al. (2001) and Frazier et al. (2004)). To address this, we investigate the extent to which results are affected by children with mental retardation (11% in our sample).

The existing literature only considers the direct link between ADHD and measures of human capital (educational outcomes) and not to what degree (or whether at all) pharmacological treatment may serve as a remedy. Currie and Stabile (2006) find that ADHD symptoms at ages 5-12 reduce learning outcomes as measured by short-run educational attainment at ages 9-16.[6] They conclude that mental disorders are much more important for average learning outcomes than physical disorders. Inclusion of siblings fixed effects does not change the results. Fletcher and Wolfe (2008) confirm Currie and Stabiles' findings for short-run educational outcomes and find similarly strong effects on long-run educational outcomes. However, they do find that accounting for family fixed effects makes most of the negative long-run effects disappear. By controlling for ADHD symptoms of siblings they show that rather than reflecting the fact that families learn how to compensate for the ADHD symptoms, a child with ADHD symptoms indeed affects siblings negatively; in other words, negative effects extend beyond those on the individual himself. In fact, for many learning

[6] In their samples from Canada and the US in 1994, only 7-10 % of children with a high hyperactivity score were in drug therapy. These numbers are similar to the 12% reported by Mannuzza and Klein (2000).

outcomes, the effect of ADHD on siblings' human capital accumulation is as high as the effect of own ADHD on human capital accumulation. For instance, for outcomes such as years of education, school drop-out, college enrolment, and school suspension, the effect of siblings' ADHD on human capital accumulation is significant and of the same order of magnitude for the sibling as for the child him- or herself. On the other hand, for outcomes such as grade repetition, special education and GPA, the effect of ADHD on siblings' outcomes is insignificant and negligible in size.

A series of papers (Ding et al. (2009) and Fletcher and Lehrer (2009, 2011)) instrument for poor mental health (including ADHD) using genetic markers and investigate the effects of poor mental health on academic performance. They find some evidence that inattentiveness is associated with lower academic achievement. The inherent problem, of course, is that there is no knowledge about direct effects of gene composition on educational outcomes. The authors have access to a series of instruments, which do pass conventional F-tests for over-identification.

As mentioned above, it is well-documented that treatment with central nervous system stimulants is effective in terms of reducing the number and impact of ADHD core symptoms.[7] This evidence is based on a series of randomized controlled trials. In the seminal Multimodal Treatment Study of Children with ADHD (henceforth MTA), 579 children aged 7-9.9 years suffering from ADHD were assigned to different types of treatment for a period of 14 months. Of these, 144 children were assigned to pharmacological treatment. Within the 14-month period careful medication management with or without behavioral treatment was shown to be superior to routine community care or behavioral treatment in terms of reducing core symptoms, see MTA (1999). In follow-up

[7] The information is surveyed and incorporated in national treatment guidelines e.g. The Danish Association for Child and Adolescent Psychiatry (2008) for Denmark and Paykina and Greenhill (2008) for the US.

studies considering children three years after randomization, the difference in symptom relief diminishes over time and eventually disappears (see MTA (2004) and Molina et al. (2009)). These studies find no impact of medication management on functioning outcomes such as social skills, relations or reading achievement.

While being informative about symptom relief, these studies cannot stand alone when it comes to determining the long-term consequences of pharmacological treatment of ADHD. Unfortunately, the MTA study, as well as other randomized controlled trials, suffers from serious problems, the most important being selection into (or out of) the experiment; in the case of the MTA study only 13 % of the children initially screened ended up participating. Children were for example excluded if they had low IQ, if they were hospitalized or were otherwise ill, if their primary care-taker was non-English speaking, or if there was no phone in the household. Similarly, a large share of parents refused to let their child enroll into experimental treatment. All of these factors are unlikely to be uncorrelated with gains from treatment. Other problems include Hawthorne effects, attrition and small sample sizes; some studies had as little as ten treated children (see van der Oord et al (2008)). In addition, absent register-based outcome measures, studies rely on test scores or self-reported outcomes collected among non-blinded respondents in follow-up evaluations. Furthermore, random controlled trials only ever measure the intention to treat (ITT) among those who choose to participate, which may be very different from the average treatment effect on the treated (ATET) in the population if persistent individual factors such as own preference for treatment or physician's prescription practices influence the take up of pharmacological treatment. And ultimately, we know little from the existing randomized controlled trials about the longer-term effects of pharmacological treatment on human capital accumulation in general and health capital more specifically.

There is some evidence of favorable long-term consequences of pharmacological treatment of ADHD on human capital accumulation based on observational methods. In a survey, Paykina and Greenhill (2008) report less school disruption, anti-social behavior and academic failure following pharmacological treatment, while others raise doubt about such effects (e.g. Mendez et al. (2011)). Regarding accumulation of health capital more specifically, we are aware of only one study by Marcus et al. (2008) that considers the link between pharmacological treatment and health. Their study uses a duration model to investigate the association between compliance in pharmacological treatment and injuries for a group of children in treatment. They find that children treated with high intensity had a non-significantly lower risk of injury than those treated with low intensity.

III. Background

This section describes the decision stages and agents involved in diagnosing and treating ADHD. We consider three stages: The first step involves the seeking of a referral for evaluation at the specialist-level, the second step the establishment of a diagnosis, and the final step the treatment decision.

III.A Seeking of a diagnosis and physician assignment

Parents – and if not parents then in some cases teachers or school nurses – decide whether to seek a referral for evaluation in the first place. Typically, this involves a visit to the family's general practitioner (GP) who serves as a gatekeeper for specialist treatment. The GP can then – if he agrees with the indications – provide parents with a referral to a specialist, either employed at a child and adolescent psychiatric outpatient clinic at general hospitals or at a private clinic. In the vast majority of cases, relevant specialist physicians are child and adolescent psychiatrists, but pediatricians and neurologists also do assessments and diagnose.

In Denmark, consultations with the GP are free of charge (for the parents) as are those with specialist physicians when equipped with a referral from the GP. Whether patients end up with a specialist employed at general hospitals or at private clinics depends on the available specialist services in the area and whether the child and adolescent psychiatric outpatient clinic at the local general hospital is overbooked. Patients are assigned an available relevant physician at the psychiatric hospital or ward. It *is* possible to consult with a specialist at a private clinic without a GP reference, but parents must then pay the costs themselves.

III.B Diagnoses

In Denmark, the *International Classification of Diseases* (ICD) diagnostic manual developed by WHO is used for diagnostic purposes.[8] Recently, the Danish Association for Child and Adolescent Psychiatry has published a so-called reference program for ADHD that examines the current evidence for diagnostic tools and treatment practices; see the Danish Association for Child and Adolescent Psychiatry (2008). Measurements of psychopathology such as the Child Behavior Checklist (CBCL) has been standardized in Danish (Bilenberg, 1999) and has been part of the standard clinical assessment in most child and adolescent psychiatric clinics in Denmark since the early 1990'ies. Multi-informants are always used in the assessment of children at hospital-based child and adolescent psychiatric units and a standard assessment often includes a direct observation of the child by a trained psychiatric nurse at the day-care/school and at home with the family is often part of the assessment and also a test of the cognitive level by a psychologist.

[8] ADHD is classified as an F90 diagnosis. This covers hyperkinetic disorders, activity and attention disorders, other hyperkinetic behavioral disorders, and hyperkinetic behavioral disorders without further specification. This definition represents a subgroup of ADHD used in the American diagnosis scheme DSM-IV and the prevalence of ADHD is therefore lower than what is reported in US data. See WHO (1993).

III.C Pharmacological treatment

Given an ADHD diagnosis, the specialist may recommend pharmacological treatment. This typically implies treatment with Methylphenidate and is the case for 98% of the children in our sample with an ADHD diagnosis established and in treatment before the age of ten. Methylphenidate is almost exclusively used to treat ADHD symptoms.[9] Medications used in the treatment of ADHD all act to increase brain catecholamine level. Although Methylphenidate has been used therapeutically for more than 60 years, the precise prefrontal cortical and subcortical mechanisms of action are poorly understood, but are associated with its ability to block the dopamine and norepinephrine re-uptake transporters (Solanto (1998)). It is well-known, however, that dopamine increases attention, interest and motivation. Common side effects are insomnia, headaches, decreased appetite, increased blood pressure and heart rate, and symptoms of depression and anxiety.

Parents may, of course, refuse pharmacological treatment. Thus, both the specialist a child meets, the severity of early symptoms, and parental preferences may impact on the likelihood of being treated.[10] Regardless of the choice of pharmacological treatment and the severity of the condition, the reference program advises that children with an ADHD diagnosis are offered social skills training.

[9] It may, however, also be used to treat the rare condition of narcolepsy.

[10] In our companion paper, Dalsgaard et al. (2012), we directly exploit variation in physicians' propensity to prescribe to study the effects of pharmacological treatment on human capital outcomes other than health. When considering schooling and crime outcomes, it is clearly not possible to exploit the difference-in-differences strategy employed in this paper.

IV. Data

We consider the population of Danish children born in the period from 1990-1999. Our main data stem from the Danish Psychiatric Central Register; see Munk-Jørgensen and Mortensen (1997) for a detailed description. These nationwide data include information about psychiatric history and diagnoses for parents and children diagnosed at Danish general hospitals. The data cover the period from 1960-2010 for the adult population but before 1994, information about children's psychiatric diagnoses was not available. Because it is extremely rare that children are diagnosed before age 4, we include children born as early as 1990.

Registers are not constructed for research, but for administrative purposes. Diagnoses in the registers are clinical diagnoses, not the result of a systematic well-described uniform psychiatric assessment and diagnostic routines may differ between different clinical departments across the country. The validity of the diagnoses of ADHD in the Danish Psychiatric Central Register has previously been shown to be good. The agreement percentage on a full diagnosis of ADHD according to the American Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DSM-IV) was 89%, while the remaining 11% lacked only 1 symptom to fulfill the ADHD diagnosis (Linnet et al. (2009)).

Via unique personal identifiers, the information from the Danish Psychiatric Central Register is merged with registers containing rich socio-economic background variables (from 1980-2009), in-patient somatic disease histories (from 1980-2010), and prescription drug purchases for both parents and children (from 1997-2008). In the period from 2007-2009, we also have additional, and very detailed, educational information including enrolment in special education.

We now outline the variables used in our empirical analysis and describe our sample in terms of observed background characteristics, treatment patterns, and outcomes.

IV.A Variable Definitions and Summary Statistics

In order to separate the definition of treatment from the measurement of outcomes, we focus on those who are diagnosed with ADHD before the age of ten. After all, we only want to consider cases for which early treatment is an option. Presumably, these represent cases with stronger symptoms or more attentive parents compared to children diagnosed later. Tables 1A and 1B show the development in diagnoses across birth cohorts. Table 1A shows the diagnosis pattern for children who are diagnosed before 2010, while Table 1B shows the diagnosis pattern for children who are diagnosed before the age of 10. About 8,700 children from the 1990-1999 birth cohorts were diagnosed with ADHD before 2010. This corresponds to just over 1% of the children and the share seems fairly robust across cohorts. 0.6% of all children are diagnosed with ADHD before the age of ten. The average age at diagnosis has decreased over time and boys are almost four times more likely than girls to receive an ADHD diagnosis. The gender distribution and prevalence rate of a clinical diagnosis of ADHD in this birth cohort is comparable to the prevalence in other Scandinavian countries (Heiervang et al. (2007)), but as expected somewhat lower than the prevalence in many population-based studies, where a sample of individuals is drawn from a country or community and assessed according to accepted diagnosis criteria (Wittchen et al. (2011)).

TABLE 1A

PERCENTAGE OF BIRTH COHORT DIAGNOSED WITH ADHD BEFORE 2010

Birth Cohort	Cohort size	Percent with ADHD among all	Average age at diagnosis	Percent with ADHD among boys	Percent with ADHD among girls
1990	69,026	0.91	12.28	1.34	0.45
1991	69,667	1.10	11.66	1.72	0.45
1992	72,869	1.25	11.32	1.91	0.54
1993	72,227	1.27	10.75	1.98	0.53
1994	74,766	1.29	10.06	2.07	0.48
1995	74,342	1.31	9.46	2.08	0.49
1996	71,700	1.32	8.93	2.11	0.49
1997	71,342	1.28	8.35	2.12	0.40
1998	69,549	1.23	7.84	1.96	0.46
1999	69,189	1.21	7.17	1.90	0.49
All cohorts	714,677	1.22	9.70	1.92	0.48

*

TABLE 1B

PERCENTAGE OF BIRTH COHORT DIAGNOSED WITH ADHD BEFORE AGE TEN

Birth Cohort	Cohort size	Percent with ADHD among all	Average age at diagnosis	Percent with ADHD among boys	Percent with ADHD among girls
1990	69,026	0.29	7.01	0.48	0.08
1991	69,667	0.37	6.85	0.63	0.10
1992	72,869	0.42	6.93	0.70	0.12
1993	72,227	0.44	7.03	0.73	0.14
1994	74,766	0.53	7.11	0.88	0.16
1995	74,342	0.63	7.24	1.04	0.19
1996	71,700	0.72	7.20	1.17	0.25
1997	71,342	0.84	7.22	1.42	0.23
1998	69,549	0.96	7.22	1.52	0.36
1999	69,189	1.21	7.17	1.90	0.49
All cohorts	714,677	0.64	7.14	1.04	0.21

TABLE 2

OBSERVABLE CHARACTERISTICS AT CHILDBIRTH, CHILDREN WITH AND WITHOUT AN ADHD DIAGNOSIS BEFORE THE AGE OF TEN*

Variable	No ADHD diagnosis			ADHD diagnosis before age 10		
	# obs	Mean	Std. Dev.	# obs	Mean	Std. Dev.
Child:						
Boy (0/1)	710120	0.51	0.50	4557	**0.84**	0.37
5-minute APGAR score	654512	9.83	0.86	4331	**9.73**	1.10
Birthweight less than 1,500 gran	656115	0.01	0.08	4353	**0.02**	0.14
Birthweight, 1,500-2,500 grams	656115	0.04	0.20	4353	**0.07**	0.25
Birthweight, above 2,500 grams	656115	0.95	0.21	4353	**0.91**	0.28
Complications at birth (0/1)	710120	0.21	0.40	4557	**0.29**	0.45
Gestation length (weeks)	654637	39.59	1.92	4346	**39.21**	2.53
Mental retardation (0/1)	710120	0.00	0.06	4557	**0.11**	0.32
Mother:						
Age at childbirth	707357	29.05	4.81	4553	**28.14**	5.15
High school or less (0/1)	648886	0.39	0.49	4358	**0.52**	0.50
Length of education (years)	648886	12.25	2.52	4358	**11.41**	2.30
Unemployed less than 13 weeks	664613	0.83	0.38	4431	**0.80**	0.40
Unemployed 13-26 weeks (0/1)	664613	0.11	0.32	4431	**0.14**	0.34
Unemployed more than 26 week	664613	0.06	0.23	4431	**0.06**	0.24
Employed in November (0/1)	664576	0.63	0.48	4431	**0.51**	0.50
Gross income (2004 prices)	664576	188327	109197	4431	**174186**	74643
Psychiatric diagnosis (0/1)	707736	0.04	0.19	4553	**0.10**	0.30
Heart disease (0/1)	707736	0.03	0.16	4553	**0.03**	0.17
Respiratory disease (0/1)	707736	0.11	0.31	4553	**0.19**	0.39
Smoker (0/1)	562081	0.08	0.27	3945	**0.18**	0.39
Father:						
Age at child birth	684806	31.89	5.76	4277	**31.23**	6.25
High school or less (0/1)	632113	0.32	0.47	4064	**0.44**	0.50
Length of education (years)	632113	12.21	2.58	4064	**11.33**	2.37
Unemployed less than 13 weeks	651266	0.88	0.32	4197	**0.84**	0.36
Unemployed 13-26 weeks (0/1)	651266	0.06	0.23	4197	**0.08**	0.27
Unemployed more than 26 week	651266	0.06	0.24	4197	**0.08**	0.27
Employed in November (0/1)	651237	0.89	0.32	4197	**0.84**	0.36
Gross income (2004 prices)	651237	296103	199811	4197	**259101**	144851
Psychiatric diagnosis (0/1)	685964	0.03	0.18	4281	**0.08**	0.27
Heart disease (0/1)	685964	0.03	0.17	4281	**0.04**	0.20
Respiratory disease (0/1)	685964	0.09	0.29	4281	**0.14**	0.34

*Bold indicates that mean for children with an ADHD diagnosis before the age of ten is significantly different from the mean for children without an ADHD diagnosis at the 5% level. With the exception of mental retardation, which is diagnosed in connection with the ADHD diagnosis, all variables are measured in the year just prior to the birth of the child or in connection with childbirth. Unemployed less than 13 weeks includes no unemployment.

Table 2 compares the 4,557 children with an early ADHD diagnosis from Table 1 and their parents to the overall population of children from the same cohorts. We see that children suffering from ADHD have worse birth outcomes, their parents have lower levels of education, are more likely to be unemployed and have lower income, are more likely to have a psychiatric diagnosis themselves and have a higher prevalence of both heart disease and respiratory disease. Finally, their mothers are much more likely to smoke during pregnancy.

We define pharmacological treatment as purchases in an amount that corresponds to at least six months of treatment in a given year before the age of ten.[11] Pharmacological treatment of ADHD consists of Amphetamine (N06BA01), Methylphenidate (N06BA04), and Atomoxetine (N06BA09). As discussed above, our sensitivity analyses will also investigate effects of *any* treatment with Amphetamine, Methylphenidate or Atomoxetine before the age of ten and effects of treatment after the age of ten.

Table 3 shows the percentage of children who are diagnosed with ADHD and in treatment before the age of ten. Roughly one third of all children with a diagnosis are treated according to our primary definition of treatment. The share of diagnosed children in early treatment increases across cohorts and the average age at first treatment is eight. We investigate the impact of this phenomenon in our sensitivity analysis below. Boys with a diagnosis tend to be more likely to be treated early than girls.

[11] This corresponds to 182 defined daily doses (e.g. 30 mg Methylphenidate) in a calendar year.

TABLE 3

PERCENTAGE OF CHILDREN DIAGNOSED WITH ADHD IN PHARMACOLOGICAL TREATMENT FOR ADHD BEFORE THE AGE OF TEN*

Birth Cohort	No. diagnosed	Percentage treated	Average age first treatment (in treatment before age 10)	Percentage treated among boys	Percentage treated among girls
1990	197	18.78	8.16	19.88	11.54
1991	257	19.84	8.14	21.43	9.09
1992	304	21.71	8.12	22.52	16.67
1993	318	22.33	8.14	22.30	22.45
1994	394	24.87	7.97	25.82	19.30
1995	468	28.21	8.19	30.08	17.39
1996	518	33.20	8.26	33.56	31.40
1997	599	34.39	7.93	35.07	30.00
1998	665	38.95	8.03	38.79	39.67
1999	837	43.61	7.93	45.54	35.76
All cohorts	4557	31.97	8.04	32.70	28.16

*Treatment is defined as pharmacological treatment for at least six months in a year before the age of ten.

TABLE 4

OBSERVABLE CHARACTERISTICS AT CHILDBIRTH, CHILDREN WITH AN ADHD DIAGNOSIS BEFORE THE AGE OF TEN*

Variable		Treatment before age 10			No treatment before age 10	
	# obs	Mean	Std. Dev.	# obs	Mean	Std. Dev.
Child:						
Boy (0/1)	1457	0.86	0.35	3100	**0.83**	0.37
5-minute APGAR score	1401	9.78	0.86	2930	**9.71**	1.20
Birthweight less than 1,500 grams (0/1)	1408	0.02	0.12	2945	0.02	0.14
Birthweight, 1,500-2,500 grams (0/1)	1408	0.06	0.23	2945	0.07	0.26
Birthweight, above 2,500 grams (0/1)	1408	0.93	0.3	2945	**0.91**	0.29
Complications at birth (0/1)	1457	0.32	0.47	3100	**0.27**	0.44
Gestation length (weeks)	1404	39.28	2.53	2942	39.17	2.53
Mental retardation (0/1)	1457	0.12	0.33	3100	0.11	0.31
Mother:						
Age at childbirth	1457	27.93	4.85	3096	28.24	5.28
High school or less (0/1)	1416	0.50	0.50	2942	0.53	0.50
Length of education (years)	1416	11.40	2.31	2942	11.41	2.30
Unemployed less than 13 weeks (0/1)	1431	0.82	0.38	3000	**0.79**	0.41
Unemployed 13-26 weeks (0/1)	1431	0.12	0.33	3000	**0.14**	0.35
Unemployed more than 26 weeks (0/1)	1431	0.06	0.24	3000	0.07	0.25
Employed in November (0/1)	1431	0.54	0.50	3000	**0.50**	0.50
Gross income (2004 prices)	1431	176823	69947	3000	172928	76761
Psychiatric diagnosis (0/1)	1457	0.10	0.30	3096	0.10	0.30
Heart disease (0/1)	1457	0.03	0.18	3096	0.03	0.17
Respiratory disease (0/1)	1457	0.21	0.41	3096	**0.18**	0.38
Smoker (0/1)	1297	0.24	0.43	2648	**0.16**	0.36
Father:						
Age at child birth	1371	30.99	6.06	2906	31.34	6.34
High school or less (0/1)	1304	0.44	0.50	2760	0.44	0.50
Length of education (years)	1304	11.29	2.31	2760	11.34	2.39
Unemployed less than 13 weeks (0/1)	1348	0.86	0.35	2849	**0.84**	0.37
Unemployed 13-26 weeks (0/1)	1348	0.08	0.27	2849	0.08	0.27
Unemployed more than 26 weeks (0/1)	1348	0.06	0.24	2849	**0.09**	0.28
Employed in November (0/1)	1348	0.86	0.35	2849	0.84	0.37
Gross income (2004 prices)	1348	264250	128305	2849	256665	152014
Psychiatric diagnosis (0/1)	1371	0.08	0.27	2910	0.08	0.26
Heart disease (0/1)	1371	0.04	0.20	2910	0.04	0.19
Respiratory disease (0/1)	1371	0.14	0.35	2910	0.13	0.34

* Treatment is defined as pharmacological treatment for at least six months in a year before the age of ten. Bold indicates that mean for treated children is significantly different from the mean for non-treated children at the 5% level. With the exception of mental retardation, which is diagnosed in connection with the ADHD diagnosis, all variables are measured in the year just prior to the birth of the child or in connection with childbirth. Unemployed less than 13 weeks includes no unemployment.

We saw that children with an early ADHD diagnosis have adverse background characteristics compared to the overall population, yet Table 4 demonstrates that the same is not true when comparing treated and non-treated children with an early diagnosis. Though some differences in background variables are statistically significant, it is not clear that treated children are either more advantaged or disadvantaged than non-treated children, and the differences are smaller in size than the differences for children with and without an early diagnosis. One characteristic stands out, however: mothers of children in treatment are far (eight percentage points) more likely to have smoked during pregnancy than mothers of non-treated children.[12] Among the advantageous characteristics, children in treatment have slightly higher 5-minute APGAR scores and are more likely to have a birthweight of 2,500 grams or more. Their parents are also slightly more likely to be employed.

We consider a range of outcomes that describe children's use of health services and risky health behavior. Variables that describe use of health services include contacts with general hospitals (beyond contacts with psychiatric units and excluding visits directly related to the treatment of ADHD) and, among all hospital contacts, also visits to the emergency ward and in-patient admissions. For all of these, we employ indicators for one or more and two or more contacts and consider separate effects at ages 10-12. Risky health behavior, on the other hand, is captured by the occurrence of injuries. Formally we use diagnoses of type S and T in the tenth version of the ICD diagnostic manual.

[12] See Obel et al. (2011), who use siblings differences to show that if smoking is a causal factor behind hyperkinetic disorders, it only has a minor impact.

Table 5 shows mean outcomes by treatment status for the full set of outcomes. More than one in four children diagnosed with ADHD are in contact with a general hospital at least once in a given year and the receiving ward is often the emergency ward. As already documented in Figure 1, children with ADHD exercise less caution than the average child; one in six children with ADHD experience injuries every year. Yet we see that treated children perform better – and in many cases significantly better – regardless of the outcome under consideration.

TABLE 5

OUTCOMES, CHILDREN WITH AN ADHD DIAGNOSIS BEFORE THE AGE OF TEN*

	Treated individuals			Non-treated individuals		
	# obs	Mean	Std. Dev.	# obs	Mean	Std. Dev.
One or more contacts with general hospitals						
- at age 10	1457	0.257	0.437	3100	0.280	0.452
- at age 11	1457	0.270	0.444	3100	0.273	0.449
- at age 12	1092	**0.257**	0.437	2628	0.298	0.460
Two or more contacts with general hospitals						
- at age 10	1457	*0.093*	0.290	3100	0.111	0.316
- at age 11	1457	0.104	0.306	3100	0.112	0.320
- at age 12	1092	**0.111**	0.315	2628	0.134	0.344
One or more visits to the emergency ward						
- at age 10	1457	0.170	0.375	3100	0.186	0.389
- at age 11	1457	0.181	0.385	3100	0.196	0.397
- at age 12	1092	**0.177**	0.382	2628	0.216	0.412
Two or more visits to the emergency ward						
- at age 10	1457	0.032	0.177	3100	0.041	0.198
- at age 11	1457	0.043	0.203	3100	0.046	0.210
- at age 12	1092	0.049	0.215	2628	0.057	0.231
One or more in-patient admissions						
- at age 10	1457	0.062	0.242	3100	0.069	0.253
- at age 11	1457	0.064	0.245	3100	0.065	0.247
- at age 12	1092	0.061	0.240	2628	0.070	0.255
Two or more in-patient admissions						
- at age 10	1457	**0.012**	0.107	3100	0.019	0.136
- at age 11	1457	0.013	0.113	3100	0.015	0.121
- at age 12	1092	0.019	0.137	2628	0.017	0.128
One or more injuries						
- at age 10	1457	0.143	0.351	3100	0.161	0.367
- at age 11	1457	0.152	0.360	3100	0.169	0.375
- at age 12	1092	**0.154**	0.361	2628	0.188	0.391

* Treatment is defined as pharmacological treatment for at least six months in a year before the age of ten. Bold (italic) indicates that the mean for the group of treated children is significantly different from the mean for non-treated children at the 5% (10%) level.

IV. Identification Strategy

Our main goal is to estimate the effects of early pharmacological treatment of children. In practice, our identification strategy exploits panel data on children diagnosed with ADHD before the age of ten. Treatment is defined as pharmacological treatment for at least six months in a year before the age of ten. In our sensitivity analyses, we also investigate effects of *any* treatment before the age of ten in addition to treatment at any age prior to the measurement of the outcome.

Table 6 shows age of first diagnosis and age at first treatment for our estimation sample. We see that in practice treatment for 6 months or more per year is rarely initiated before the age of five and never before the age of four.[13] We therefore employ a difference-in-differences strategy, comparing outcomes for treated children prior to (age 4 and as a robustness check also age 3) and after treatment (in our main analysis age 10 +) with untreated diagnosed children before and after, corresponding to a fixed effects or first difference analysis; see Blundell and Costa Dias (2008). In a world with heterogenous treatment effects, this will provide estimates of the average treatment effect on the treated (ATET). See Lechner (2010) for an extensive discussion of strengths and weaknesses associated with difference-in-differences strategies. Strictly speaking, we are investigating the effects of early treatment initiation. Figure A1 in the Appendix shows treatment enrolment at age ten or later for our treatment and control groups. We see that the majority of children enrolled in treatment early on continue to be treated but opt out and, in line with Table 6 some of the children in the control group receive treatment later on.

Our identification strategy allows for selection into treatment based on, for instance, severity of symptoms or parental characteristics *as long* as these influences are constant over time. Thus, if particularly attentive parents are systematically more (or less) likely to engage in pharmacological treatment *and* more (or less) likely to use health care services at any time, this does not violate the identifying assumptions. However, if attentive parents are more (or less) likely to engage in

[13] We exclude one child treated before the age of five.

pharmacological treatment *but only* more (or less) likely to use health care services when children are below 5, this would indeed violate the identifying assumptions.

Our main regression model is the following:

$$Y_{ia} = \alpha_i + \beta_1 1(age > 9)_i + \beta_2 treat_i \cdot 1(age > 9)_i + \varepsilon_{it}$$

where Y is the outcome of interest, *treat* indicates that the child belongs to the treatment group (i.e. receives pharmacological treatment before age ten), $1(age > 9)$ indicates post-treatment age, ε is an error term, i indexes individuals, and a indexes age, β_2 is the parameter of interest. Note that since background variables are measured prior to or at childbirth and thus do not vary across time, they will be cancelled out along with the individual level fixed effect.

TABLE 6

AGE AT FIRST DIAGNOSIS AND TREATMENT, ESTIMATION SAMPLE

Age	Sample size	All First diagnosed at age…		Treatment 0 months + First treated at age…		Treatment 6 months + First treated at age…	
		# obs	Share of sample	# obs	Share of sample	# obs	Share of sample
0	4557	11	0.002	0	0	0	0
1	4557	23	0.005	0	0	0	0
2	4557	42	0.009	0	0	0	0
3	4557	104	0.023	8	0.002	0	0
4	4557	239	0.052	23	0.005	1	0.000
5	4557	414	0.091	119	0.026	23	0.005
6	4557	562	0.123	285	0.063	111	0.024
7	4557	796	0.175	488	0.107	255	0.056
8	4557	1152	0.253	705	0.155	453	0.099
9	4557	1215	0.267	841	0.185	614	0.135
10	4557	0	0	379	0.083	522	0.115
11	4557	0	0	121	0.027	186	0.041
12	3720	0	0	57	0.015	92	0.025

The key identifying assumption in a difference-in-differences set-up is that there can be no differential trends between the treatment and control group in the absence of treatment. Figure 1 above suggests that treated and non-treated children develop in parallel prior to the initiation of treatment. We investigate this issue in our sensitivity analysis by using both age four and three comparisons.[14] Calculating the differences in the estimated effects from regressions using age three and age four comparisons corresponds to performing a naturalistic and non-randomized placebo test of the effect of treatment on age four outcomes using age three outcomes as pre-treatment comparison. We show these results too. Other specification checks include differential time trends according to pre-treatment characteristics predictive of future treatment receipt and clustering at the cohort level to account for common shocks for children born in the same cohort and at the cohort-county level to account for common shocks regarding hospital, pharmacological, pedagogical, or schooling practices for children born into the same cohort and county.

Another concern is co-treatment. If pharmacologically treated children are also more exposed to other types of treatment for ADHD, we will likely not measure the effect of medication on its own. We therefore investigate whether treated and controls vary with regards to non-pharmacological behavioral treatment (special school enrolment), other pharmacological treatment (nervous system drugs, ATC-code N), comorbidities, and parental investment (maternal labor supply and cohabitation). Some of the mentioned variables could also be thought of as intermediate outcomes or mediating variables. Related to this, diagnosis age may be correlated with health outcomes; firstly, there may be a causal effect of early interaction with specialists, and secondly early diagnosis is more likely if symptoms are severe. To account for this, we investigate the sensitivity of our results to holding fixed the age of diagnosis. We do not do this in our main analysis because

[14] We also use age two comparisons. Results are similar and not shown.

diagnosis age is potentially endogenous. Similarly, we investigate more thoroughly treatment initiation prior to the age of ten. We can only do this to some extent because there is limited variation in age of take-up; see Table 6. Here we consider the effects of treatment initiation prior to the age of 7 (8 and 9) on outcomes measured at age 7 (8 and 9). This sensitivity analysis naturally leads to further placebo-type analyses; here we that treatment initiation after the age of 7 (8 and 9) must not affect previous outcomes.

Our sensitivity analysis will also investigate whether results are robust across different subgroups defined by pre-treatment characteristics.

VI. Main Results

The first column in Table 7 shows a simple OLS and column two our main estimation results from performing difference-in-differences estimation using age four as pre-treatment comparison.[15] Here we estimate the effects of receiving pharmacological treatment for at least six months in a given year before the age of ten. In the OLS analysis we condition on the covariates shown in Table 4 in addition to cohort and county dummies.

Early pharmacological treatment for 6 months or more is effective in significantly improving all outcomes except for in-patient admission: the probability of being in contact with a general hospital at least once is reduced with 5-8 percentage points, corresponding to just below 30% of the mean at age 10. Effects on higher margins are smaller and most often insignificant. Emergency ward contacts are similarly reduced. In line with this, we also see a significant and large reduction in the probability of injuries of around 30% compared to the mean. We conclude that such a treatment

[15] We exclude children diagnosed at age four or earlier.

reduces risky health behavior resulting in emergency ward visits and injuries and thereby reduces the demand for hospital services and improves the overall health. The OLS results are more conservative in terms of the size of the estimates but generally support this conclusion.

TABLE 7

EFFECTS OF PHARMACOLOGICAL TREATMENT OF ADHD

DIFFERENCE-IN-DIFFERENCES ESTIMATES, AGE FOUR COMPARISONS*

	# obs	OLS		Difference-in-difference					
		Treatment for at least six months in given year before age ten		Treatment for at least six months in given year before age ten		Any prior treatment for at least six months in given year		Any treatment before age ten	
		Coef. Est.	Std. Error	Coef. Est.	Std. Error	Coef. Est.	Std. Error	Coef. Est.	Std. Error
One or more contacts with general hospitals									
- at age 10	4138	*-0.028*	0.015	**-0.067**	0.021	**-0.067**	0.021	**-0.054**	0.020
- at age 11	4138	0.004	0.015	**-0.047**	0.021	**-0.042**	0.020	**-0.044**	0.020
- at age 12	3384	**-0.036**	0.017	**-0.084**	0.020	**-0.044**	0.022	**-0.064**	0.022
Two or more contacts with general hospitals									
- at age 10	4138	**-0.020**	0.009	*-0.028*	0.015	*-0.028*	0.015	-0.012	0.014
- at age 11	4138	0.000	0.010	-0.020	0.016	-0.017	0.015	*-0.027*	0.015
- at age 12	3384	*-0.021*	0.012	-0.028	0.018	-0.012	0.016	-0.023	0.017
One or more visits to the emergency ward									
- at age 10	4138	-0.015	0.012	**-0.048**	0.019	**-0.048**	0.019	-0.027	0.018
- at age 11	4138	-0.006	0.013	**-0.050**	0.019	**-0.036**	0.018	**-0.046**	0.020
- at age 12	3384	**-0.040**	0.014	**-0.081**	0.018	**-0.053**	0.013	**-0.065**	0.012
Two or more visits to the emergency ward									
- at age 10	4138	-0.008	0.005	-0.015	0.010	-0.015	0.017	-0.001	0.010
- at age 11	4138	-0.001	0.006	-0.011	0.010	-0.009	0.010	-0.013	0.011
- at age 12	3384	-0.010	0.007	-0.018	0.012	-0.007	0.010	-0.008	0.006
One or more in-patient admissions									
- at age 10	4138	-0.004	0.007	-0.001	0.013	-0.001	0.013	-0.002	0.012
- at age 11	4138	0.000	0.007	-0.001	0.013	0.007	0.012	-0.003	0.012
- at age 12	3384	-0.003	0.009	-0.002	0.015	0.003	0.014	-0.004	0.014
Two or more in-patient admissions									
- at age 10	4138	-0.005	0.002	-0.011	0.007	-0.011	0.006	-0.007	0.006
- at age 11	4138	0.000	0.003	-0.009	0.007	-0.003	0.006	-0.006	0.006
- at age 12	3384	0.004	0.003	-0.002	0.008	0.006	0.007	-0.002	0.007
Injuries									
- at age 10	4138	-0.016	0.011	**-0.045**	0.017	**-0.045**	0.017	**-0.045**	0.017
- at age 11	4138	-0.012	0.012	**-0.051**	0.018	**-0.045**	0.017	**-0.048**	0.017
- at age 12	3384	**-0.034**	0.013	**-0.067**	0.020	**-0.055**	0.019	**-0.054**	0.019

*Bold (italic) indicates significance at the 5% (10%) level. The analysis excludes 419 children diagnosed before the age of five. OLS analysis conditions on variables from Table 4 in addition to cohort and county dummies. Standard errors assume homoscedasticity.

VI.A Sensitivity Analyses

This section investigates the sensitivity of our results to a series of robustness checks focusing on alternative definitions of treatment, differential trends, the role of co-treatments, and subgroup analyses. Due to space considerations, we only show effects on selected outcomes but all results are available on request.

Alternative treatment definitions. One might be interested in alternative definitions of treatment. The second column in Table 7 shows the effects of receiving intensive pharmacological treatment in any year prior to the measurement of outcome. Here we therefore add children who take up treatment at age 10 to the group of treated when considering outcomes measured at age 11 and so forth. Clearly, effects at age 10 are the same as in the main analysis. Effects are slightly smaller in size but not significantly so. The third column of Table 7 investigates effects of *any* pharmacological treatment before the age of ten. As expected, estimated effects are smaller when treatment intensity is lower on average, but the overall conclusion is the same: we find that treated children benefit.

Differential trends. To address concerns for differential trends, we document that results from using age 3 comparisons align with the results from the age 4 comparisons. An analogous way of showing this is by performing a placebo test using age 4 outcomes as post-treatment measures and age 3 as pre-treatment comparisons.[16] We also include differential time trends according to pre-treatment characteristics predictive of future treatment receipt (gender, birthweight between 1,500 and 2,500 grams, birthweight above 2,500 grams, mother employed prior to birth, maternal smoking during pregnancy, and an indicator for injuries at age three) and county trends. Finally, we account for

[16] As noted above, we also investigate age two comparisons. Results are similar and available on request.

clustering at the cohort and cohort-county level to allow for common shocks to children born in the same year and county. Table 8 shows the results from these estimations.

TABLE 8

EFFECTS OF PHARMACOLOGICAL TREATMENT OF ADHD DIFFERENTIAL TRENDS, SELECTED OUTCOMES*

	# obs	Age 3 comparisons		Placebo-test Age 4 vs. Age 3		Differential trends		Standard errors clustered at cohort		Standard errors clustered at cohortXcounty	
		Coef. Est.	Std. Error	Coef. Est.	Std. Error	Coef. Est.	Std. Error	Coef. Est.	Std. Error	Coef. Est.	Std. Error
One or more contacts with general hospitals											
- at age 10	4138	**-0.068**	0.021			**-0.065**	0.021	**-0.067**	0.022	**-0.067**	0.021
- at age 11	4138	**-0.049**	0.022			*-0.040*	0.021	**-0.047**	0.008	**-0.047**	0.021
- at age 12	3384	**-0.086**	0.024			**-0.081**	0.024	**-0.084**	0.026	**-0.084**	0.020
One or more visits to the emergency ward											
- at age 10	4138	**-0.059**	0.019			**-0.043**	0.019	-0.048	0.028	**-0.048**	0.026
- at age 11	4138	**-0.061**	0.019			**-0.039**	0.019	**-0.050**	0.016	**-0.050**	0.019
- at age 12	3384	**-0.084**	0.021			**-0.078**	0.022	**-0.081**	0.030	**-0.081**	0.017
One or more in-patient admissions											
- at age 10	4138	0.008	0.014			0.002	0.013	-0.001	0.008	-0.001	0.023
- at age 11	4138	0.010	0.014			0.003	0.013	-0.001	0.010	-0.001	0.013
- at age 12	3384	0.007	0.016			-0.001	0.015	-0.002	0.009	-0.002	0.013
One or more contacts with generals hospitals											
- at age 4				-0.001	0.030						
One or more visits to the emergency ward											
- at age 4				-0.011	0.027						
One or more in-patient admissions											
- at age 4				0.009	0.019						

*Treatment is defined as pharmacological treatment for at least six months in a year before the age of ten. Age four comparisons in columns 3 and 4. Differential time trends specification allows for different trends for boys, children with a birthweight above 2,500 grams, children whose mothers were employed prior to birth and who were smoking during pregnancy, children with at least one injury at age three, and counties. Bold (italic) indicates significance at the 5% (10%) level. The analysis excludes 419 children diagnosed before the age of five. Standard errors assume homoscedasticity unless otherwise noted.

Potential co-treatments. An important concern is the role played by co-treatments. If pharmacologically treated children are also more exposed to other types of treatment for ADHD, we cannot isolate the effect of medication. We therefore investigate whether treated and controls vary with regards to behavioral treatment (special school enrolment), other pharmacological treatment (the five most common nervous system drugs other than ADHD medication prescribed to children with ADHD), comorbid psychiatric disorders, and parental investment (maternal labor supply and cohabitation).

Table 9 shows means for these variables across the groups of treated and controls. We do not have complete information about special school enrolment for all cohorts[17], but the results are still reassuring in that treated children are not more likely to be enrolled at special schools. Except for Diazepam, treated children are not prescribed other types of nervous system drugs than non-treated children. Diazepam is used to treat anxiety and insomnia and is sometimes prescribed as a remedy for status epilepticus. Note however, that fewer children among the group of treated suffer from anxiety. We speculate, therefore, that diazepam may be prescribed to treat adverse effects of ADHD medication or to treat insomnia, which is common even in untreated children with ADHD (Yoon (2011)). In any case, results are completely robust to excluding children in treatment with Diazepam and to excluding children suffering from anxiety.

Another concern is differential parental investment across the two groups. It is possible that pharmacological treatment of the child affects parental labor supply and cohabitation (see Kvist et al. (2011)) and through this affects child health outcomes. Table 9 shows that there is no significant

[17] The registers inform about special school enrolment in grade 8 or later for all cohorts, but only enrolment below grade 8 from 2007 and onwards.

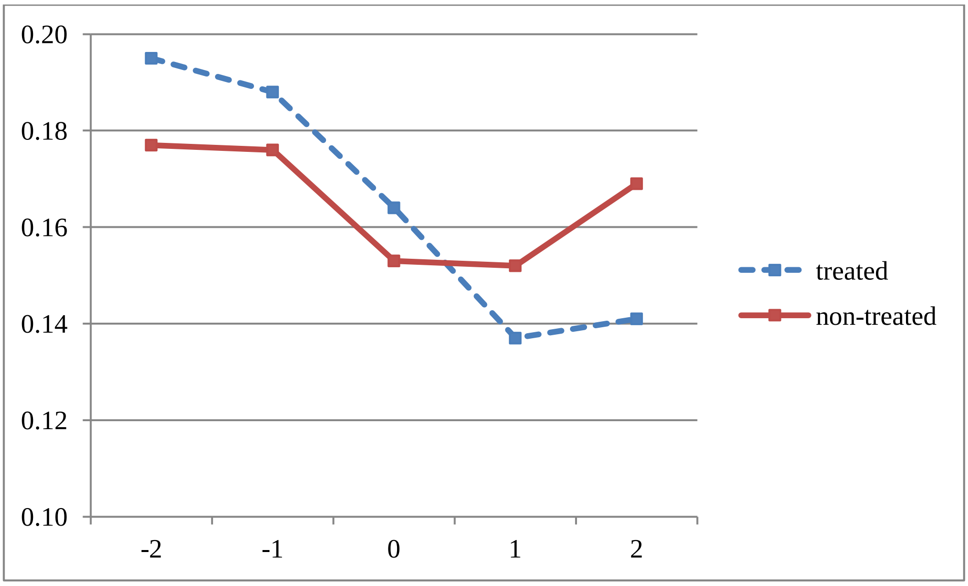
difference in the probability that the mother is single when the child is nine years old across treated and non-treated children. Mothers of treated children are slightly less likely to be employed at age nine (3 percentage points). We saw above that mothers of treated children were slightly *more* likely to be employed prior to the birth of the child. Taken together, this might indicate that this group of mothers is more involved in child rearing than mothers in the control group or that treated children have worse symptoms (in line with Figure 1) which affect maternal labor supply. Since the differences in parental investments are small, we are convinced that we measure effects of pharmacological treatment and not of differences in parental behavior.

Next we investigate differences in diagnosis age since this may be correlated with health outcomes. Figure 2 first aligns children according to diagnosis age and shows the probability of injuries prior to and after the year of diagnosis for the group of treated and non-treated children. In line with Figure 1, we see that treated children have a higher probability of injuries prior to diagnosis, but this pattern changes after the diagnosis is established and treatment has begun. Our results from above are therefore not likely to be driven by differences in diagnosis age. Still, age of diagnosis (or the severity of ADHD) may be important for the effectiveness of pharmacological treatment. To account for this, we investigate the sensitivity of our results to holding fixed the age of diagnosis, which is slightly lower for the group of treated children. Formal results for children with early and later diagnosis age are shown in Table 10. Treatment effects are larger for the group diagnosed before the age of seven, but the differences across the groups are not significant. Regardless of age at diagnosis, though, treatment is effective in improving health outcomes.

FIGURE 2

PROBABILITY OF INJURIES BEFORE AND AFTER DIAGNOSIS

BY TREATMENT STATUS*



*Treatment is defined as pharmacological treatment for at least six months in a year before the age of ten.

TABLE 9

CO-TREATMENTS AND OTHER MECHANISMS*

Variable	Treated individuals			Non-treated individuals		
	# obs	Mean	Std. Dev.	# obs	Mean	Std. Dev.
Special school participation:						
Age 8	135	0.193	0.396	320	0.191	0.393
Age 9	294	0.204	0.404	624	0.218	0.413
Other types of nervous system drugs:						
Valproic acid (N03AG01), antiepileptic/migrain	1457	0.030	0.171	3100	0.028	0.166
Lamotrigine (N03AX09), anti-epileptic	1457	0.023	0.151	3100	0.025	0.155
Risperidone (N05AX08), antipsychotic	1457	0.048	0.214	3100	0.029	0.168
Clopenthixol (N05AF02), antipsychotic	1457	0.019	0.137	3100	0.018	0.134
Diazepam (N05BA01), anxiety/insomnia	1457	**0.084**	0.278	3100	0.056	0.231
Comorbidities:						
All types	1457	0.641	0.480	3100	0.646	0.478
- Anxiety	1457	**0.058**	0.233	3100	0.075	0.263
Age at diagnosis:	1457	**6.820**	1.587	3100	7.290	1.840
Parental investments:						
Mother single when child is aged 9	1092	0.061	0.24	2628	0.048	0.214
Mother employed when child is aged 9	984	*0.552*	0.498	2351	0.586	0.493

*Treatment is defined as pharmacological treatment for at least six months in a year before the age of ten. Nervous system drugs are described by name and ATC-code. Bold (italic) indicates that the mean for the group of treated children is significantly different from the mean for non-treated children at the 5% (10%) level.

TABLE 10

EFFECTS OF PHARMACOLOGICAL TREATMENT OF ADHD

BY AGE OF DIAGNOSIS, AGE FOUR COMPARISONS, SELECTED OUTCOMES*

	Diagnosis before age 7		Diagnosis at age 7 or later	
	Coef. Est.	Std. Error	Coef. Est.	Std. Error
One or more contacts with general hospitals				
- at age 10	**-0.085**	0.031	**-0.058**	0.024
- at age 11	**-0.070**	0.031	*-0.035*	0.022
- at age 12	**-0.112**	0.035	**-0.069**	0.029
One or more visits to the emergency ward				
- at age 10	**-0.087**	0.027	*-0.041*	0.023
- at age 11	**-0.067**	0.025	*-0.040*	0.022
- at age 12	**-0.121**	0.030	**-0.061**	0.027
One or more in-patient admissions				
- at age 10	-0.002	0.019	0.004	0.015
- at age 11	-0.004	0.018	-0.002	0.016
- at age 12	-0.001	0.021	-0.001	0.016

* Treatment is defined as pharmacological treatment for at least six months in a year before the age of ten. Bold (italic) indicates significance at the 5% (10%) level. *Indicate that estimates for the two groups differ significantly (10% level). The analysis excludes 419 children diagnosed before the age of five. Standard errors assume homoscedasticity.

We finally take a closer look at treatment initiation prior to the age of ten by considering effects of treatment initiation prior to the age of 7, 8, and 9 on outcomes measured at these ages. In line with our main analysis we condition on receiving a diagnosis prior to measuring the outcome. The first column of Table 11 shows these results. Few children are treated before age 7 and the estimated effect of treatment on at least one hospital contacts at age 7 is small and insignificant. At age 8 and 9 we uncover large and significant effects of treatment. This sensitivity analysis naturally leads to further placebo-type analyses since treatment initiation after a given age must not affect previous outcomes. In fact, our placebo analysis in the second column of Table 11 shows exactly this: none of the estimated "effects" prior to treatment enrollment are significant and all are small in size.

TABLE 11

EFFECTS OF PHARMACOLOGICAL TREATMENT OF ADHD BY AGE OF TREATMENT INITIATION, AGE FOUR COMPARISONS, SELECTED OUTCOMES*

	# obs	Difference-in-difference			
		Treatment for at least six months prior to outcome		Treatment for at least six months after outcome	
		Coef. Est.	Std. Error	Coef. Est.	Std. Error
One or more contacts with general hospitals		*Main effects*			
- diagnosed before age 7, outcome at age 7	976	-0.015	0.078		
- diagnosed before age 8, outcome at age 8	1722	**-0.102**	0.042		
- diagnosed before age 9, outcome at age 9	2924	**-0.055**	0.028		
				Placebo effects	
Sample: children never treated or treated after age 7					
- outcome at age 5	4053			0.003	0.020
- outcome at age 6	4053			0.009	0.020
Sample: children never treated or treated after age 8					
- outcome at age 5	3827			0.004	0.020
- outcome at age 6	3827			0.012	0.021
- outcome at age 7	3827			0.010	0.020
Sample: children never treated or treated after age 9					
- outcome at age 5	3400			0.007	0.022
- outcome at age 6	3400			0.009	0.022
- outcome at age 7	3400			0.013	0.022
- outcome at age 8	3400			0.012	0.023

* Treatment is defined as pharmacological treatment for at least six months in a year before the age of ten. Bold (italic) indicates significance at the 5% (10%) level. *Indicate that estimates for the two groups differ significantly (10% level). The analysis excludes 419 children diagnosed before the age of five. Standard errors assume homoscedasticity.

Subgroup analyses and other sensitivity checks. We finally investigate whether results vary across subgroups. Table 12 presents results for boys, children born to mothers with more than a high school degree, children without a mental retardation diagnosis, children with a birthweight above 3,000 grams, children born to mothers who did not smoke during pregnancy, and children with no injuries at age four. Estimates for boys are slightly lower than the overall estimates as are estimates for the positively selected groups in columns 2-5 of Table 12. Children with no injuries at age three seem to gain to the same extent as the full sample. As was evident from Table 6, many more children are diagnosed early and treated pharmacologically in the later cohorts. Two competing hypotheses may explain this development. First of all, it is possible that diagnostic tools have improved in recent years and that diagnosed cases born in later cohorts suffer from ADHD to the same extent as children born in earlier cohorts. In this case we will expect the effects of pharmacological treatment to be the same in early and late cohorts. Secondly, it is possible that the group of treated has been broadened to include children with less severe symptoms. In this case we will expect the effects of pharmacological treatment to decline in late cohorts. Table 13 investigates this. We distinguish between the 1990-1994 cohorts (1,309 children after excluding children diagnosed before age five) and the 1995-1999 cohorts (2,829 children after excluding children diagnosed before age five) from the original sample. We see that estimated effects are significantly smaller among later cohorts. There are still significant gains from treatment in the later cohorts, but the results are at least in line with diminishing returns to broadening the group of treated.

TABLE 12

EFFECTS OF PHARMACOLOGICAL TREATMENT OF ADHD

SUBGROUP ANALYSES, AGE FOUR COMPARISONS, SELECTED OUTCOMES*

	Boys		Mentally retarded excluded		Mothers more than high school degree		Birthweight above 3000 g		Non-smoking mothers		No injuies before age four	
	Coef. Est.	Std. Error	Coef. Est.	Std. Error	Coef. Est.	Std. Error	Coef. Est.	Std. Error	Coef. Est.	Std. Error	Coef. Est.	Std. Error
One or more contacts with general hospitals												
- at age 10	**-0.060**	0.023	**-0.065**	0.022	*-0.052*	0.030	**-0.049**	0.024	**-0.069**	0.023	**-0.070**	0.023
- at age 11	**-0.044**	0.023	*-0.036*	0.021	-0.012	0.029	-0.029	0.024	*-0.030*	0.023	**-0.055**	0.023
- at age 12	**-0.093**	0.026	**-0.073**	0.026	-0.030	0.034	**-0.065**	0.027	**-0.092**	0.026	**-0.082**	0.027
One or more visits to the emergency ward												
- at age 10	*-0.043*	0.022	**-0.044**	0.020	-0.035	0.024	-0.032	0.021	**-0.058**	0.021	**-0.053**	0.020
- at age 11	**-0.049**	0.020	**-0.045**	0.018	-0.011	0.023	*-0.036*	0.021	**-0.046**	0.018	**-0.052**	0.019
- at age 12	**-0.087**	0.028	**-0.068**	0.023	-0.024	0.028	**-0.068**	0.026	**-0.095**	0.023	**-0.076**	0.025
One or more in-patient admissions												
- at age 10	0.002	0.014	0.005	0.013	0.009	0.017	0.004	0.013	0.003	0.013	-0.001	0.014
- at age 11	0.007	0.015	0.007	0.014	0.020	0.017	0.008	0.014	0.008	0.014	-0.004	0.014
- at age 12	0.002	0.016	0.004	0.013	0.018	0.018	0.001	0.016	-0.002	0.014	0.002	0.017
# obs at age 10	3486		3697		2120		3065		3483		3352	

*Treatment is defined as pharmacological treatment for at least six months in a year before the age of ten. Bold (italic) indicates significance at the 5% (10%) level.

Standard errors assume homoscedasticity.

TABLE 13

EFFECTS OF PHARMACOLOGICAL TREATMENT OF ADHD

COHORT DIFFERENCES, AGE FOUR COMPARISONS*

	1990-1994 cohorts		1995-1999 cohorts	
	Coef. Est.	Std. Error	Coef. Est.	Std. Error
One or more contacts with general hospitals				
- at age 10	**-0.128**	0.043	**-0.051**	0.024
- at age 11	-0.066	0.043	*-0.041*	0.025
- at age 12	**-0.148***	0.043	*-0.054*	0.030
One or more visits to the emergency ward				
- at age 10	**-0.117***	0.047	-0.022	0.020
- at age 11	*-0.071*	0.038	*-0.033*	0.020
- at age 12	**-0.139***	0.046	*-0.045*	0.026
One or more in-patient admissions				
- at age 10	0.010	0.025	-0.009	0.015
- at age 11	0.025	0.027	-0.011	0.015
- at age 12	0.006	0.023	-0.010	0.017

*Treatment is defined as pharmacological treatment for at least six months in a year before the age of ten. Bold (italic) indicates significance at the 5% (10%) level. *indicates that the estimate for the 1990-1994 cohorts is significantly different from the estimate for the 1995-1999 cohorts (10% level). Standard errors assume homoscedasticity.

VII. Conclusion

This paper uses a difference-in-differences strategy to investigate the effects of early pharmacological treatment of ADHD on children's health. Specifically, since a diagnosis is rarely established and treatment initiated before the age of five, we compare outcomes of treated children prior to (age four and three) and after treatment (age 10 +) with untreated diagnosed children before and after. Our analysis is based on Danish register-based panel data for children born in 1990-1999.

We find that treated children use health services more extensively and experience more injuries *prior* to treatment compared to non-treated children yet after treatment is initiated, this is no longer true. Our formal results show that treated children benefit from pharmacological treatment in terms of fewer emergency ward contacts and fewer incidents of injuries and poisoning at the age of 10-12. Estimated effects are large. In fact, early pharmacological treatment is effective in reducing the probability of having at least one hospital contact by 30% compared to the mean. Our conclusions are robust to a number of sensitivity checks. We do find, however, that estimated effects are significantly smaller in later cohorts where more children are diagnosed and treated pharmacologically before the age of ten. There are still significant gains from treatment in the later cohorts, but the results are consistent with a hypothesis of diminishing returns to broadening the group of treated.

From the point of view of the individual, the family and the society, the long-term benefits of pharmacological treatment of ADHD extend beyond the relief of the symptoms related to the syndrome. These benefits should be traded off against the (low) financial costs of the drugs combined with the potential detrimental short- and long-term side effects of medication such as insomnia, decreased appetite and increased blood pressure.

This paper is the first in a range of papers to document the longer-term consequences of pharmacological treatment of ADHD on socioeconomic outcomes based on nationwide population registers for Denmark. Future work will investigate whether not only the individual suffering from ADHD is affected by its treatment; it may be that also parents, siblings, and peers in the classroom benefit.

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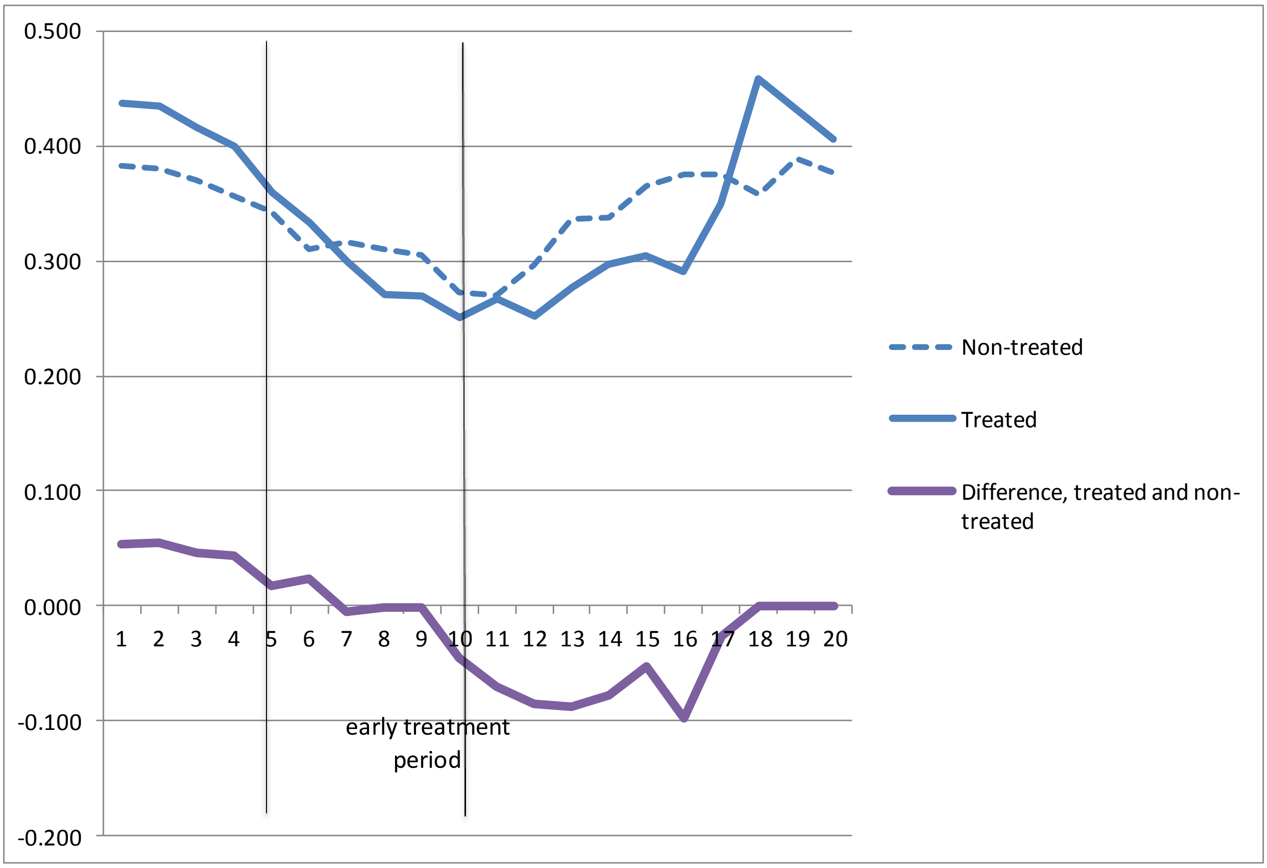
Appendix

FIGURE A1

PROBABILITY OF HOSPITAL VISITS BY TREATMENT STATUS*



*Treatment is defined as pharmacological treatment for at least six months in a year before the age of ten.

FIGURE A2

PROBABILITY OF RECEIVING TREATMENT FOR AT LEAST 6 MONTHS

AT A GIVEN AGE BY TREATMENT STATUS BEFORE AGE 10.