Parental and Child Time Investments and the Cognitive Development of Adolescents

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While a large literature has focused on the impact of parental investments on child cognitive development, very little is known about the role of the child’s own investments alongside that of the parents. By using the Child Development Supplement of the Panel Study of Income Dynamics, we model the cognitive production function for adolescents using an augmented value-added model and adopt an estimation method that takes account of unobserved child characteristics. We find that a child’s own investments made during adolescence matter more than the mother’s. Our empirical results appear to be robust to several sensitivity checks.

I. Introduction

This study analyzes the impact of parental time investments on children’s cognitive outcomes during adolescence in relation to the impact of time in-

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vestments made by children themselves. Previous studies have focused either on the effect of parental investments (see Cunha, Heckman, and Lochner 2006; Cunha and Heckman 2007) or on the effect of children’s own investments as measured by study effort, such as time spent on homework or studying (see Stinebrickner and Stinebrickner 2004, 2008; Cooper, Robinson, and Patall 2006; Eren and Henderson 2011; Kalenkoski and Pabilonia 2014), but not on both. This is the first analysis comparing the impact of parental and child time investments on cognitive outcomes in adolescence.

Empirical evidence suggests that the effect of parental investments on child development declines during adolescence (see Cunha and Heckman 2008; Del Boca, Flinn, and Wiswall 2014), whereas the effect of time spent on homework increases (see Cooper et al. 2006). This implies that there is scope for policy interventions targeting adolescents rather than their families. It is during adolescence, in fact, that teenagers start taking responsibility for their own actions and that their cognitive investments begin to depend on their own decisions, such as how much time and effort to spend doing homework or reading instead of watching television.

Our paper differs from previous studies in that (i) we use data from time-use diaries to distinguish the effect of time investments made by parents from that made by children by considering the amount of time spent by the child in the mother’s supervision versus the time spent alone doing formative activities; (ii) we extend the definition of a child’s own time investment to include time spent on homework as well as time spent on other activities, such as playing an instrument or going to the theater; and (iii) we use a new identification strategy that exploits both the within-family between-siblings variation in investments and the within-child between-ability variation in cognitive test scores.

To investigate whether parental investments or child self-investments matter more during adolescence, we estimate a cognitive production function using the Child Development Supplement (CDS) of the Panel Study of Economics Seminar in Bologna, the CHILD-ReCENT workshop on The Economics of the Family, Education, and Social Capital in Modena, the workshop Parental Investments and Child Outcomes in Moncalieri (Turin), the 26th annual conference of the European Society for Population Economics (Bern), and the Department of Economics seminar in Girona. Sarah Grace See provided outstanding research assistantship. The research is partially supported by the Economic and Social Research Council through their grants to the Research Centre on Micro-Social Change in ISER (ES/H00811X/1 and ES/L009153/1), a Collegio Carlo Alberto Grant on Parental and Public Investments and Child Outcomes, the National Science Foundation grant Household Decision Making and Child Development no. 1,357,636, and the European Union Seventh Framework Programme (FP7/2007–2013) under grant agreement no. 320116. Contact the corresponding author, Cheti Nicoletti, at cn619@york.ac.uk. Information concerning access to the data used in this article is available as supplementary material online.
Income Dynamics (PSID). We measure cognitive abilities using a revised version of a set of intelligence tests developed by Woodcock and Johnson in 1977. More specifically, we use three test scores measuring symbolic learning and reading, comprehension and vocabulary, and mathematical abilities.

The main econometric challenge in evaluating the effect of investments on child cognitive outcomes is accounting for unobserved child characteristics. Three of the most common strategies adopted are these: controlling for the lagged test score in an attempt to reduce the bias caused by omitted past inputs (value-added model), considering child fixed effects estimation using the within-child across-time variation in a panel data approach, and using an instrumental variable estimation (see Todd and Wolpin [2003] for a review). While papers focusing on the effect of parental investments on child’s cognitive abilities have adopted one of these three strategies, most studies looking at the time spent by children on their homework have generally neglected the issue of unobserved child characteristics (see Cooper [2006] for a review of these papers). Among the few exceptions are Aksoy and Link (2000), who use a child fixed (as well as random) effect estimation that exploits repeated observations over time; Stinebrickner and Stinebrickner (2008), who instrument the time a child spends studying with her roommate’s characteristics; and Dolton, Marcenaro, and Navarro (2003), who consider both a valued added model and an instrumental variable estimation. (Note: While both male and female children are included in our study, for ease of reference, a single “child” will be referred to as being female.) Another approach to control for unobserved child characteristics that has been adopted when inputs and test scores are subject-specific is the within-pupil between-subject estimation (e.g., Dee 2005, 2007), which uses repeated observations of inputs and school test scores across subjects to control for child fixed effects. Eren and Henderson (2011) adopt this approach to control for unobserved child characteristics when evaluating the effect of homework on school test scores in mathematics, science, English, and history.

Our empirical strategy is an improvement over valued-added models because we relax two strong assumptions (discussed thoroughly in Todd and Wolpin [2003]): first, that past inputs are irrelevant after controlling for the lagged test, and second, that unobserved child-specific characteristics are independent of lagged test scores. While we relax the first assumption by controlling for the lagged test, current inputs, and lagged inputs, that is, by adopting what Todd and Wolpin (2003) call an augmented value-added model, we relax the second assumption by resorting to the within-pupil between-subject estimation. We implement the within-pupil between-subject estimation using three cognitive test scores rather than school test scores in different subjects. More specifically, we use test scores for symbolic learning and reading, comprehension and vocabulary, and mathematical abilities to estimate the effect of the lagged cognitive ability on the contemporaneous ability with a child fixed effects approach to control for unobserved child
characteristics. We then use this estimated effect of the lagged cognitive ability in a second-step estimation, which, by exploiting within-family between-sibling variation to control for family fixed effects, allows us to evaluate the effect of investments. Therefore, the novelty of our procedure is to introduce a two-step estimation to evaluate the effect of the lagged cognitive ability, as well as of the mother’s and child’s time investments, on the contemporaneous cognitive ability.¹

Our estimation results show that adolescent cognitive development seems to be affected much more by the time invested by the child during adolescence than by the time invested during childhood. In contrast, maternal time investments during childhood matter more than during adolescence. When comparing the time children spend on their own versus the time they spend with their mother doing formative activities during adolescence, we find that the child’s own time investment affects her test scores much more than the time investment of her mother. This finding highlights the importance of self-investments during adolescence and suggests potential channels through which cognitive development can be influenced at later ages, such as policies using financial transfers to encourage student effort and educational activities.

II. Background

Several surveys have shown that parental time investments on children have important impacts on child cognitive and noncognitive outcomes (see Haveman and Wolfe 1995; Carneiro and Heckman 2003; Ermisch and Francesconi 2005). Since the majority of socioeconomic surveys lack appropriate measures of parental time, most studies have been forced to use proxy measures, such as mother’s employment (Todd and Wolpin 2007; Bernal 2008; Liu, Mroz, and Van der Klaauw 2010; Bernal and Keane 2011). A more accurate measure of the time investments in children is provided by the time-use diary surveys,² which usually contain detailed information on the time children spend in different activities together with their mother, their father, and other adults. Nevertheless, only a few papers have actually used time-use diaries to measure investments in children. Among these few exceptions are Hsin (2007, 2009), Carneiro and Rodriguez (2009), and Del Boca et al. (2014), who have used the Child Development Supplement (CDS) of the Panel Study of Income Dynamics (PSID) for the United States. These papers estimate the effect on children’s skills of different measures of parental time investments. Carneiro and Rodriguez (2009) consider the total time spent with the mother; Hsin (2007) defines measures of maternal total time, engaged time, and qual-

¹ See Nicoletti and Rabe (2012) for an application of this method to evaluate the effect of expenditure per pupil using school test scores in different subjects.
² Time investments measured using time-use diaries are not completely free of measurement errors (see Stinebrickner and Stinebrickner 2004), and we address this issue in our empirical analysis in Sec. VI.C.
ity time; Del Boca et al. (2014) distinguish between the time the children spend with their mother and with their father and between the time when the parents are actively engaged and when they are simply around.

As in these previous papers, we use time-use diary surveys to measure parental time investments, but the novelty of our paper is that we also consider the time children spend on their own. How children spend time on their own becomes important as children grow into teenagers (Kooreman 2007). This is because adolescents begin to take independent decisions on how to spend their time, and these decisions can affect their cognitive development. There are only a few examples of economic models that consider both children and parents as decision makers. Dauphin et al. (2011) estimate a collective model and provide evidence that children who are age 16 and over and living with their parents influence the household consumption and labor supply decisions. Lundberg, Romich, and Tsang (2009) adopt a noncooperative model to distinguish between children’s decisions taken on their own and those shared with their parents, and they find that the probability of taking independent decisions increases sharply between the ages of 10 and 14.

Given that during adolescence children begin to take decisions on their own on how to use their time, cognitive production models for adolescents should include the time children spend on their own engaged in formative activities. The question is then how to define formative activities and time investments made by children.

In the economic literature, there are a few papers that have defined time investments by parents (see, besides the papers cited at the beginning of this section, Guryan, Hurst, and Kearney [2008] and Price [2008]). The common approach is to consider the time parents spend with their children in formative activities, such as reading, doing homework, and playing sports and to exclude activities that are usually considered detrimental or not beneficial to the child’s development, such as, for example, watching television. A natural extension of this definition to time investments by the children themselves would consider the time the child spends on her own doing formal and informal educational activities, as well as socializing and participating in sports activities that can contribute to the child’s development. This is actually the definition that we will adopt in our empirical application (see Sec. III for more details).

Different definitions of children’s time investments have been used in other papers, but none of them distinguishes between the time the child spends on her own and the time the child spends actively supervised by a parent. Fiorini and Keane (2014) consider time-use diaries from the Longitudinal Study of Australian Children to estimate the effect of the time children spend on doing a set of different activities (e.g., school-day care, educational activities with parents, and social activities). There are also several studies that have looked at the time invested by children on doing home-
work or studying, but again they do not distinguish between the time spent by children on their own and time when they are supervised by their parents. Dolton et al. (2003) consider the time spent by children on educational activities done on their own, but they only analyze adult students using data from one university in Spain. Similarly, Stinebrickner and Stinebrickner (2004, 2008) consider the time students invest in studying by using data from a liberal arts college in Kentucky (Berea College). Aksoy and Link (2000) and Eren and Henderson (2011) use the National Education Longitudinal Study of 1988 and analyze the effect of homework for children in high school between grades 8 and 12 and in grade 8, respectively. All these studies find that there is a positive effect of time spent studying or doing homework (especially in mathematics) on cognitive achievements. However, this positive effect of spending more time doing homework does not seem to extend to primary school students (see Farrow, Tymms, and Henderson 1999; Cooper et al. 2006).

The above-mentioned research suggests that children’s time investments are important inputs in their cognitive development process. If we split the children’s investments into the time invested on their own and the time invested under the active supervision of an adult, the former will presumably be increasingly important as they get older. On the contrary, the effect of parental investments on cognitive skills has been shown to decrease rapidly with age (see Cunha and Heckman 2007, 2008). In particular, looking at mothers’ and fathers’ time investments, Del Boca et al. (2014) find that the time that parents spend actively engaged with their child has an effect on cognitive skills that decreases with the child’s age.

Policies aimed at parents are still relevant to child development. In fact, when children become adolescents, parents may still have some influence on the way their child uses her time when she is on her own. For instance, parents may set strict rules on what their child can and cannot do, or they may be able to transmit to their child time-use habits (some evidence on the transmission of time-use habits is provided in Mancini et al. [forthcoming]). Nevertheless, children during adolescence have more freedom in deciding how to use their own time, and they can potentially disobey parental advice; therefore, the time they spend on their own studying or doing other formative activities can be considered the result of their own choice and a measure of self-investments.

The importance of adolescents’ self-investments has raised interest in policies that encourage study effort and educational activities. For example, Angrist and Lavy (2009) have analyzed a randomized trial where cash awards were given to students in low-achieving schools conditional on passing their matriculation exam at the end of high school, which is a prerequisite for enrolling at university in Israel. They find that these cash incentives increase students’ effort, measured by the number of exams taken, and ultimately the
matriculation success rate. Over the past decade, similar conditional cash transfer (CCT) programs have been used as a tool to reduce poverty and improve human capital development in several developing countries (see Aber and Rawlings 2011). Some CCT programs aiming at improving child development have also been adopted in the United States. An example is provided by the Opportunity New York City Family Rewards, which introduced different types of cash incentives, including cash transfers conditional on educational outcomes (such as school attendance and requirement levels on standardized test scores). Evaluation of this program indicates that these CCT have led to changes in the time use of teenagers, in particular in encouraging more engagement in educational activities (see Morris et al. 2012).

III. Data and Preliminary Evidence

Our analysis relies on the Child Development Supplement (CDS), funded by the National Institute of Child Health and Human Development (NICHD). The CDS covers a maximum of two children for a subsample of households interviewed in the Panel Study of Income Dynamics. About 3,500 children aged 0–12 (from about 2,400 households) were first interviewed in 1997 and then followed in two subsequent waves, 2002–3 and 2007. The number of successful reinterviews was quite high: 91% in the second wave and 90% in the third one. The CDS collects information on cognitive and noncognitive development of the sampled children, as well as their time-use diaries and other individual and family characteristics. All the household and parental variables included in the PSID survey are also available for the CDS children. In our analysis, we include teenagers aged between 11 and 15 who are living with both biological parents. To avoid small sample size issues, we pool two cohorts of children, born respectively in the periods 1982–86 (adolescents in 2002) and 1987–92 (adolescents in 2007), and we obtain a sample of 726 children. This makes available two repeated observations for each adolescent: one during adolescence, when the child is between 11 and 15 years old (either in 2002 or in 2007), and the other during childhood, when the child is between 6 and 10 years old (either in 1997 or in 2002). This is the main sample used in the descriptive statistics in this section. For the estimation of our production models we will use the subsample of siblings, the sibling sample, which allows us to consider the family fixed effects estimation. We have 202 pairs of siblings (404 children out of the 726 included in the main sample). The main summary statistics for the main and sibling samples are reported in Appendix A in tables A1 and A2, respectively.

3 The Panel Study of Income Dynamics is a US longitudinal survey of a nationally representative sample of individuals and families. It started in 1968 with a sample of 4,800 families. It collects yearly individual information on economic, demographic, sociological, psychological, and well-being variables.
A. Time Investments

Crucial to our research question is the availability of detailed information on child’s time-use allocation for one randomly selected week day and one randomly selected weekend day. Time diaries for each day contain recording of activities performed in the 24 hours on a continuous basis. Each spell of a given activity comes with information on its duration and location and on whether the activity was done by the child on her own, in the presence of somebody not actively participating, or in the presence of somebody actively engaged.

This allows us to define a measure of weekly parental time investment as well as a measure of weekly child own time investments. These time investments are measured in a specific week when parents and children are interviewed, but we assume that these represent the usual or average time inputs during the past 5 years.

We measure the parental time investment as the time the parent spends actively engaged with the child reading, doing homework, doing arts and crafts, doing sports, playing, attending performances and museums, engaging in religious activity, having meals and talking with the child, or providing personal care for the child. This aggregate measure of parental investment corresponds to the parent’s quality time defined by Price (2008). It is meant to include all the activities in which either the child is the primary focus or there is a sufficient interaction between the parent and the child. The positive relationship between the frequency of activities such as reading, playing, or eating with children and their outcomes is well documented in the literature (see Price [2008], Sec. II, for a concise review). The positive productivity of both mother’s and father’s active time has also been very recently documented by Del Boca et al. (2014), who have estimated a structural model of household choice on a sample of children in the age group 3–16 from the PSID CDS data set.

In order to take the novel perspective of the child’s own investments in her development process, we select from the above-listed activities those that improve the child’s human capital when performed independently by the child (i.e., either on her own or without anyone actively engaged). The resulting aggregate measure of the child’s own investment includes, besides the time spent doing homework, all active leisure components, such as read-

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4 Activities are coded and registered from midnight of one day (00:00) to midnight of the following day (24:00), using a 24-hour clock. The ending time of an activity coincides with the starting time of the following activity, so there are no gaps in time.

5 The weekly measure is obtained multiplying by five the week day time and summing the result with the weekend day time multiplied by two.

6 Price (2008) derives parental time inputs from the parents’ time-use diaries, which are available in the American Time Use Survey.
ing, doing arts and crafts, doing sports, playing, attending performances and museums, and engaging in religious activity. Both intuition and scientific evidence highlight that human capital includes components other than formal knowledge, such as personal interaction skills that can be enhanced by time spent with friends or engaging in physical activities. Cardoso et al. (2010) consider socializing, together with reading and studying, as activities related to the acquisition of human capital, as opposed to passive leisure such as television watching, often portrayed as detrimental and crowding out other useful activities. Felfe, Lechner, and Steinmayr (2011) report that a positive link between participation in active leisure sport activities and educational attainment is well established for adolescence, and they show that sports club participation during kindergarten and primary school has a positive effect on school performance.

The upper part of table 1 contains the composition of the child’s own time investments in childhood (ages 6–10) and adolescence (ages 11–15). The total active time spent by children on their own increases by about 1 hour a week (25%), on average, across the two stages of their life. The reading and homework activities bring the largest contribution to this increase (re-

Table 1
Mother’s and Child’s Time Investment: Main Sample

|                          | Child’s Age Range 6–10 | Child’s Age Range 11–15 |
|--------------------------|------------------------|-------------------------|
|                          | Mean  SD  Min  Max     | Mean  SD  Min  Max      |
| Child’s own time investment: |                        |                         |
| Total time investment    | 4.08  5.15   .00  30.92 | 5.12  6.86   .00  41.25 |
| Reading                  | .69   1.79    .00   24  | .96   2.5     .00   21.83 |
| Homework                 | .46   1.72    .00   17.50 | 1.25  3.52    .00  29.00 |
| Playing                  | 2.27  3.81    .00   24.75 | 2.48  5.10    .00  41.25 |
| Arts and craft           | .27   1.14    .00   11.25 | .20   1.24    .00  19.75 |
| Sports                   | .28   1.30    .00   22.10 | .16   .95     .00  15.00 |
| Attending performances   | .00   .00     .00   .00  | .01   .20     .00  5.33  |
| Attending museums        | .00   .00     .00   .00  | .00   .00     .00  .00   |
| Religious activity       | .11   .70     .00   6.33  | .08   .56     .00  7.17   |
|                          |                        |                         |
| Mother’s time investment: |                        |                         |
| Total time investment    | 9.47  7.08   .00  40.42 | 5.46  5.20   .00  35.42 |
| Reading                  | .50   1.21    .00   11.25 | .11   .84     .00  12.33 |
| Homework                 | .24   1.12    .00   10.83 | .11   .84     .00  11.17 |
| Playing                  | 1.11  2.56    .00   25.17 | .31   1.49    .00  21.25 |
| Talking                  | .37   .98     .00   8.33  | .57   1.48    .00  12.42 |
| Arts and crafts          | .11   .78     .00   14.92 | .04   .35     .00  4.97   |
| Sports                   | .41   1.47    .00   15.00 | .09   .68     .00  10.67 |
| Attending performances   | .14   1.01    .00   13.33 | .10   .90     .00  13.33 |
| Attending museums        | .05   .56     .00   9.50  | .00   .00     .00  .00   |
| Religious activity       | .78   2.07    .00   14.32 | .78   2.21    .00  20.00 |
| Meals                    | 4.57  3.18    .00   22.17 | 3.11  2.91    .00  21.75 |
| Personal care            | 1.20  2.50    .00   24.17 | .24   1.21    .00  16.17 |

Note.—The table presents weekly time investments in hours. Number of observations = 726.
respectively, about 16 and 48 minutes per week on average), followed by the playing category (with an average increase of about 13 minutes per week). On the contrary, sports and arts activities appear less frequently performed on average during adolescence compared to childhood. The bottom panel of the same table shows a sharp decrease in the mother’s time investments from childhood to adolescence. Mothers spend on average about 9.5 hours per week actively engaged with their children aged 6–10 years but only 5.5 hours when their children become adolescents. All categories of mother’s time investment except for religious activity diminish across the two life stages. In Appendix A, table A3, we report the father’s composition of time investments. The total time fathers spend with children declines with the child’s age: on average, fathers spend 6 hours a week with their children aged 6–10 years but only 4 hours when the children are aged 11–15. However, time spent on helping with homework, talking, and attending performances increases slightly.

B. Cognitive Outcomes

The cognitive tests we use come from the Woodcock-Johnson Revised Tests of Achievement, “a well-established and respected measure that provides researchers with information on several dimensions of intellectual ability” (CDS User Guide). The CDS provides three cognitive test scores measuring symbolic learning and reading, comprehension and vocabulary, and mathematical abilities: the Letter-Word Identification, Passage-Comprehension, and Applied-Problems test scores. These tests were administered to respondents aged 6 years and older by the interviewer, following a standardized administrative protocol and adjusting the test by difficulty according to the respondent’s age (see CDS User Guide for details). Each of these three tests provides a score that is a measure of the child’s cognitive ability. The Letter-Word Identification Score (LWS) measures symbolic learning (matching pictures with words) and reading identification skills (identifying letters and words). It starts from the easiest items (identification of letters and pronunciation of simple words), progressing to the more difficult items. The Passage Comprehension Score (PCS) assesses comprehension and vocabulary skills through multiple-choice and fill-in-the-blank formats. The Applied Problems Score (APS) measures mathematical skills in analyzing and solving practical problems. The test scores are available in both raw and standardized formats. The former essentially counts the number of items correctly answered, while the latter are obtained by standardizing the raw scores according to the respondent’s age.7 We use the standardized measures throughout our analysis.

7 The age standardization process allows for comparison of children of different ages, eliminating the discrepancy in the results due to age differences.
C. Time Investments and Cognitive Ability: Preliminary Evidence

In tables 2 and 3, we provide descriptive evidence on the link between time investments and child cognitive outcomes. In table 2, we look at the differences between average test scores for adolescents, dividing them into two groups: those receiving a high level of investments from their mother (higher than average) and those receiving a low level of investments (lower than average). It can be noticed that children receiving low time investments from their mothers during adolescence have essentially the same outcomes in adolescence as children receiving high time investments, while the time spent with the mother actively engaged in childhood displays some association with adolescents’ cognitive outcomes (the difference is statistically different at the 1% level for PCS and marginally significant and at the 15% level for APS).

Turning to child’s own investments in table 3, the pattern is reversed, and investments during adolescence display a much stronger relationship with adolescents’ outcomes than investments during childhood. The highly significant differences in the test scores between children with high own time investments and those with low own time investments strongly support our investigation about the relevance of autonomous decisions taken by children at this stage of life.

IV. Modeling Cognitive Achievement Production Function during Adolescence

We model the cognitive achievement production function considering inputs that reflect decisions by schools and families as well as by the children.
themselves. We also take into account the fact that cognitive development is a cumulative process by allowing the production function to depend on both contemporaneous and past investments.

By assuming that the production function is additive, separable, and linear in its inputs, we specify the achievement production model during the adolescent stage, that is, between ages 11 and 15, as follows:

$$Y_{ijt} = \beta_0 + \beta_1 X_{ijt} + \beta_2 X_{ijt-5} + \beta_3 X_{ijt-10} + \mu_{ijt} + \eta_{ijt}, \quad (1)$$

where the outcome $Y_{ijt}$ is a general measure of cognitive ability for adolescent $i$ in household $j$ at $t$ years old, $t = 11, ..., 15$, and the arguments are given by:

- the vector of contemporaneous cognitive investments during adolescence by the child herself, $X'_{ijt}$, her family, $X^f_{ijt}$, and her school, $X^s_{ijt}$,
- the corresponding vector of inputs during childhood (5 years earlier), $X'_{ijt-5}$ = $[X^c_{ijt-5}, X^f_{ijt-5}, X^s_{ijt-5}]$;
- the corresponding vector of inputs during early childhood (10 years earlier), $X'_{ijt-10}$ = $[X^c_{ijt-10}, X^f_{ijt-10}, X^s_{ijt-10}]$;
- the child’s unobserved cognitive endowment $\mu_{ijt}$; and
- a random (idiosyncratic) shock in period $t$, $\eta_{ijt}$.

**Table 3**

|                        | LWS Average | PCS Average | Average |
|------------------------|-------------|-------------|---------|
| **Main sample**        | 726         | 105.842     | 104.055 | 107.135 |
| **Own time investment in adolescence:** |             |             |         |
| Subsample with mother’s time investment: |             |             |         |
| Higher than average    | 249         | 108.566     | 107.365 | 110.438 |
| Lower than average     | 477         | 104.419     | 102.327 | 105.411 |
| Difference between the two sub samples | 4.147*** | 5.038*** | 5.026*** |
| Standard error          | 1.305       | 1.155       | 1.170   |
| **Own time investment in childhood:** |             |             |         |
| Subsample with mother’s time investment: |             |             |         |
| Higher than average    | 268         | 108.160     | 105.944 | 108.585 |
| Lower than average     | 458         | 104.484     | 102.950 | 106.286 |
| Difference between the two sub samples | 3.675*** | 2.994*** | 2.300** |
| Standard error          | 1.285       | 1.145       | 1.162   |

**NOTE.**—LWS = Letter-Word Identification Score; PCS = Passage Comprehension Score. Two-sided $t$-test for $H_0$: difference of means $= 0$.

**** Statistically significant at the 5% level.

*** Statistically significant at the 1% level.
Notice that we assume that the parameters of the above model are invariant during the stage of adolescence, that is, for children aged 11–15 (t = 11, ..., 15), but we do not impose that this model is invariant across different child life stages. The following specification for children during the childhood stage (ages 6–10) is useful in some cases:

\[ Y_{ijt-5} = \gamma_0 + \gamma_1 X_{ijt-5} + \gamma_2 X_{ijt-10} + \mu_{ij} + \eta_{ijt-5}, \]  

(2)

where the outcome(s) and inputs are observed 5 years earlier than in equation (1), \( \mu_{ij} \) captures the unobserved cognitive endowment during childhood, which can differ from the corresponding endowment during adolescence, and the parameters \( \gamma_0, \gamma_1, \) and \( \gamma_2 \) are not imposed to be equal to \( \beta_0, \beta_1, \) and \( \beta_2. \) Our production function is similar to the one considered by previous works on child cognitive development, with the main difference that it considers the investments made by the children themselves alongside the inputs by families and schools (see Todd and Wolpin 2003, 2007).

In our sample, we do not observe a general measure of cognitive ability \( Y_{ijt} \), but we observe three different specific skills measured by the Letter-Word Identification, Passage-Comprehension, and Applied-Problems test scores. We indicate these three observed skills with \( Y_{kijt} \), where the subscript \( k \) denotes each of the three cognitive test scores, and we impose the following assumptions, which we call maintained assumptions because they are imposed throughout the rest of paper:  

\[ \text{MAINTAINED ASSUMPTION M1.} \] The specific measure of ability \( k \) in adolescence follows the model:

\[ Y_{kijt} = Y_{ijt} + \epsilon_{kijt}, \]  

(3)

where \( t = 11, \ldots 15 \), \( \epsilon_{kijt} \) measures the deviation of skill \( k, Y_{kijt}, \) from the general latent ability, \( Y_{ijt}, \) and it is assumed to be identically and independently distributed across skills, individuals, and households, with mean zero, variance \( \sigma^2 \), uncorrelated with the production function inputs, the latent general ability, and the unobserved endowment, but it is allowed to be correlated across time.

\[ \text{MAINTAINED ASSUMPTION M2.} \] The specific measure of ability \( k \) in the childhood period follows the model:

\[ Y_{kijt-5} = Y_{ijt-5} + \epsilon_{kijt-5}, \]  

(4)

where \( t - 5 = 6, \ldots, 10 \), \( \epsilon_{kijt-5} \) measures the deviation of skill \( k, Y_{kijt-5}, \) from the general latent ability, \( Y_{ijt-5}, \) and it is assumed to be identically

\[^8\text{We abstract from any measurement error in skills in our main analysis, but we explore the issue in Sec. VI.D.}\]
and independently distributed across skills, individuals, and households, with mean zero, variance $\sigma^2_j$, uncorrelated with the production function inputs, the latent general ability, and the unobserved endowment, but it is allowed to be correlated across time.

Under maintained assumption M1, the production function during adolescence (1) can be rewritten as:

$$Y_{kijt} = \beta_0 + \beta_1 X_{ijt} + \beta_2 X_{ijt-5} + \beta_3 X_{ijt-10} + \mu_{ijt} + \epsilon_{kijt} + \eta_{ijt}.$$  \hspace{1cm} (5)

Model (5) is similar to what Todd and Wolpin (2003) call the cumulative model, where the child’s outcome during adolescence at age $t$ depends on current and past inputs. Since we only observe inputs every 5 years, the outcome during adolescence at age $t$ ($t = 11, \ldots, 15$) depends only on inputs observed at age $t$, $t-5$, and $t-10$; that is, we assume that inputs during adolescence, childhood, and early childhood can be approximated by inputs observed at three points in time, $t$, $t-5$, and $t-10$.

In the following subsections, we list the assumptions needed to obtain consistent estimators of the cumulative model during adolescence (Sec. IV.A) and of an extended model that includes the lagged cognitive score $Y_{kijt-5}$ as an additional input, called the augmented value-added model (Sec. IV.B). For the cumulative model, we discuss consistency of the ordinary least squares (OLS) estimator, the family fixed effects (FE) estimator, and the estimator obtained taking differences across time, which we call the time difference (TD) estimator. For the augmented value-added model, we do not consider the TD estimator, which is not applicable in our context,\footnote{This would require observing the test scores $Y_{kijt}$ in more than two periods.} and, in addition to OLS and family FE, we discuss a two-step estimator that we propose below.

**A. Cumulative Model**

Breaking down investments by children, families and schools, the cumulative model during adolescence (5) can be written as:

$$Y_{kijt} = \beta_0 + \beta_1 X_{ijt}^C + \beta_1 X_{ijt}^F + \beta_2 X_{ijt-5}^C + \beta_2 X_{ijt-5}^F + \beta_3 X_{ijt-5}^S + \mu_{ijt} + e_{kijt} + \eta_{ijt},$$  \hspace{1cm} (6)

where $\beta_0$ is the intercept, $\beta = [\beta_1^C, \beta_1^F, \beta_2^C, \beta_2^F, \beta_3^C, \beta_3^F, \beta_3^S]$ are vectors of coefficients corresponding to contemporaneous, 5-year, and 10-year lagged inputs.

Estimation of the above model is quite demanding in terms of data on current and past investments. In our empirical application, we are able to mea-
sure parental investments by looking at the time the mother spends actively engaged with her child, whereas we measure child investments by the time children spend on formative activities on their own without the supervision of an adult (see Sec. III for details on these definitions). We are able to observe these parental and child investments during late childhood and adolescence, whereas we are unable to observe school inputs, \(X_{ijt}^{s}, X_{ijt-5}^{s}, X_{ijt-10}^{s}\), and early childhood inputs, \(X_{ij}^{c-10}\). For this reason, we have to collapse these investments into the idiosyncratic error of the model, which becomes \(\tilde{\eta}_{ijt} = \eta_{ijt} + \beta_1 X_{ijt}^{s} + \beta_2 X_{ijt-5}^{s} + \beta_3 X_{ijt-10}^{s} + \beta_4 X_{ijt-10}^{c} + \beta_5 X_{ijt-10}^{f}\):

\[
Y_{kjt} = \beta_0 + \beta_1 X_{ijt}^{c} + \beta_2 X_{ijt}^{f} + \beta_3 X_{ijt-5}^{c} + \beta_4 X_{ijt-5}^{f} + \mu_y + \epsilon_{kjt} + \tilde{\eta}_{ijt}. \tag{7}
\]

To consistently estimate the cumulative model (7) using OLS, besides maintained assumption M1, the following condition must hold:

**Assumption 1.** The observed inputs are uncorrelated with the unobserved endowment \(\mu_y\) and with the unobserved inputs, that is, with the idiosyncratic shock \(\tilde{\eta}_{ijt}\).

Clearly assumption 1 is quite restrictive because it is hardly credible that parental and child investments are uncorrelated with the child’s unobserved endowment, the school inputs, and the early childhood investments. Omitting the time investment by the child herself during early childhood, \(X_{ijt}^{c-10}\), is not a major concern, because children aged 0–5 spend zero or very little time on their own (i.e., without the supervision of an adult). On the contrary, the omission of early parental investments and of school inputs can be relevant.

Next, let us consider the family fixed effects (FE) estimation. In our empirical application, we observe up to two siblings for each household, and we can therefore compute the family FE estimator by regressing sibling differences in test scores on the sibling differences in their inputs and endowments:10

\[
Y_{kjt} - Y_{k'jt} = \beta_1 X_{ijt}^{c} - X_{ijt'}^{c} + \beta_2 X_{ijt}^{f} - X_{ijt'}^{f} + \beta_3 X_{ijt-5}^{c} - X_{ijt-5'}^{c} + \beta_4 X_{ijt-5}^{f} - X_{ijt-5'}^{f} + \mu_y + \epsilon_{kjt} - \epsilon_{k'jt} + \tilde{\eta}_{ijt} - \tilde{\eta}_{ijt'}, \tag{8}
\]

10 The difference in the variables between two siblings is taken either at the same calendar period (year) or in the two available periods.
where the subscripts $i$ and $i'$ denote the two siblings in household $j$. The consistency of the family FE estimation requires the following assumption:

**Assumption 2.** Sibling differences in observed inputs are uncorrelated with sibling differences in their unobserved endowment, $(\mu_{ij} - \mu_{i'})$ and sibling differences in unobserved inputs, that is, sibling differences in the idiosyncratic shock, $(\tilde{\eta}_{ijt} - \tilde{\eta}_{i'jt})$.

Assumption 2 is likely to be less restrictive than assumption 1, because inputs are allowed to depend on the unobserved family-specific endowment and on unobserved inputs, which do not vary between siblings. In fact, in model (8), we actually control for all unobserved family-specific characteristics using sibling differences. The consistency of the family FE estimation still requires that the inputs not respond to the unobserved child-specific endowment. Rather than requiring a zero response of parental and child investments to changes in omitted school inputs (as assumption 1 in model [7] does), it only requires that sibling differences in parental and child’s investments not react to sibling differences in omitted school inputs. In our empirical section, we will test the validity of such an assumption in the augmented value-added model, which will be our preferred specification.

An alternative estimation strategy for model (7) is analogous to first-difference estimation in the context of panel data, which exploits the test scores and time investments available at different points in time for the same child. In our framework, the time difference for a variable is between the variable observed in $t$ and in $t-5$ and the corresponding estimation. We call this the time difference (TD) estimation, and it is implemented by differencing model (7):

\[
Y_{ijt} - Y_{ijt-5} = \beta_0 \left( X_{ij}^C - X_{ij-5}^C \right) + \beta_1 \left( X_{ij}^C - X_{ij-5}^C \right) \\
+ \beta_2 \left( X_{ij-5}^F - X_{ij-10}^F \right) + \beta_3 \left( X_{ij-5}^F - X_{ij-10}^F \right) \\
+ \left( \epsilon_{ijt} - \epsilon_{ijt-5} \right) + \left( \tilde{\eta}_{ijt} - \tilde{\eta}_{ijt-5} \right).
\]

(9)

The consistency of the TD estimation requires, besides maintained assumptions M1 and M2, the following assumptions:

**Assumption 3.** The production models in adolescence and in childhood are identical, that is, $\beta_0 = \gamma_0$, $\beta_1 = \gamma_1$, $\beta_2 = \gamma_2$, and $\mu_{ij} = \mu_{i'}$.

**Assumption 4.** Time differences in observed inputs are uncorrelated with time differences in unobserved inputs, that is, time difference in the idiosyncratic shock, $(\tilde{\eta}_{ijt} - \tilde{\eta}_{ijt-5})$. 

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ASSUMPTION 5. Time differences in observed inputs are uncorrelated with $(\epsilon_{kijt} - \epsilon_{kiijt-5})$.

While assumption 5 is satisfied because of maintained assumptions M1 and M2, assumptions 3 and 4 are quite strong. Assumption 3 is hardly credible, especially in light of recent literature that emphasizes that the child development process is a multistage process and that some inputs can be more productive in some stages and less in others (Cunha et al. 2006; Cunha, Heckman, and Schennach 2010). Assumption 4 is also not credible because investments in $t$, $X_{ijt}^C$ and $X_{ijt}^F$, are taken by the child and her parents after observing $Y_{kijt-5}$, or some other correlated measure of cognitive ability, and are likely to respond to $Y_{kijt-5}$. Because $Y_{kijt-5}$ depends on $\tilde{\eta}_{ijt-5}$, we cannot exclude that $X_{ijt}^C$ and $X_{ijt}^F$ are correlated with $\tilde{\eta}_{ijt-5}$, which implies that assumption 4 cannot be satisfied. In other words, every time that investments in $t$ react to cognitive ability in $t - 5$, the TD estimation is biased by a reverse causality issue. In the case of the family FE, this reverse causality issue does not occur because decisions on investments in $t$, $(X_{ijt}^C - X_{ijt}^C)$ and $(X_{ijt}^F - X_{ijt}^F)$, are taken before observing sibling differences in test score in $t$, $(Y_{kijt} - Y_{kijt})$. Nevertheless, if investments respond to past cognitive abilities and past cognitive abilities are relevant in the production of current cognitive abilities, then both the TD and family FE estimation are inconsistent. For this reason, in the next subsection, we extend the production model to include past cognitive abilities as inputs.

B. Augmented Value-Added Model

The family FE estimator of the cumulative model allows the inputs to depend on the unobserved endowment and characteristics that are identical between siblings, but, as with the OLS estimator, it is unable to take account of the possible dependence of inputs on the unobserved child-specific endowment or on past cognitive achievements. Parents may respond to the child’s past cognitive abilities or to differences in the past cognitive abilities between their children with reinforcing or compensating behaviors, and these are sources of inconsistency for the OLS and the family FE estimators.

To control for this dependence between lagged cognitive ability and inputs, we add the lagged true cognitive ability $Y_{ijt-5}$ as an explanatory variable in the cumulative production model during adolescence (1), which yields the augmented value-added model (as defined by Todd and Wolpin [2007]):

$$Y_{ijt} = \delta_0 + \delta_1 X_{ijt} + \delta_2 X_{ijt-5} + \rho Y_{ijt-5} + \mu_{ijt} + \eta_{ijt}^a,$$

where $\mu_{ijt}^a$ is the new unobserved child-specific endowment and $\eta_{ijt}^a$ is an idiosyncratic shock.

For this augmented value-added model we consider, besides maintained assumptions M1 and M2, the following new maintained assumption:
MAINTAINED ASSUMPTION M3. The persistence\footnote{By persistence, we mean the net autocorrelation, i.e., the correlation between a variable in $t$ and the corresponding variable in $(t-5)$ net of the explanatory variables in the production model.} in each of the three $k$-specific abilities, $Y_{kijt}$ ($k = 1, 2, 3$), $\rho_3$, is identical to the persistence in latent general ability, $Y_{ijt}$, and equal to $\rho$.

Maintained assumption M3 states that each of the three different abilities (Letter-Word Identification, Passage-Comprehension, and Applied-Problems) depreciates at the same rate from $t - 5$ to $t$. This seems a reasonable pattern and is supported by the empirical evidence we provide in Section VI.B.\footnote{Maintained assumption M2 also implies that the correlation between $\epsilon_{kijt}$ and $\epsilon_{kijt-5}$ is equal to $\rho$ for each $k$. Since $\epsilon_{kijt}$ and $\epsilon_{kijt-5}$ are not errors but measures of extra ability of child $i$ in subject $k$ with respect to her general ability, $Y_{ijt}$, an equal persistence in this extra ability and in the general latent ability, seems reasonable.}

By replacing the unobserved latent general ability with the observed $k$-specific ability, we can rewrite model (10) as

$$Y_{kijt} = \delta_0 + \delta_1 X_{ijt} + \delta_2 X_{ijt-5} + \rho Y_{kijt-5} + \mu_{ijt} + \eta_{ijt},$$

where $\eta_{ijt} = \epsilon_{kijt} - \rho \epsilon_{kijt-5} + \eta_{ijt}$.

Consistency of the OLS estimator of model (11) requires, besides maintained assumptions M1–M3, additional assumptions:

ASSUMPTION 6. Conditionally on the past cognitive ability $Y_{kijt-5}$, the observed inputs are uncorrelated with the unobserved endowment $\mu_{ijt}$ and with the unobserved inputs, that is, with the idiosyncratic shock, $\eta_{ijt}$ (but they are allowed to be correlated with the past cognitive ability $Y_{kijt-5}$).

ASSUMPTION 7. The past cognitive ability, $Y_{kijt-5}$, is uncorrelated with both the unobserved endowment $\mu_{ijt}$ and the idiosyncratic shock $\eta_{ijt}$.

Notice that in model (11) $Y_{kijt-5}$ and the error term $\eta_{ijt}$ are correlated, since both $Y_{kijt-5}$ and $\eta_{ijt}$ depend on $\epsilon_{kijt-5}$. This correlation would generally bias the estimation, but, under the above assumptions, we can prove that the asymptotic bias cancels out, and the OLS estimator of $\rho$ converges asymptotically to

$$\text{plim } \widehat{\rho}_{OLS} = \frac{\text{Cov}(\varepsilon_{kijt}, \mu_{ijt})}{\text{Var}(\varepsilon_{kijt})} - \rho - \frac{\text{Cov}(\varepsilon_{kijt}, \mu_{ijt})}{\text{Var}(\varepsilon_{kijt})} = \rho,$$

By replacing the unobserved latent general ability with the observed $k$-specific ability, we can rewrite model (10) as

$$Y_{kijt} = \delta_0 + \delta_1 X_{ijt} + \delta_2 X_{ijt-5} + \rho Y_{kijt-5} + \mu_{ijt} + \eta_{ijt},$$

where $\eta_{ijt} = \epsilon_{kijt} - \rho \epsilon_{kijt-5} + \eta_{ijt}$.

Consistency of the OLS estimator of model (11) requires, besides maintained assumptions M1–M3, additional assumptions:

ASSUMPTION 6. Conditionally on the past cognitive ability $Y_{kijt-5}$, the observed inputs are uncorrelated with the unobserved endowment $\mu_{ijt}$ and with the unobserved inputs, that is, with the idiosyncratic shock, $\eta_{ijt}$ (but they are allowed to be correlated with the past cognitive ability $Y_{kijt-5}$).

ASSUMPTION 7. The past cognitive ability, $Y_{kijt-5}$, is uncorrelated with both the unobserved endowment $\mu_{ijt}$ and the idiosyncratic shock $\eta_{ijt}$.

Notice that in model (11) $Y_{kijt-5}$ and the error term $\eta_{ijt}$ are correlated, since both $Y_{kijt-5}$ and $\eta_{ijt}$ depend on $\epsilon_{kijt-5}$. This correlation would generally bias the estimation, but, under the above assumptions, we can prove that the asymptotic bias cancels out, and the OLS estimator of $\rho$ converges asymptotically to

$$\text{plim } \widehat{\rho}_{OLS} = \frac{\text{Cov}(\varepsilon_{kijt}, \mu_{ijt})}{\text{Var}(\varepsilon_{kijt})} - \rho - \frac{\text{Cov}(\varepsilon_{kijt}, \mu_{ijt})}{\text{Var}(\varepsilon_{kijt})} = \rho,$$
where $M_X$ is the projection matrix on the space orthogonal to the one generated by the variables $X' = (X'_{ijt}, X'_{ijt-5})$. The consistency is guaranteed by the facts that:

- Assumption 7 implies that the asymptotic bias caused by the omission of the unobserved individual endowment cancels out, that is,
  \[
  \frac{\text{Cov}(\mu'_{ijt}, M_X Y_{kij-5})}{\text{Var}(M_X Y_{kij-5})} = 0;
  \]

- \[
  \begin{bmatrix}
  \text{Cov}(\epsilon_{kijt}, \epsilon_{kij-5}) \\
  \text{Var}(M_X Y_{kij-5})
  \end{bmatrix} - \rho \frac{\text{Var}(\epsilon_{kij-5})}{\text{Var}(M_X Y_{kij-5})},
  \]

  which is the asymptotic bias caused by the correlation between $(\epsilon_{kijt} - \rho \epsilon_{kij-5})$ and the lagged test $Y_{kij-5}$, is also zero because of maintained assumptions M1–M3:

  \[
  \frac{\text{Cov}(\epsilon_{kijt}, \epsilon_{kij-5})}{\sqrt{\text{Var}(\epsilon_{kij-5}) \text{Var}(\epsilon_{kijt})}} = \frac{\text{Cov}(\epsilon_{kijt}, \epsilon_{kij-5})}{\text{Var}(\epsilon_{kij-5})} = \rho.
  \tag{13}
  \]

Assumptions 6 and 7 can be quite restrictive, so we also consider family FE estimation, that is, we express model (11) as differences between siblings:

\[
Y_{kijt} - Y_{kijt} = \delta_1^C (X^C_{ijt} - X^C_{ijt}) + \delta_1^F (X^F_{ijt} - X^F_{ijt}) + \delta_2^C (X^C_{ijt-5} - X^C_{ijt-5}) + \delta_2^F (X^F_{ijt-5} - X^F_{ijt-5}) + \rho (Y_{kij-5} - Y_{kij-5}) + (\mu''_{ijt} - \mu''_{ijt}) + (\mu''_{kijt} - \mu''_{kijt}).
\tag{14}
\]

Family FE estimation is consistent under the following assumptions (besides the maintained assumptions M1–M3):

**Assumption 8.** Conditionally on the sibling difference in the past cognitive ability $(Y_{kij-5} - Y_{kij-5})$, sibling differences in observed inputs are uncorrelated with sibling differences in their unobserved endowment, $(\mu''_{ijt} - \mu''_{ijt})$, and with sibling differences in unobserved inputs, that is, the sibling difference in the idiosyncratic shock, $(\eta''_{ijt} - \eta''_{ijt})$, but they are allowed to be correlated with the sibling difference in past cognitive attainment, $(Y_{kij-5} - Y_{kij-5})$.

**Assumption 9.** The sibling difference in the past cognitive test score, $(Y_{kij-5} - Y_{kij-5})$, is uncorrelated with the sibling difference in unob-
served endowment, \((\mu_{ij}^{a} - \mu_{ij}^{a})\), and in the idiosyncratic shock \((\eta_{ijt}^{a} - \eta_{ijt}^{a})\).

Assumptions 8 and 9 are likely to be less restrictive than assumptions 6 and 7 because using differences between siblings eliminates the unobserved family-specific characteristics and endowment that do not vary between siblings. Assumption 8 is in line with the view that there exists exogenous sibling variation in time investments that can explain sibling differences in cognitive abilities after controlling for the lagged abilities and other variables. Borrowing from the seminal paper of Ashenfelter and Rouse (1998), this variation can be seen as originated by random deviations from optimal investment choices caused, for example, by unexpected influence of school peers and friends (e.g., Stinebrickner and Stinebrickner 2008) or by experiencing events that change the child’s preferences about time use but do not directly affect test scores.

The assumption that the unobserved child-specific endowment is uncorrelated with the lagged test (assumption 9) is likely to be less restrictive than assumption 7, but it is still likely to be invalid. If assumption 9 does not hold, then being unable to control for sibling differences in the unobserved endowment will lead to an overestimation of the effect of the lagged test score, the persistence \(\rho\), which can contaminate the input coefficients as well (Andrabi et al. 2011).

We solve this further issue of endogeneity by adopting a two-step estimation procedure. In the first step, we use the observed scores for the three different skills available for each child in \(t\) and \(t-5\) to compute an individual fixed effects (individual FE) estimation, which controls for the child-specific endowment, \(\mu_{ij}^{a}\). This individual FE estimation can be implemented by considering model (11) expressed in deviations from the mean:

\[
Y_{kijt} - \bar{Y}_{ijt} = \rho (Y_{kijt-5} - \bar{Y}_{ijt-5}) + (\mu_{kijt} - \bar{\mu}_{ijt}),
\]

where the bar indicates the mean over the three skills. This individual FE estimation method is identical to the within-pupil between-subject estimation used by Dee (2005, 2007) to estimate the effect of teacher characteristics on test scores. Because none of the right-hand-side variables in model (11) changes across the three skills except the test score, the individual fixed effects estimation provides an estimate only for the persistence parameter, \(\hat{\rho}_{\text{IndFE}}\).

In the second step, we replace \(\rho\) in model (14) with its estimate from the first step:

\[\hat{\rho}_{\text{IndFE}}.\]

Notice that, if the inputs changed across different skills, then we could include them in eq. (15), and we would be able to estimate their effect directly in the first-stage estimation, with no need for a second stage.
and we use family FE estimation to produce estimates for the coefficients $d_{C1}$, $d_{F1}$, $d_{C2}$, and $d_{F2}$. Thanks to this novel two-step estimation, we obtain results that are purged of the bias induced by the lagged test regressor. We are actually not the first to assume that different cognitive test scores are related to a same latent cognitive ability and to use the multiplicity of measures to solve the issue of endogeneity of the lagged test. For example, Cunha and Heckman (2008) use multiple measures of tests and inputs to derive three latent measures corresponding to cognitive and noncognitive abilities and investment. Furthermore, they use multiple measures of tests and inputs to instrument the lagged tests and inputs in their cognitive development model (see Pudney [1982] for more details on this other type of estimation). Our procedure imposes some different restrictions, but it is simpler and has the advantage of distinguishing between parents’ and child’s inputs and therefore allows us to evaluate the contribution of children’s decisions to their cognitive development process.

Under maintained assumptions M1–M3, it can be proven that the individual fixed effects estimation of the persistence, $\rho_{\text{IndFE}}$, is consistent because

$$\text{plim} \hat{\rho}_{\text{IndFE}} = \frac{\text{Cov} (\epsilon_{kij}, \epsilon_{kij} - 5)}{\text{Var} (\epsilon_{kij} - 5)} = \rho.$$  

The two-step estimation, which uses the child individual estimation in the first step and the family fixed effects estimation in the second step is consistent under assumption 8 plus the maintained assumptions M1–M3. These assumptions are identical to those required for the consistency of the family FE estimation of the augmented value-added model, except for assumption 9, which is now relaxed.

Notice that, as for the family fixed effects estimation of the augmented value-added model, the two-step estimation does not require that parental and school investments be identical between siblings or that they be uncorrelated with lagged test scores. Since the seminal paper of Behrman, Pollak, and Taubman (1982), several studies have tried to explain why parental investments differ between siblings and have examined whether these investments compensate for or reinforce children’s differences in abilities. Bernal (2008), for example, finds that compensating behavior seems to dominate
when looking at time investments of mothers. We take into account that the mother’s investment may compensate for or reinforce differences between her children’s abilities by controlling for lagged test score realizations. However, we assume that any other unobserved ability or input is either identical between siblings or that, if a difference exists, it is uncorrelated with the sibling differences in observed inputs once controlling for their gaps in the lagged test and other variables. Clearly, sibling differences in unobserved characteristics that cause a response in investments would make assumption 8 invalid and lead to an overestimation (or underestimation) of the investment effect if the investments reinforce (or compensate for) the sibling gap in cognitive abilities. In Section VI.A, we test empirically whether omitted inputs are a cause of concern by considering three sets of potential omitted variables: (i) school inputs, (ii) early childhood inputs, and (iii) child’s health shocks.

V. Estimation Results of the Cognitive Production Model

In tables 4 and 5, we report our main estimation results for the cumulative model (7) and the augmented value-added model (11). For the cumulative model, we report the results of the ordinary least squares (OLS), family fixed effects (family FE), and time difference (TD) estimations (cols. 1–3 of table 4); for the augmented valued-added model, we report the estimates of the OLS, family FE, and two-step estimation methods (cols. 1–3 of table 5). Both the cumulative and the augmented value-added models include the same explanatory variables, except for the lagged test, which is included only in the augmented model. The outcome variable is measured by the three standardized test scores described in Section III: the Letter-Word Identification Score (LWS), the Passage Comprehension Score (PCS), and the Applied Problems Score (APS). We treat the three tests as repeated measures of the child’s ability, so our number of observations increases from 404 (the number of siblings) to 1,212 (the number of siblings multiplied by the number of tests available for each child). We estimate the production models using the sibling sample for all estimations, except for the TD estimation, which also requires information on twice-lagged time investments and is therefore based on the subsample that excludes missing cases for these investments.14

Our main coefficients of interest are the effects of time investments, which we measure by the weekly number of hours the child and her mother invest in formative activities during adolescence (child’s and mother’s time investments) and during childhood (child’s and mother’s lagged time investments). We focus our discussion mainly on these four coefficients and

14 In table A2 in Appendix A, we report some summary statistics of the variables used.
on the coefficient of the lagged test, which captures the correlation between the contemporaneous and lagged tests net of the explanatory variables and allows us to assess whether a bad test result today may create a trap into low cognitive achievements for the child’s future.

There are differences across different specifications and estimations, but two findings clearly emerge from all but the TD estimation: (i) the mother’s investment during childhood matters, while the mother’s investment during adolescence does not (see rows 1 and 3 in table 4 and rows 2 and 4 in table 5); (ii) the child’s own investment during childhood matters less than the child’s investment during adolescence (see rows 2 and 4 in table 4 and rows 3 and 5 in table 5).

Table 4
Cumulative Model Estimation Results

|                      | OLS         | Family FE    | TD       |
|----------------------|-------------|--------------|----------|
| Mother’s time investment | -.004 (.006) | -.007 (.007) | .001 (.005) |
| Child’s time investment     | .022*** (.004) | .010* (.005) | .018*** (.004) |
| Lag(Mother’s time investment) | .009* (.004) | .010* (.005) | .002 (.002) |
| Lag(Child’s time investment) | .013*** (.005) | .007 (.006) | .008* (.004) |
| Child’s age              | -.185 (.427) | .045 (.411)  |          |
| (Child’s age)²          | .004 (.016)  | -.001 (.016) |          |
| Male                   | -.107* (.055) | -.099 (.063) |          |
| Mother’s age            | .302*** (.070) | -.144 (.233) |          |
| (Mother’s age)²        | -.003*** (.001) | -.002 (.002) |          |
| Birth order             | -.225*** (.037) | .011 (.085)  |          |
| Born 1982–87            | -.051 (.058)  | 1.587 (1.026) |          |
| Constant                | -5.081* (3.079) | 8.498 (8.426) | .023 (.046) |
| R²                     | .126        |              |          |
| Number of observations  | 1,212       | 1,212        | 591      |
| Number of sibling groups | 202         |              |          |
| Sibling correlation     | .918        |              |          |

**NOTE.**—Dependent variable: standardized test scores (LWS, PCS, APS). LWS = Letter-Word Identification Score; PCS = Passage Comprehension Score; APS = Applied Problem Score. OLS = ordinary least squares. FE = fixed effects, TD = time difference. Sibling sample (cols. 1 and 2) and subsample with details on twice-lagged test (col. 3). Standard errors are in parentheses.

* Statistically significant at the 10% level.
** Statistically significant at the 5% level.
*** Statistically significant at the 1% level.
The TD estimation is the only model for which the above finding (i) is not confirmed, but we think that this might be caused by the failure of assumptions 3 and 4. Because mothers and children take decisions on time investments in \( t \) before observing the test results in \( t \) but after observing the test results (or some correlated measures of cognitive abilities) in \( t - 5 \), the TD estimation is biased by a reverse causality issue that invalidates assumption 4. We also think that assumption 3, which imposes an identical production model for children ages 6–10 and ages 11–15, is hard to believe. For these reasons, we judge the TD estimation to be inadequate for the estimation of our cumulative model. Stinebrickner and Stinebrickner (2008) reach

### Table 5
Augmented Value-Added Model Estimation Results

|                         | OLS   | Family FE | Two-Step |
|-------------------------|-------|-----------|----------|
| Lag(test)               | .528*** | .352***   | .279***  |
|                         | (.023) | (.028)    | (.044)   |
| Mother’s time investment| .003  | .000      | -.001    |
|                         | (.005) | (.007)    | (.006)   |
| Child’s time investment | .022*** | .014***   | .013**   |
|                         | (.004) | (.005)    | (.005)   |
| Lag(Mother’s time investment) | .010*** | .009*     | .010*    |
|                         | (.003) | (.005)    | (.005)   |
| Lag(Child’s time investment) | .005  | .005      | .005     |
|                         | (.004) | (.005)    | (.006)   |
| Child’s age             | -.631*  | -.476     | -.368    |
|                         | (.355) | (.384)    | (.414)   |
| (Child’s age)\(^2\)     | .022  | .018      | .014     |
|                         | (.014) | (.015)    | (.016)   |
| Male                    | -.020  | -.087     | -.092    |
|                         | (.046) | (.058)    | (.262)   |
| Mother’s age            | .139** | -.079     | -.002    |
|                         | (.058) | (.216)    | (.002)   |
| (Mother’s age)\(^2\).   | -.001* | -.002     | -.089    |
|                         | (.001) | (.002)    | (.065)   |
| Birth order             | -.106*** | -.021     | -.014    |
|                         | (.031) | (.079)    | (.088)   |
| Born 1982–87            | -.045  | 1.024     | 1.139    |
|                         | (.048) | (.953)    | (1.219)  |
| Constant                | 1.025  | 8.385     | 8.409    |
|                         | (2.573)| (7.815)   | (9.471)  |
| \( R^2 \)               | .396  |           |          |
| Number of observations  | 1,212  | 1,212     | 1,212    |
| Number of sibling groups| 202   | 202       | 202      |
| Sibling correlation     | .860  |           |          |

**NOTE.**—Dependent variable: standardized test scores (LWS, PCS, APS). LWS = Letter-Word Identification Score; PCS = Passage Comprehension Score; APS = Applied Problem Score. OLS = ordinary least squares; FE = fixed effects. Sibling sample. Standard errors (in parentheses) are bootstrapped for the two-step estimation.

* Statistically significant at the 10% level.
** Statistically significant at the 5% level.
*** Statistically significant at the 1% level.
a similar conclusion for their first-difference estimation applied to evaluate the effect of students’ study effort on test scores during college.

The finding that the mother’s investment during childhood matters more than the mother’s investment during adolescence in explaining adolescents’ cognitive ability suggests a decreasing importance of the mother’s time investment as the child grows. Empirical evidence on the decreasing importance of the mother’s investment is also provided by our descriptive statistics in table 1, where we can see that the mother’s time investment decreases from about 9 hours per week to 5 hours per week when children move from childhood to adolescence. The fact that only child self-investments during adolescence and not during childhood affect their cognitive outcomes in adolescence suggests that the importance of child own investments increases with age as children become more independent.

A third clear finding emerges within the results of the augmented value-added model (see table 5): (iii) the lagged test coefficient is always highly significant, suggesting a very high persistence in the test score results. Nevertheless, this coefficient decreases from 0.528 to 0.352 when we control for the family fixed effects (see cols. 1 and 2 in table 5) and to 0.279 when we also control for the individual fixed effects (see col. 3), revealing that part of the test persistence is explained by the unobserved ability endowment.

By estimating a regression of the difference in mother’s time investment between her two siblings on the sibling differences in the lagged test scores, we found that mothers’ investments compensate for sibling differences in cognitive abilities. This evidence corroborates our choice of including the lagged test score in the production function, obtaining the augmented value-added specification model. Therefore, hereafter we discuss the differences across the estimation results we obtain for this model (see table 5). We are concerned with the potential omission of family characteristics and endowment, and for this reason we compare the OLS and the family fixed effects estimations. The results seem to change when moving from the OLS to the family fixed effects estimation (compare cols. 1 and 2 in table 5), and this suggests that the OLS estimation suffers from a variable omission problem.

The next question is whether considering the lagged test and family fixed effects is enough to control for all unobserved characteristics that are associated with the explanatory variables and relevant in explaining the cognitive tests. It is certain that family fixed effects estimation fails to control for unobserved individual abilities that differ between siblings. As explained in Section IV.B, we have an issue of endogeneity of the lagged cognitive test, which we can address by means of a two-step estimation. The results of this two-step estimation are reported in the last column of table 5, where standard errors have been bootstrapped using 1,000 replications. These are our preferred results because the two-step estimation takes account of all our main econometric concerns. The main difference in the results between columns 2 and 3 in table 5 is an attenuation of the coefficient of the lagged test,
and this confirms that the family fixed effects estimation presented in column 2 is inadequate to control for unobserved individual characteristics that differ between siblings.\textsuperscript{15} Nevertheless, we find that the coefficients of the time investments as well as the effects of all variables remain almost unaltered in size and statistical significance.

Considering our preferred estimates (see col. 3 in table 5), an increase of 10 hours per week in the mother’s time investment during childhood seems to have an effect similar to an increase of 10 hours per week in the child’s own time investment during adolescence: both changes lead to an increase of about 10\%–13\% of a standard deviation of the cognitive test. The effect of decreasing child’s time investments during adolescence by 10 hours per week is identical to the effect of having a mother working full-time and using child care during 1 year on children’s cognitive tests measured in the preschool period, as found by Bernal (2008) using National Longitudinal Survey of Youth 79 (NLSY79) in the United States. A similar effect is found also in Bernal and Keane (2011) when evaluating the effect of an increase of 1 year in full-time child care using again the NLSY79 but considering exogenous changes in the work/child-care decisions caused by the introduction of new welfare policy rules for single mothers in the United States.

In conclusion, the main results of our empirical analysis may be summarized in the following three main points. First, the time children spend on their own during adolescence explains their test scores much more than the time the mothers spend with them during adolescence. Second, time investments during childhood by the mother are relevant to explain adolescents’ test scores (even after controlling for lagged test scores), while children’s own time investments during childhood are not as important as the quality time they spend with their mother. Third, the test scores are highly persistent, which implies that if a child obtains a bad result on a test during childhood, there is a strong probability that she will get a bad result again during adolescence.

\textbf{VI. Testing the Model’s Assumptions}

In this section, we present a set of robustness checks providing evidence on the validity of the main assumptions required for the consistency of the proposed two-step augmented value-added estimator (see col. 3 in table 5). Each robustness analysis is performed either on the sibling sample (1,212 observations) or on a subsample whose size is dictated by the availability of the additional information needed.

\textsuperscript{15} We check formally whether the lagged test is independent of the unobserved individual characteristics in the augmented value-added model by testing whether there is no difference between the lagged test coefficient obtained considering the family fixed effect estimation (table 5 col. 2) and the one obtained using the individual fixed effect estimation, i.e., the first-step estimation of our two-step procedure (table 5 col. 3).
A. Omission of Variables

One of our maintained assumptions is that we do not neglect differences between siblings in unobserved inputs or characteristics that have a direct effect on test results and are correlated with differences in time investments by children and parents (assumption 8). To convince ourselves that this is not a main concern, we considered a set of potential omitted variables that have been found to be relevant to explain investments as well as child’s abilities by previous papers: (i) school inputs, (ii) early childhood inputs, and (iii) children’s health shocks (see Datar and Mason 2008; Currie and Almond 2011; Almond and Mazumder 2013; Yi et al. 2015).

In table 6, we begin by considering the subsample of children for whom we can observe the class size and the main teacher’s experience (number of

| School Inputs | Early Inputs | Health Shocks | All Factors |
|---------------|--------------|---------------|-------------|
| Lag(test)     | .279***      | .279***       | .279***     | .279***     |
|               | (.059)       | (.043)        | (.043)      | (.058)      |
| Mother’s time investment | −.003       | −.001         | −.001       | −.002       |
|               | (.014)       | (.006)        | (.006)      | (.015)      |
| Child’s time investment | .015*       | .013**        | .013**      | .016*       |
|               | (.009)       | (.005)        | (.005)      | (.009)      |
| Lag(Mother’s time investment) | .007        | .010*         | .010*       | .007        |
|               | (.009)       | (.005)        | (.005)      | (.009)      |
| Lag(Child’s time investment) | .003        | .005          | .005        | .002        |
|               | (.008)       | (.005)        | (.006)      | (.008)      |
| Primary school class size | .004        |               | −.002       |             |
|               | (.008)       |               | (.013)      |             |
| Primary school teacher’s experience | −.002       |               | .004        |             |
|               | (.012)       |               | (.008)      |             |
| Breast-fed    |               | .019          | .097        |             |
|               |               | (.128)        | (.242)      |             |
| Mother employed during first year of life | −.002       | −.157         |             |             |
|               |               | (.081)        | (.181)      |             |
| Any hospital admission in last 12 months |               | .010          | −.081       |             |
|               |               | (.129)        | (.185)      |             |
| Constant      | 18.420        | 8.468         | 8.446       | 21.107      |
|               | (14.801)      | (9.131)       | (9.047)     | (15.329)    |
| Number of observations | 726          | 1,212         | 1,212       | 726         |

**NOTE.**—Dependent variable: standardized test scores (LWS, PCS, APS). LWS = Letter-Word Identification Score; PCS = Passage Comprehension Score; APS = Applied Problem Score. Sibling sample (cols. 2 and 3) and subsample with details on school inputs (cols. 1 and 4). Two-step estimation. Controls include Child’s age, Child’s age squared, Male, Mother’s age, Mother’s age squared, Birth order, and Born 1982–87 dummy. Bootstrapped standard errors are in parentheses.

* Statistically significant at the 10% level.
** Statistically significant at the 5% level.
*** Statistically significant at the 1% level.
years of total teaching experience) during primary school, and we evaluate the two-step estimator of an extended augmented value-added model that includes these school inputs. The magnitude of the time investment coefficients is very similar to that observed in our main estimation (compare the first column of table 6 and the last column of table 5), despite the increased standard errors caused by the smaller sample size. In the second column of table 6, we test for omission of early childhood inputs, exploiting information about whether the child was breastfed and whether the mother was working in the year after childbirth. Again, we do not observe any change in our coefficients of interest. Finally, we check for a potential bias caused by the omission of child’s health shocks by including a dummy variable capturing whether the child experienced any hospitalization in the past 12 months. Column 3 in table 6 shows that our main results on time investments are robust to inclusion of this measure of health shocks. The last column of the table reports the estimation results obtained by including all potential omitted variables, and again we do not observe any relevant changes in the estimated coefficients of interest. We conclude from our sensitivity analysis that our results are relatively invariant with respect to these changes in the model specification.

B. Equal Persistence in the Three Test Scores

Our augmented value-added model imposes the assumption of equal persistence in the three test scores (see maintained assumption M3). To show that this assumption is not too restrictive, we compute our estimation results again by allowing each of the three lagged test scores to have a different effect on the corresponding current test score in the first step of our two-step estimation. In table 7, we report the results of the first-step estimation (the individual fixed effects estimation). The coefficients corresponding to the three test scores are very similar, and we do not reject the equality of the three coefficients when looking at the Wald test whose p-value is .51.

We also carried out a factor analysis for the three test scores, finding that the first component explains more than 70% of the total variance and that its factor loadings are very similar for the three tests (varying between 0.813 and 0.882). This supports the representation in equations (3) and (4) and suggests that the three test scores measure the same latent cognitive ability (see maintained assumptions M1 and M2).

16 These two school measures have been extensively used in previous papers to control for school inputs and reflect to some extent the quality and quantity of teachers (e.g., Hanushek 2006; Jepsen and Rivkin 2009; Altinok and Kingdon 2012; Mueller 2013).

17 We also used as an alternative measure of health shocks a dummy indicating more than one doctor visit in the last 12 months, which leads to the same conclusion.

18 See Lavy et al. (2012) for a similar approach in relaxing the equality of the effect of the lagged test scores.
C. Measurement Errors in Time Investments

Our analysis builds on the assumption that the time investments we observe represent a reasonable proxy of the long-run time investments. It is acknowledged that the short reference period and the collection methodology (exhaustive recording of all activities performed) make time-use diary data much more accurate than retrospective survey questions that are affected by recall bias, but this comes at the cost of other measurement errors. These arise from different sources, such as the day-to-day variation in time-use patterns of individuals, or from the possible low frequency of the analyzed activity, with the high proportion of false zeros typically observed for infrequent activities (see Frazis and Stewart 2012; Foster and Kalenkoski 2013). Aggregation over different activities and/or multiple days is a way to mitigate measurement error problems (see Stinebrickner and Stinebrickner 2004). We resort to both types of aggregation in our analysis. First, we adopt a broad definition of time investments, which includes a whole set of formative activities. Second, we are able to define an aggregate measure of weekly time investment, thanks to the availability of time-use diary information for 2 days, 1 week day, and 1 weekend day for each child in the CDS.19 The first

19 This is a considerable advantage offered by the CDS design survey since most time-use data are single diary or include 2 consecutive days, not necessarily a week day and a weekend day (Frazis and Stewart 2012).
and second columns of Table 8 display the results of separate regressions where we consider time investments during weekdays and during weekend days. It can be observed that adopting this different definition of time investments based on a single day period makes the time investment effects very imprecisely estimated (compare, e.g., the standard errors of the child’s time coefficient in the first column of Table 8 and in the last column of Table 5). In the presence of measurement errors, it could also be argued that our result of a diminished importance of parental time and an increased importance of child’s own time during adolescence might be caused by the variability over time of the measurement errors. In particular, our pattern of estimates could be explained by time investments being more variable for parents of older children (than for parents of younger children) and for younger children (than for older children). However, we were not able to find any evidence in the literature on variability of measurement errors of time investments—as defined in this paper—over child life periods, and therefore we have no reason to expect this to be a pattern leading to our main findings.

In order to test for possible measurement error bias caused by day-to-day variation, we also performed the following sensitivity analysis (the full set of results is available upon request). We purged the daily time investments from the potential effect of the type of the day (and of the year) by evaluating the residuals of the regression of daily time investments on dummy variables.

Table 8
Augmented Value-Added Model Considering Daily Investments and Typical Days

|                         | Daily Investment | Weekly Investment |
|-------------------------|------------------|-------------------|
|                         | Weekday          | Weekend Day       | Typical Days    |
| Lag(Test)               | .279***          | .279***           | .284***         |
|                         | (.043)           | (.043)            | (.057)          |
| Mother’s time investment| .019             | -.023             | -.001           |
|                         | (.045)           | (.025)            | (.011)          |
| Child’s time investment | .050             | .063***           | .019**          |
|                         | (.035)           | (.022)            | (.009)          |
| Lag(Mother’s time investment) | .047         | .022              | .009            |
|                         | (.031)           | (.023)            | (.008)          |
| Lag(Child’s time investment) | .019          | .022              | .001            |
|                         | (.036)           | (.027)            | (.008)          |
| Constant                | 9.110            | 6.934             | 11.623          |
|                         | (9.139)          | (8.930)           | (11.440)        |
| Number of observations  | 1,212            | 1,212             | 798             |

Note.—Dependent variable: standardized test scores (LWS, PCS, APS). LWS = Letter-Word Identification Score; PCS = Passage Comprehension Score; APS = Applied Problem Score. Sibling sample (cols. 1 and 2) and subsample for typical days (col. 3). Two-step estimation. Controls include Child’s age, Child’s age squared, Male, Mother’s age, Mother’s age squared, Birth order, and Born 1982–87 dummy. Bootstrapped standard errors are in parentheses.

** Statistically significant at the 5% level.
*** Statistically significant at the 1% level.
iables for the different days of the week and for the different years.\textsuperscript{20} We then estimated two separate augmented value-added models (one for a week day, one for a weekend day) using these daily investments net of the effect of the type of day and year and compared the coefficients with the corresponding coefficients of the daily time investments in columns 1 and 2 of table 8. Since we found very similar figures, we argue that the day-to-day variation does not represent an important source of bias. This evidence is corroborated by the regression results we obtain using the subsample of children filling in the diary on typical or very typical days (about 66\% of our sibling sample), for which the observed time investments should be much less affected by day-to-day variation (col. 3 of table 8). The coefficients of the weekly time investments are of similar size with respect to our benchmark model, but they are less precisely estimated because of the decreased sample size. The slightly higher value observed for the effect of the child investment seems to suggest the presence of a classical measurement error causing some attenuation bias in our main sample.

D. Measurement Errors in Test Scores

So far we have assumed that each of the three test scores is an accurate measure of the corresponding skill (Letter-Word Identification, Passage-Comprehension, and Applied-Problems). In this section, we allow for the presence of measurement errors in the test scores, and we let the observed measure of skill $k$ in $t$ follow the model:

\[ Y_{kijt} = Y_{ijt} + \epsilon_{kijt} + \nu_{kijt}, \]

where $t = 6, \ldots, 15$, $(Y_{ijt} + \epsilon_{kijt})$ is the true measure of ability $k$ in $t$ and $\nu_{kijt}$ is a classical measurement error identically and independently distributed across skills, individuals, households, and time, with mean zero and variance $\sigma_{\nu}^2$, uncorrelated with $\epsilon_{kijt}$, $Y_{ijt}$, the inputs in the production function during childhood and adolescence and the unobserved endowment. When we regress $Y_{kijt}$ on $Y_{kijt-5}$ in our first-step estimation, the classical measurement error in $Y_{kijt-5}$ can lead to an attenuation bias of the persistence, $\rho$. To correct for this attenuation bias, we adopt an analytic correction formula (see Appendix B for details); that is, we multiply the $\rho$ coefficient by a correction factor given by $\text{Var}(\epsilon_{kijt-5} + \nu_{kijt-5})/\text{Var}(\epsilon_{kijt-5})$. The estimation results by assuming that the correction factor is equal to 1.613 and 2.327 (see Appendix B for a justification of these two choices) are reported in columns 2 and 3 in table 9. These results seem to suggest that measurement errors in the test scores do not cause any bias in the effect of the mother’s and

\textsuperscript{20} We run separate regressions for week days and weekend days.
child’s time investments. In table B1 of Appendix B, we also show that our main conclusions hold for a wide range of $\rho$, from 0.1 to 0.9.

### VII. Sensitivity Analysis

In this section, we present our sensitivity analysis, which allows us to check the robustness of our empirical results to (i) alternative definitions of mother’s and child’s time investments, (ii) the inclusion of father’s time investments, (iii) the extension of the sample to nonintact families, and (iv) the adoption of specifications that allow for a nonlinear effect of the time investments on the child’s cognitive skill.

#### A. Alternative Definitions of Time Investments

We begin by considering the robustness of our results to finer definitions of time investments, with the idea of capturing the measure of investment that is more relevant for child development. For the mother’s investment, we consider a new definition that excludes the time the mother spends with her child playing and having meals to take account of the fact that these two activities might be less relevant for the child’s development, especially during adolescence. The results are reported in the first column of table 10, and they show that the effect of the time a mother spends with her child during adolescence is still not statistically significant, while the effect of the time a mother spends with her child during childhood, which was statistically significant in our benchmark estimation, becomes insignificant. This might in-
dicate that playing and having meals are important activities during childhood that have a long-term effect even during adolescence, but this may also be in part the consequence of a finer definition of mother’s investments, leading to larger measurement errors and less precise estimates.

We also run two new regressions where the child’s investment is specified, including (a) two separate variables: the time a child spends doing homework or reading and the time the child spends doing other formative activities, and (b) only the child’s homework and reading time. In theory, we would expect a larger effect on cognitive abilities of the time a child spends doing homework and reading, but, because we are using time-use diaries, the use of a narrower definition of time investment can come at the cost of larger measurement errors. The results in columns 2 and 3 of table 10 seem to confirm this and to support the adoption of a broader concept of investment, as used in our benchmark estimation.

### B. Investments by Fathers

We consider here two new model specifications that include the father’s time investments. In the first column of table 11, we report, for comparison,
the estimates obtained by considering the mother’s time investments (which were already reported in the last column of table 5), while in the second column, we show the estimates obtained by replacing the mother’s time investments with the father’s. Finally, in the last column of table 11, we report the results computed by using both the mother’s and the father’s time investments. The effect of the child’s time investments remains the same across specifications. Similarly, the coefficients of the lagged test and the lagged mother’s time are almost unaffected. We find that the effect of the father’s time investments is not significantly different from zero. The difference between the effect of the mother’s and father’s time investment during childhood might be explained in part by the fact that the father’s time investment during childhood is on average much lower than the mother’s (about 40% lower). We also checked whether the effect of the father’s investment might depend on gender and be more relevant for boys than for girls (see Bertrand and Pan 2013), but again we find a nonsignificant effect (results are available upon request).

C. Nonintact Families

In our main analysis, we have focused on families where the children live with their biological parents. In many countries, the proportion of children

| Table 11 | Augmented Value-Added Model with Child’s, Mother’s, and Father’s Investments |
|---------|-------------------------------|
|          | Mother | Father | Both Parents |
| Lag(Test) | .279*** | .279*** | .279*** |
|          | (.044)  | (.044)  | (.045)  |
| Mother’s time investment | −.001 | −.004 |
|          | (.006)  | (.008)  |
| Father’s time investment | .002  | .003 |
|          | (.007)  | (.009)  |
| Child’s time investment | .013** | .014*** | .013** |
|          | (.005)  | (.005)  | (.005)  |
| Lag(Mother’s time investment) | .010* | .012** |
|          | (.005)  | (.006)  | (.007)  |
| Lag(Father’s time investment) | .000  | −.006 |
|          | (.006)  | (.007)  |
| Lag(Child’s time investment) | .005  | .003 |
|          | (.006)  | (.005)  | (.006)  |
| Constant | 8.409  | 9.723  | 7.331  |
|          | (9.471) | (8.449) | (8.731) |

Note.—Dependent variable: standardized test scores (LWS, PCS, APS). LWS = Letter-Word Identification Score; PCS = Passage Comprehension Score; APS = Applied Problem Score. Sibling sample. Number of observations = 1,212. Two-step estimation. Controls include Child’s age, Child’s age squared, Male, Mother’s age, Mother’s age squared, Birth order, and Born 1982–87 dummy. Bootstrapped standard errors are in parentheses.

* Statistically significant at the 10% level.

** Statistically significant at the 5% level.

*** Statistically significant at the 1% level.
growing up with both biological parents has declined dramatically over time. Using an extended sample, which includes children living in households where the biological father is absent (16.5% of the sample), leads to results that are similar to those obtained considering just families with both biological parents (results are available upon request).

D. Nonlinearities in Time Investments

Finally, in table A4 in Appendix A, we introduce some nonlinearities in the effect of the mother’s and child’s time investments. We estimate three different specifications: (i) a model where the coefficient of each type of time investment is allowed to differ for levels of investment below and above the corresponding median (switching coefficients); (ii) a model with an additional dummy variable for each time investment, which takes value one when the time investment is zero and zero otherwise; (iii) a model where all time investments are expressed in logarithms (see, respectively, the first, second, and third columns in table A4). The first specification allows the effect of each time investment to be different for values that are below and over the median. The results suggest that each of the time investments has a coefficient that does not vary significantly below and over the median, so our linear specification is not rejected. The second model allows for a discontinuity at zero, so when a time investment is zero, its effect is not imposed to be null. The dummy variables indicating zero time investments have coefficients that are not significantly different from zero, suggesting again that our linear specification is not rejected. Finally, the third model allows for a further form of nonlinearity of the partial effects by resorting to the log transformation of the various time investment variables. In this specification, the estimated coefficients are interpretable as semi-elasticities, and this explains the observed change in magnitude, which is, however, coherent with our benchmark model results.

VIII. Conclusions

While a large literature has focused on the effects of parental time on child’s outcomes, there are no studies that evaluate and compare the time investments made by parents and children. In our paper, we model the cognitive production function for adolescents using an augmented value-added specification and considering parental time investments alongside child time self-investments. We account for different sources of endogeneity that typically undermine the identification of the inputs’ coefficients. First, we are able to control for the endogeneity of parents’ and children’s time investments arising from unobserved household-specific inputs by way of family fixed effects estimation. Second, we take account of the endogeneity of the lagged test, which is caused by its dependence on the unobserved child-specific characteristics, by applying an individual fixed effects estima-
tion which makes use of the multiplicity of cognitive tests available in our data.

We show that the time investments made by children during adolescence affect their test scores much more than the time investments made by their mothers. Our results suggest that one way to improve the cognitive abilities of adolescents is to influence their time allocation decisions and their investments in formative activities. The fact that adolescents become important actors in their development process has important policy implications, suggesting that educational policies should target adolescents directly rather than their parents. Recent educational policies, such as conditional cash transfers, are in line with our findings, since they target not only parental time investments but also children’s time investments in themselves.

Appendix A

Additional Tables

| Table A1  | Summary Statistics: Main Sample |
|-----------|---------------------------------|
| Variable  | Mean   | SD   |
| Tests:    |        |      |
| LWS       | 105.842| 16.792|
| PCS       | 104.055| 14.956|
| APS       | 107.135| 15.149|
| Lag(LWS)  | 109.649| 16.530|
| Lag(PCS)  | 110.299| 14.261|
| Lag(APS)  | 110.745| 16.940|
| Time investments: |        |      |
| Mother’s time investment | 5.463 | 5.197 |
| Lag(Mother’s time investment) | 9.472 | 7.082 |
| Father’s time investment | 4.078 | 5.045 |
| Lag(Father’s time investment) | 5.996 | 5.943 |
| Child’s time investment | 5.123 | 6.859 |
| Lag(Child’s time investment) | 4.076 | 5.149 |
| Control variables: |        |      |
| Age       | 13.025 | 1.410 |
| Mother’s age | 41.397 | 5.276 |
| Male      | .479   | .500 |
| Birth order | 1.886 | .847 |
| Born 1982–87 | .528 | .500 |

Note.—Number of observations = 726. LWS = Letter-Word Identification Score; PCS = Passage Comprehension Score; APS = Applied Problem Score.
| Variable                  | Sibling Sample | Mean  | SD    | Mean Differences between Sibling and Main Samples |
|--------------------------|----------------|-------|-------|--------------------------------------------------|
| **Tests:**               |                |       |       |                                                  |
| LWS                      | 107.606        | 16.266|       | 1.765*                                           |
| PCS                      | 105.255        | 14.686|       | 1.200                                            |
| APS                      | 108.973        | 14.914|       | 1.838**                                          |
| Lag(LWS)                 | 110.906        | 16.966|       | 1.257                                            |
| Lag(PCS)                 | 111.196        | 14.318|       | .897                                             |
| Lag(APS)                 | 112.347        | 16.806|       | 1.601                                            |
| **Time investments:**    |                |       |       |                                                  |
| Mother’s time investment | 5.253          | 4.918 |       | -.210                                            |
| Lag(Mother’s time investment) | 9.711       | 6.951 |       | .239                                             |
| Father’s time investment | 4.096          | 4.812 |       | .017                                             |
| Lag(Father’s time investment) | 6.067       | 5.875 |       | .069                                             |
| Child’s time investment  | 5.148          | 6.458 |       | .025                                             |
| Lag(Child’s time investment) | 4.201        | 5.265 |       | .125                                             |
| **Control variables:**   |                |       |       |                                                  |
| Age                      | 12.998         | 1.403 |       | -.270                                            |
| Mother’s age             | 41.354         | 4.912 |       | -.043                                            |
| Male                     | .475           | .500  |       | -.004                                            |
| Birth order              | 1.839          | .785  |       | -.047                                            |
| Born 1982–87             | .525           | .500  |       | -.003                                            |

**NOTE.**—Number of observations = 404. LWS = Letter-Word Identification Score; PCS = Passage Comprehension Score; APS = Applied Problem Score. Two-sided t-test for $H_0$: difference of means = 0.

* Statistically significant at the 10% level.

** Statistically significant at the 5% level.

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| Father’s Time Investment | Child’s Age Range 6–10 |         |         | Child’s Age Range 11–15 |         |         |
|--------------------------|-------------------------|---------|---------|-------------------------|---------|---------|
|                          | Mean | SD  | Min  | Max  | Mean | SD  | Min  | Max  |
| Total time investment    | 6.00 | 5.94| .00  | 45.92| 4.08 | 5.04| .00  | 36.25|
| Reading                  | .15  | .58 | .00  | 6.67 | .06  | .58 | .00  | 12.33|
| Homework                 | .05  | .46 | .00  | 7.50 | .09  | .78 | .00  | 11.17|
| Playing                  | .99  | 2.49| .00  | 23.33| .35  | 1.65| .00  | 25.67|
| Talking                  | .23  | .83 | .00  | 7.73 | .33  | 1.10| .00  | 13.25|
| Arts and crafts          | .13  | 1.38| .00  | 33.75| .05  | .60 | .00  | 11.00|
| Sports                   | .44  | 1.60| .00  | 15.00| .17  | 1.13| .00  | 16.5 |
| Attending performances   | .04  | .48 | .00  | 7.50 | .08  | .73 | .00  | 13.33|
| Attending museums        | .02  | .39 | .00  | 9.50 | .00  | .00 | .00  | .00  |
| Religious activity       | .60  | 1.84| .00  | 15.27| .55  | 1.92| .00  | 20.00|
| Meals                    | 3.04 | 2.8 | .00  | 20.50| 2.34 | 2.74| .00  | 21.75|
| Personal care            | .31  | 1.16| .00  | 15.25| .07  | .47 | .00  | 6.00 |

**NOTE.**—Weekly time investment in hours. Number of observations = 726.
Table A4
Augmented Value-Added Model with Nonlinearities in Time Investments

|                                | Switching Coefficient for Time < Median | Including Dummy for Zero Time | Time in Logs |
|--------------------------------|----------------------------------------|------------------------------|--------------|
| Lag(test)                      | .279***                                | .279***                      | .279***      |
|                                | (.043)                                 | (.045)                       | (.043)       |
| Mother’s time investment       | .000                                   | -.000                        | .005         |
|                                | (.007)                                 | (.007)                       | (.041)       |
| Mother’s time if below the median | .021                                  |                              |              |
|                                | (.033)                                 |                              |              |
| Dummy for zero mother’s time   | .025                                   |                              |              |
|                                | (.102)                                 |                              |              |
| Child’s time investment        | .014**                                 | .011*                        | .075***      |
|                                | (.005)                                 | (.006)                       | (.033)       |
| Child’s time if below the median | -.009                                 |                              |              |
|                                | (.071)                                 |                              |              |
| Dummy for zero child’s time    | -.051                                  |                              |              |
|                                | (.085)                                 |                              |              |
| Lag(Mother’s time investment)  | .010*                                  | .010*                        | .084         |
|                                | (.006)                                 | (.005)                       | (.053)       |
| Lag(Mother’s time) if below the median | .002                                 |                              |              |
|                                | (.014)                                 |                              |              |
| Dummy for zero Lag(Mother’s time) | -.058                                 |                              |              |
|                                | (.190)                                 |                              |              |
| Lag(Child’s time investment)   | .007                                   | .003                         | .024         |
|                                | (.006)                                 | (.006)                       | (.033)       |
| Lag(Child’s time) if below the median | .042                                 |                              |              |
|                                | (.050)                                 |                              |              |
| Dummy for zero Lag(Child’s time) | -.044                                 |                              |              |
|                                | (.095)                                 |                              |              |
| Constant                       | 9.144                                  | 8.951                        | 9.310        |
|                                | (9.433)                                | (9.243)                      | (9.144)      |

**Note.**—Dependent variable: standardized test scores (LWS, PCS, APS). LWS = Letter-Word Identification Score; PCS = Passage Comprehension Score; APS = Applied Problem Score. Sibling sample. Number of observations = 1,212. Two-step estimation; Bootstrapped standard errors are in parentheses. Controls include Child’s age, Child’s age squared, Male, Mother’s age, Mother’s age squared, Birth order, and Born 1982–87 dummy.

* Statistically significant at the 10% level.
** Statistically significant at the 5% level.
*** Statistically significant at the 1% level.

Appendix B
Measurement Error Correction

In Section VI.D, we reported the estimation results of the production model during adolescence in the presence of measurement error on the test scores and using an analytic formula for correcting for the consequent attenuation bias for the persistence $\rho$. In this section, we provide details on how to compute this correction formula.
Our first-step estimation of the persistence $\rho$ is given by the individual fixed effects estimation of the regression of the test score observed during adolescence, $Y_{kijt} = Y_{ijt} + \epsilon_{kijt} + \psi_{kijt}$, on the lagged test score observed 5 years earlier, during childhood, $Y_{ijt-5} = Y_{ijt-5} + \epsilon_{ijt-5} + \psi_{ijt-5}$. When relaxing the assumption of no measurement errors, that is, the assumption that $\psi_{kijt}$ and $\psi_{ijt-5}$ have degenerate distribution with zero mean and zero variance, the individual fixed effects estimator of the persistence $\rho$ converges to

$$\text{plim} \tilde{\rho}_{\text{indFE}} = \frac{\text{Cov}(\epsilon_{kijt} + \psi_{kijt}, \epsilon_{ijt-5} + \psi_{ijt-5})}{\text{Var}(\epsilon_{ijt-5} + \psi_{ijt-5})} = \frac{\text{Cov}(\epsilon_{kijt}, \epsilon_{ijt-5})}{\text{Var}(\epsilon_{ijt-5} + \psi_{ijt-5})} = \rho \frac{\text{Var}(\epsilon_{ijt-5})}{\text{Var}(\epsilon_{ijt-5} + \psi_{ijt-5})}.$$  

(B1)

In other words, the error term in the lagged test scores, $\psi_{ijt-5}$, is an example of classical measurement error and causes an attenuation bias of the $\rho$ coefficient estimated in the first step. Instead, the error term in the current test score, $\psi_{kijt}$, simply causes a decrease in the precision of the estimation of $\rho$. To correct for the attenuation bias, we simply need to multiply the $\rho$ coefficient estimated in the first step by an estimate of the following correction factor:

$$\frac{\text{Var}(\epsilon_{ijt-5} + \psi_{ijt-5})}{\text{Var}(\epsilon_{ijt-5})}.$$  

(B2)

We do not observe the above correction factor, but we can compute it using information on the reliability ratio, $\text{Var}(Y_{ijt-5} + \epsilon_{ijt-5})/\text{Var}(Y_{ijt-5} + \epsilon_{ijt-5} + \psi_{ijt-5})$, and on the share of the variance of the observed test score in ability $k$ explained by the latent ability $Y_{ijt-5}$, that is, $\text{Var}(Y_{ijt-5})/\text{Var}(Y_{ijt-5} + \epsilon_{ijt-5} + \psi_{ijt-5})$. This is because, under our maintained assumptions, there is no correlation between $Y_{ijt-5}$, $\epsilon_{ijt-5}$, and $\psi_{ijt-5}$, and $\text{Var}(Y_{kijt-5}) = \text{Var}(Y_{ijt-5}) + \text{Var}(\epsilon_{kijt}) + \text{Var}(\psi_{kijt-5}) = 1$.\(^{21}\)

Previous studies on the reliability of the Woodcock-Johnson Revised tests we use in this paper suggest that the reliability ratio is always above 0.8 and often above 0.9. By implementing a factor analysis for the three observed lagged test scores, we find that 77.0% (79.2% and 65.0%) of the variance of the Letter-Word Identification (Passage-Comprehension and Applied-Problems) test score is explained by the main common factor. By considering this common factor as a measure of the latent ability $Y_{ijt-5}$, we can impute to $\text{Var}(Y_{ijt-5})/\text{Var}(Y_{ijt-5} + \epsilon_{ijt-5} + \psi_{ijt-5})$ a value of 0.737, which is the aver-

\(^{21}\) $\text{Var}(Y_{kijt-5}) = 1$ because our test scores are standardized by skill.
By imposing a reliability ratio of 0.9 and 0.85 and \( \frac{\text{Var}(Y_{ijt})}{\text{Var}(Y_{ijt} + \epsilon_{kijt} + \psi_{kijt})} = 0.737 \), we can assume that \( \frac{\text{Var}(\epsilon_{kijt} + \psi_{kijt})}{\text{Var}(\epsilon_{kijt})} \) takes values 1.613 and 2.327, and we can apply the analytic error correction for the \( \rho \) estimation suggested by equation B1. These two correction factors are the ones used in table 9, where we reported the estimation results corrected for measurement error in the test scores.

In table B1, we also report results for our second-step estimation when imposing different values for the persistence that range from a 0.1 to 0.9. The aim of this exercise is to show how much the effects of mother’s and child’s time investments can be biased by measurement errors or by any other issue that might affect the estimation of \( \rho \).

### Table B1
**Augmented Value-Added Model with Imposed Values for \( \rho \)**

| Imposed Value for \( \rho \) | .1 | .2 | .3 | .4 | .5 |
|-----------------------------|----|----|----|----|----|
| Mother’s time investment    | -.005 | -.003 | -.001 | .001 | .003 |
| Child’s time investment     | .011** | .012** | .013*** | .015*** | .016*** |
| Lag(Mother’s time investment) | .010** | .010** | .010*** | .009* | .009* |
| Lag(Child’s time investment) | .006 | .006 | .005 | .004 | .004 |
| Constant                    | 8.466 | 8.434 | 8.402 | 8.370 | 8.338 |

| Imposed Values for \( \rho \) | .6 | .7 | .8 | .9 |
|-----------------------------|----|----|----|----|
| Mother’s time investment    | .005 | .007 | .009 | .011 |
| Child’s time investment     | .017*** | .018*** | .019*** | .021*** |
| Lag(Mother’s time investment) | .009* | .009* | .009 | .008 |
| Lag(Child’s time investment) | .003 | .003 | .002 | .002 |
| Constant                    | 8.306 | 8.273 | 8.241 | 8.209 |

**NOTE.**—Dependent variable: standardized test scores (LWS, PCS, APS). LWS = Letter-Word Identification Score; PCS = Passage Comprehension Score; APS = Applied Problem Score. Sibling sample. Number of observations = 1,212. Two-step estimation (first-step estimates results replaced with given values). Standard errors are in parentheses. Controls include Child’s age, Child’s age squared, Male, Mother’s age, Mother’s age squared, Birth order, and Born 1982–87 dummy.

* Statistically significant at the 10% level.
** Statistically significant at the 5% level.
*** Statistically significant at the 1% level.
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